Experimentation Campaign on QPUs Using Q-score Metric

Damien Nicolazic *(Eviden)* – Jami Rönkkö *(IQM)* - *Louis-Paul Henry (Pasqal)* - *Vassilis Apostolou (Quandela)* - *Ward van der Schoot (TNO)*

4 June 2024

CONFIDENTIAL LNE

Q-score: A Broader View

EVIDEN

QUANTUM FRANCE 2030 BACQ MetriQs-France

Q-score Highlights:

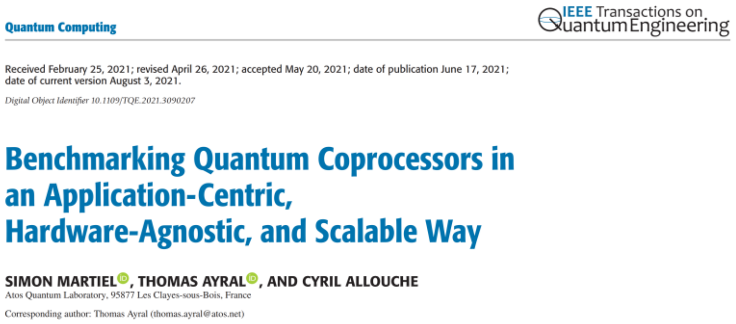
- Q-score, introduced by Atos in 2021
- Quantifies the performances of quantum devices in solving specific problems
- Unlike existing metrics, Q-score is application-oriented and provides a scalable way to assess QPU capabilities
- Q-score allows us to compare the true performances of various QPUs

Application-Driven Metrics:

- Q-score methodology covers not only gate-based QPUs but also analog simulators and quantum annealers
- Application-driven metrics like Q-score provide transparency and guide users and manufacturers

Future Prospects:

- Expect more Q-score variants for different use cases beyond optimization problems
- Collaboration with international scientists will further refine and expand the Q-score family
- Q-score maturity and its widespread adoption open the door to discussions about benchmarking standardization


Quantum Computing — IEEE Transactions on Quantum Engineering

Received February 25, 2021; revised April 26, 2021; accepted May 20, 2021; date of publication June 17, 2021; date of current version August 3, 2021.

Digital Object Identifier 10.1109/TQE.2021.3090207

Benchmarking Quantum Coprocessors in an Application-Centric, Hardware-Agnostic, and Scalable Way

SIMON MARTIEL, THOMAS AYRAL, AND CYRIL ALLOUCHE
Atos Quantum Laboratory, 95877 Les Clayes-sous-Bois, France
Corresponding author: Thomas Ayral (thomas.ayral@atos.net)

LABORATOIRE NATIONAL DE MÉTROLOGIE ET D'ESSAIS LNE · THALES Building a future we can all trust · EVIDEN an atos business · cea · cnrs · Teratec

Fast-Track BACQ initiative

- **Fast-Track Quantum Computing Benchmarking Initiative:**
  - A collaborative effort among quantum computing industry leaders
  - Objective: Conduct a comprehensive measurement campaign on existing Quantum Processing Units (QPUs) using the Q-score metric
  - Significance: Marks a pivotal moment in quantum computing evaluation and benchmarking
- **Broad Collaboration**
- **Open Collaboration**
- **Future and Impact:**
  - Fast-Track stands as evidence of collaborative innovation in quantum computing
  - Advanced partnerships and open contributions will shape the future of quantum computing benchmarks
  - Fast-Track's success leads to an extension of our tests, deepening our understanding of quantum computer benchmarking

Illustration generated by IA (Dall-E 3)

Q-score experimentation Campaign

- **IQM:**
  - Qubit technology: Superconducting
  - Presented by Jami Rönkkö (10 mins / remote)
  - Q-score/Max-Cut With QAOA
- **Pasqal:**
  - Qubit technology: Neutral Atom
  - Presented by Louis-Paul Henry (10 mins / In-person)
  - Q-score/Max-Cut with Maximum Independent Set (MIS)
- **Quandela:**
  - Qubit technology: Photonic
  - Presented by Vassilis Apostolou (10 mins / remote)
  - Q-score/Max-Cut with Variational Quantum Eigensolver (VQE)
- **TNO:**
  - Research institute: Toegepast Natuurwetenschappelijk Onderzoek
  - Presented by Ward van der Schoot (10 mins / remote)
  - Q-score/Max-Cut implementation on D-wave

IQM

Experimentation Campaign on QPUs Using Q-score Metric

Jami Rönkkö *(IQM)*

4 June 2024

Teratec LNE THALES

STRATÉGIE NATIONALE QUANTIQUE

MetriQs France

FRANCE 2030

anr agence nationale de la recherche

WE BUILD QUANTUM COMPUTERS

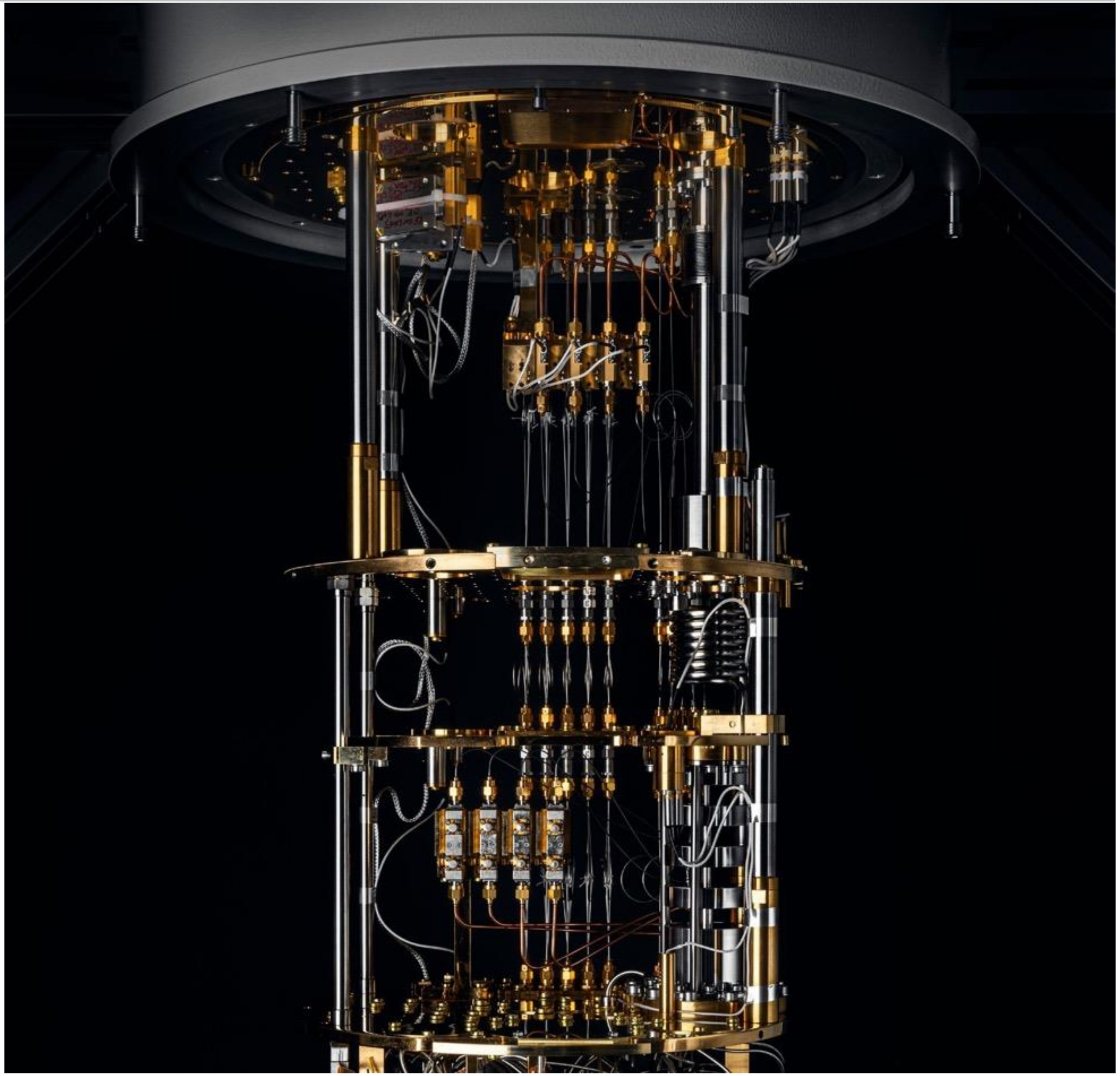
Q-score at IQM:

Results and Suggestions

Jami Rönkkö

IQM Quantum Computers

www.meetiqm.com

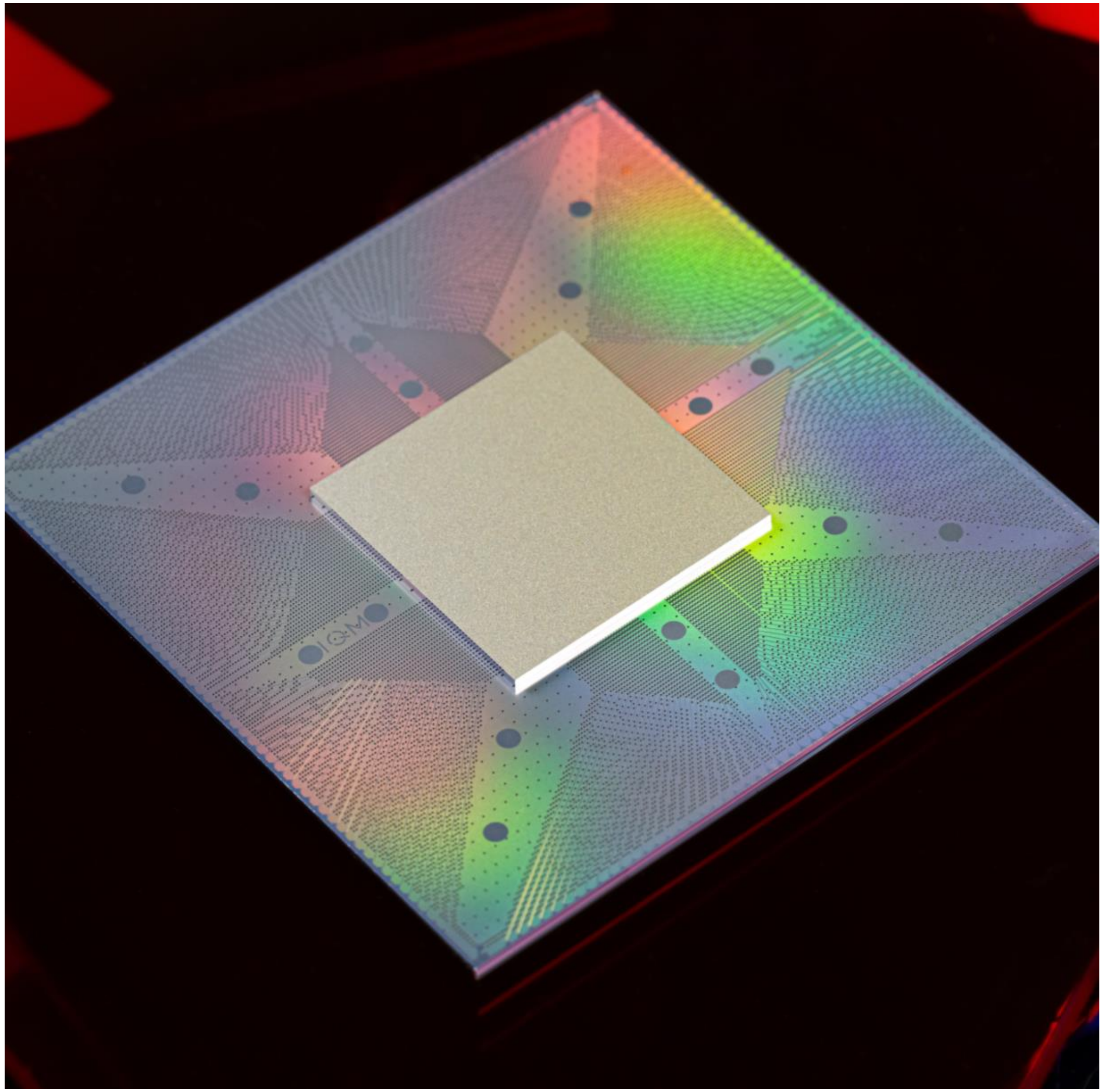


Contents

1. Preliminaries

2. Results

3. Suggestions



1. Preliminaries: Q-score definition

I. Definition

$$\beta(n) = \frac{C(n) - \frac{n^2}{8}}{\lambda n^{3/2}} \quad \rightarrow \quad \beta(n) = \frac{C(n) - \frac{(n-1)n}{8}}{\lambda n^{3/2}}$$

II. Number of shots: 2048 → 20 000

III. Number of instances: 100 (we use 100 instances though more might be needed to get reliable averages)

Martiel, Simon, Thomas Ayral, and Cyril Allouche. *IEEE Transactions on Quantum Engineering* 2 (2021): 1-11.

1. Preliminaries: algorithmic tricks

I. Readout error mitigation

II. For ansatz layer depth p=1 one can use classically computed optimal angles
→ no need for quantum-classical loop for finding angles

Theorem 1. *For QAOA with $p = 1$, for each edge $\langle uv \rangle$,*

$$\begin{aligned} \langle C_{uv} \rangle &= \frac{1}{2} + \frac{1}{4}(\sin 4\beta \sin\gamma)(\cos^{d_u}\gamma + \cos^{d_v}\gamma) \\ &- \frac{1}{4}(\sin^2 2\beta \cos^{d_u+d_v-2\lambda_{uv}}\gamma)(1 - \cos^{\lambda_{uv}} 2\gamma), \end{aligned} \tag{14}$$

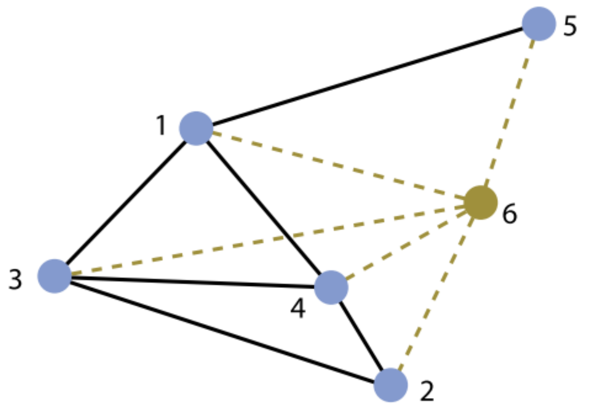
where $d_u + 1$ and $d_v + 1$ are the degrees of vertices u and v, respectively, and λ_{uv} is the number of triangles in the graph containing edge $\langle uv \rangle$.

Wang, Zhihui, et al. *Physical Review A* 97.2 (2018): 022304.

III. Break the Z2 symmetry of MaxCut problems by pre-assigning one node to 1
→ solve n node graphs with n-1 qubits

Bravyi, Sergey, et al. *Physical review letters* 125.26 (2020): 260505.

Figure 12 Maxcut problem for six nodes. Node 6 is a fictitious qubit in $|1\rangle$ state while rest are physical qubits. Solid lines represent physical couplings while dashed lines fictitious couplings

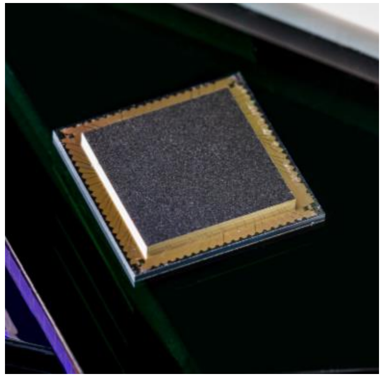


Rönkkö, Jami, et al. *EPJ Quantum Technology* 11.1 (2024): 32.

2. IQM Quantum Computer - Garnet

20 qubit superconducting data qubits and 30 coupler qubits

Cloud access at: https://resonance.meetiqm.com/



TOPOLOGY
Square-lattice topology

QUBITS
20

NATIVE GATES
barrier, cz, measure, prx

MAXIMUM CIRCUITS / MAXIMUM SHOTS PER JOB
200 / 20000

MEDIAN T1
42.23 μs

MEDIAN T2
7.72 μs

MEDIAN SINGLE-QUBIT GATE FIDELITY
99.92 %

MEDIAN CZ GATE FIDELITY
99.41 %

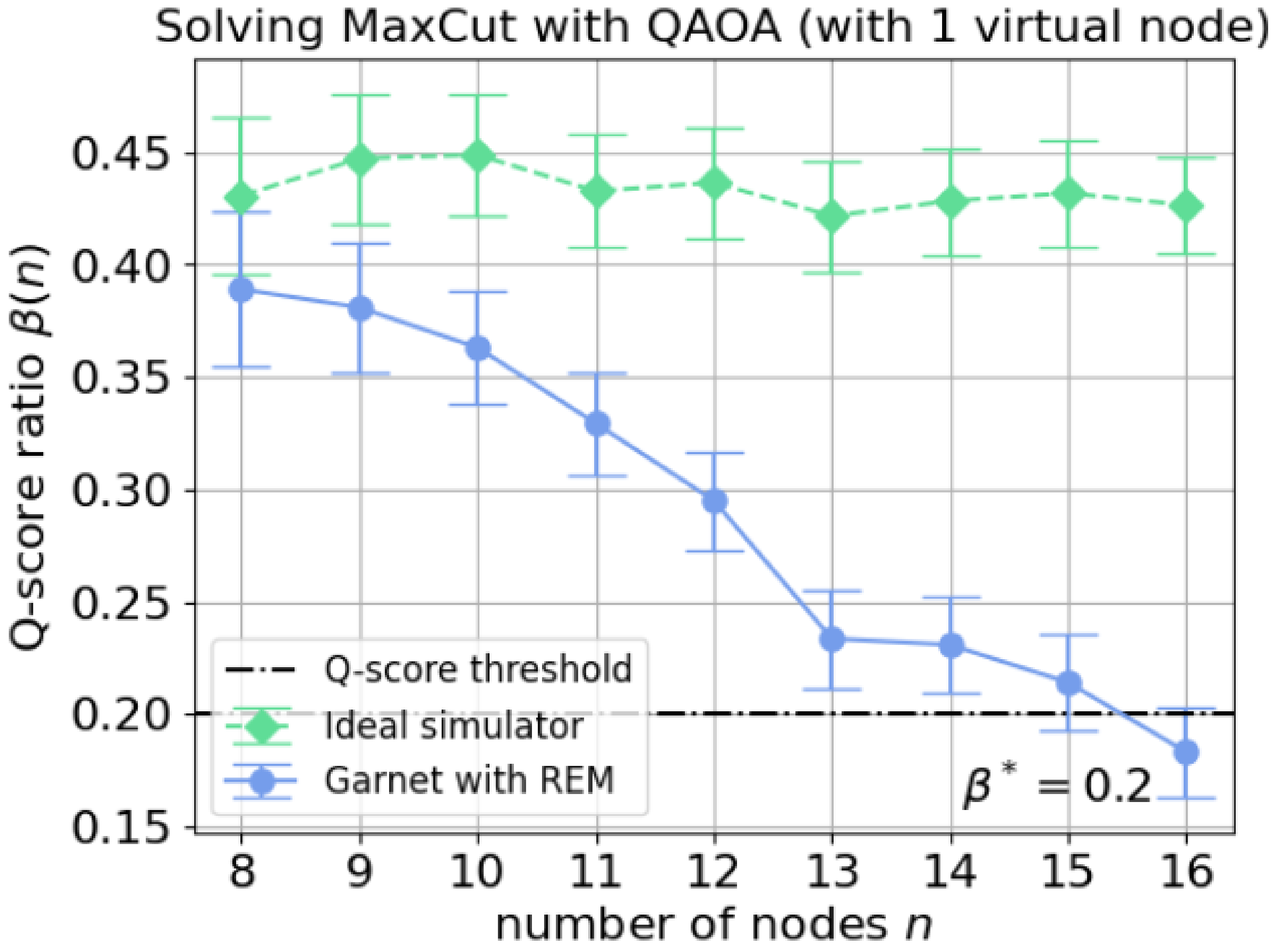
Gate times:
cz : 48 ns
prx : 20 ns

Sub-10 ns prx gates being implemented at the moment: Hyyppä, Eric, et al. *arXiv preprint arXiv:2402.17757* (2024).

2. Results

Q-score = 15

- seed = 1
- 100 instances
- 20 000 shots



3. Suggestions for modifying Q-score

Make the benchmark even more application centric

1. Look for best solution, not for average
   - this is what real users are interested in

2. Demand reporting of time-to-solution or alternatively total shot budget
   - time to solution could be in terms of flops

3. Compare to best classical polynomial-time approximation algorithm (Goemans and Williamson) instead of random sampling
   - e.g. for how many nodes one can get as good solution as G&W and how long/many flops did it take

4. Clarify whether default QAOA should be used or if iterative (hybrid) versions of QAOAs are allowed. These will lead to higher Q-scores at the cost of extra classical processing.

Experimentation Campaign on QPUs Using Q-score Metric

Louis-Paul Henry *(Pasqal)*

4 June 2024

Pasqal Defining the quantum reality

Optimization benchmarks for neutral atom QPUs

—

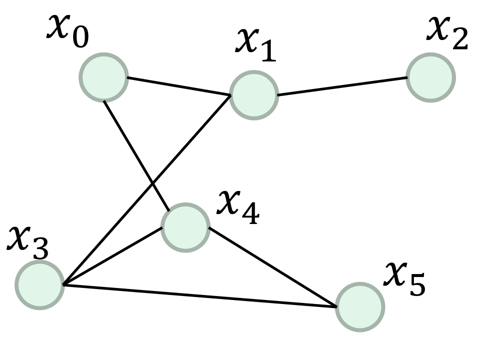
Extending the Q-Score definition

Louis-Paul Henry

The Max-Cut Problem

Pasqal

The QUBO formulation for the Max-Cut problem



$$x_i = \{0,1\}$$

The MAX-CUT set is found as:

$$\underset{\{x_i\}}{\text{argmin}}\left(-\sum_{i\in V} N_i x_i + \sum_{i,j\,\in\,\mathrm{E}} x_i x_j\right)$$

$$N_i = Numbers\ of\ neighbours$$

Any QUBO matrix can be translated into a Weighted Max-Cut instance

Barahona, Francisco, Michael Jünger, and Gerhard Reinelt. "Experiments in quadratic 0–1 programming." *Mathematical Programming* 44.1-3 (1989): 127-137.

Q-score (for Max-Cut)

Pasqal

Associated cost function ($z_i \in \{+1; -1\}$)

$C(z_1, \dots, z_N) = \sum_{(i,j)\in E} z_i z_j$

Max-Cut for Erdös-Renyi graphs of size N

Average cost for a random cut[1]:

$$Rand(N) \approx \frac{N^2}{8}$$

Optimal cost :

$$Opt(N) \approx \frac{N^2}{8} + \lambda N^{\frac{3}{2}} \ (\lambda \sim 0.178)$$

Any algorithm such that $Algo(N) > Rand(N)$:

$$\lim_{N\to\infty} Algo(N)/\ Opt(N) = 1$$

[1] A. Dembo, A. Montanari, S. Sen, "Extremal cuts of sparse random graphs", The Annals of Probability, vol. 45, no. 2, pp. 1190 –1217, 2017

Q-score

Refined approximation ratio :

$$\beta(N) = \frac{Algo(N) - Rand(N)}{Opt(N) - Rand(N)} = \frac{Algo(N) - \frac{N^2}{8}}{\lambda N^{\frac{3}{2}}}$$

One expects $\beta(N)$ to decrease as $N \to \infty$

Q-score defined as

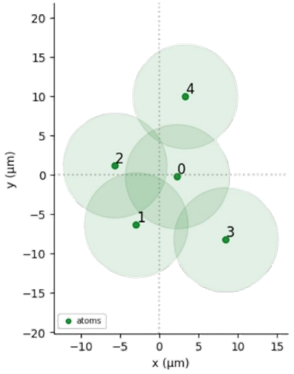
$$Qs(Algo) = \max\{N \mid \beta(N) > 0.2\}$$

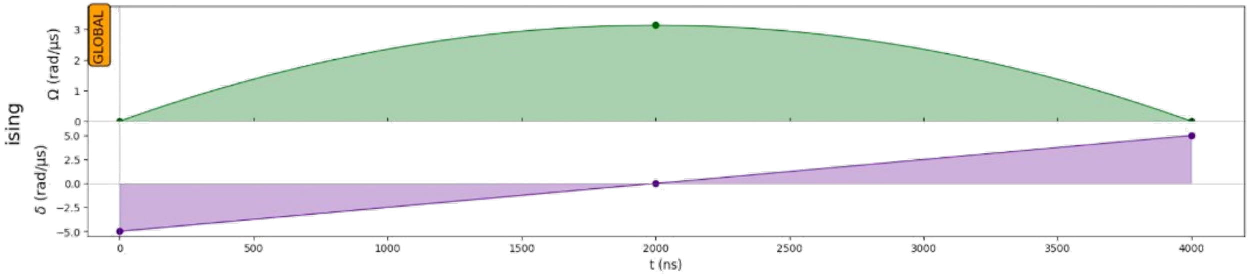
Analog Quantum Computing with neutral atoms

Pasqal

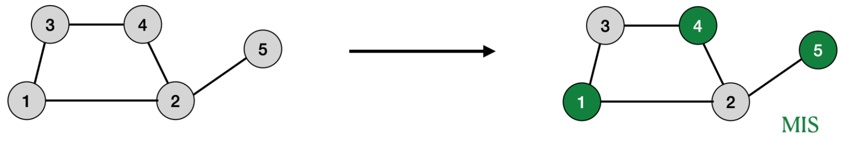
Native Hamiltonian : Ising

$$H_{Ising} = \frac{\hbar\Omega(t)}{2}\sum_{i=1}^{N}\hat{X}_i - \hbar\delta(t)\sum_{i=1}^{N}\hat{n}_i + \sum_{i<j}\frac{C_6}{\left|r_i - r_j\right|^6}\ \hat{n}_i\hat{n}_j$$





Native Problem : Maximum Independent Set (MIS)



Each node has a label $n_i = \{0; 1\}$

Space of solutions $S = \{0; 1\}^N$ and $|S| = 2^N$

Associated cost function

$$C(n_1, \dots, n_N) = -\sum_{i=1}^{N} n_i + U\sum_{(i,j)\in E} n_i n_j$$

with $U \gg 1$

Extension to Q-score

Pasqal

Constrained optimization

- MaxCut is *unconstrained* optimization
  ⟹ « easier » to approximate

- Sampling/exploring constrained space is typically hard
  ⟹ typically $Random(N) \to 0$

- Example 1 : MIS

$$\underset{\boldsymbol{n} \in \{\mathrm{IS}\}}{\operatorname{argmax}} \sum_{i=1}^{N} n_i$$

- Example 2 : *weighted*-MIS ($\{w_i\} \in \mathbb{R}^N$)

$$\underset{\boldsymbol{n} \in \{\mathrm{IS}\}}{\operatorname{argmax}} \sum_{i=1}^{N} w_i n_i$$

Extended Q-score

- Scaling of naïve algorithm (Random, Greedy, …)
  $Naive(N)$
- Scaling of best algorith (State-of-the-art, theoretical, …)
  $Best(N)$

- Extended approximation ratio

$$\beta(N) = \frac{Algo(N) - Naive(N)}{Best(N) - Naive(N)}$$

- Extended Q-score defined as

$$Qs(Algo) = \max\{N \mid \beta(N) > \alpha\}$$

Where the threshold α can be application specific

Method

Pasqal

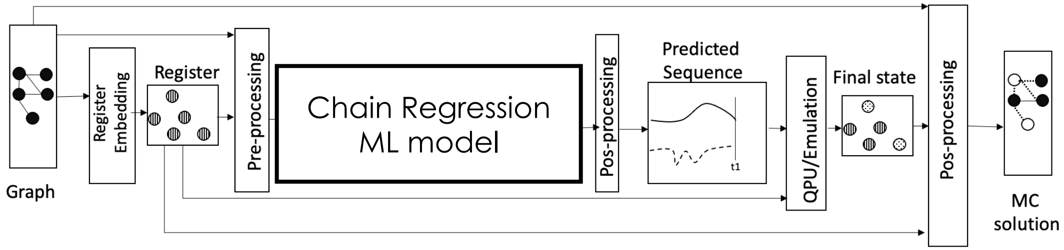
Properly accounting for cost

- Cost of classical preprocessing
- Cost of optimizating parameters
  - QOAO parameters
  - Register embedding (n. atoms, …)
  - Pulse shaping (analog, …)
- Sampling cost (number of shots)
  - $N_{shots}^{final} \sim (overlap\ of\ state\ with\ sol.)^{-1}$
  - $N_{shots}^{total} \sim N_{shots}^{final} + N_{shots}^{optim}$

    $\Longrightarrow$ Trade off

ML-assisted pulse shaping and register embedding

- The goal : $N_{shots}^{total} \sim N_{shots}^{final} +$ ~~N_{shots}^{optim}~~
- The idea : Train a model that outputs one or more « good enough pulse », given a graph and a Register

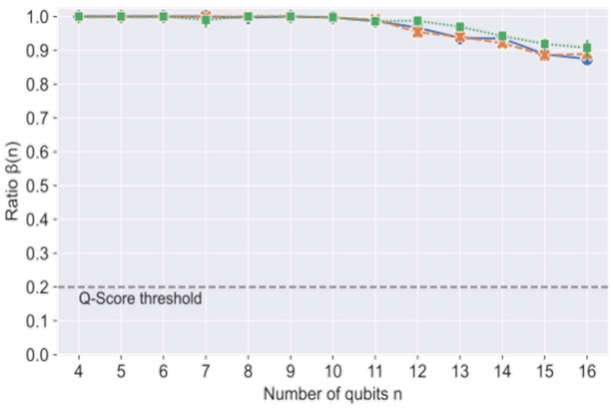


- Input parameters :
  - graph properties : *order, size, density, min/max/av. neighbourhood size*
  - Register : *min/max/av. distance (in μm) between connected/disjoint nodes*
- Supervized training (but dataset was *not* optimal)

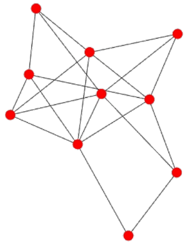
Results

Pasqal

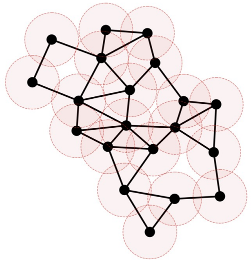
MaxCut

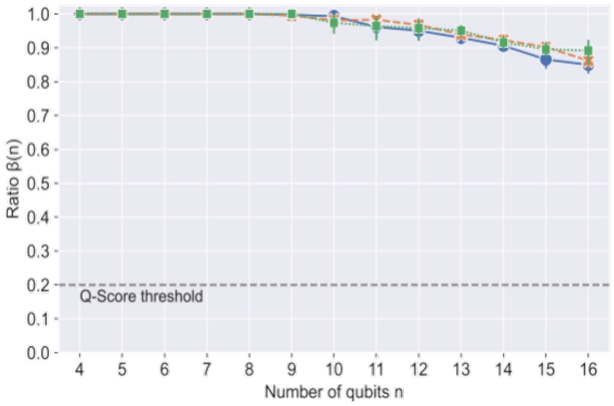


Non-Unit Disk

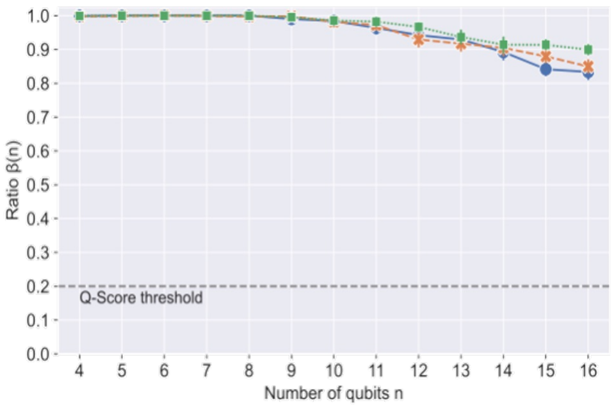


Unit Disk

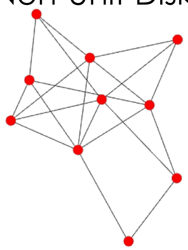




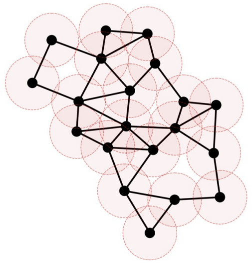
MIS

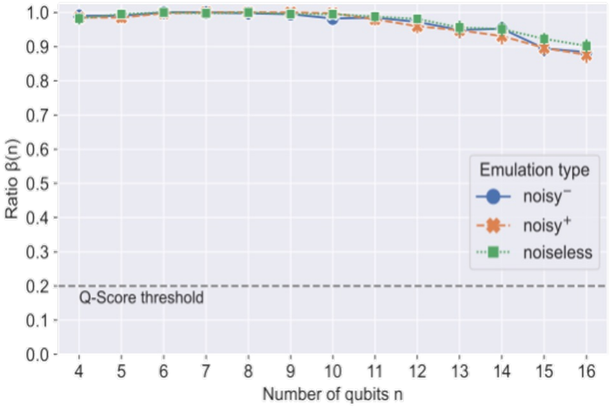


Non-Unit Disk



Unit Disk



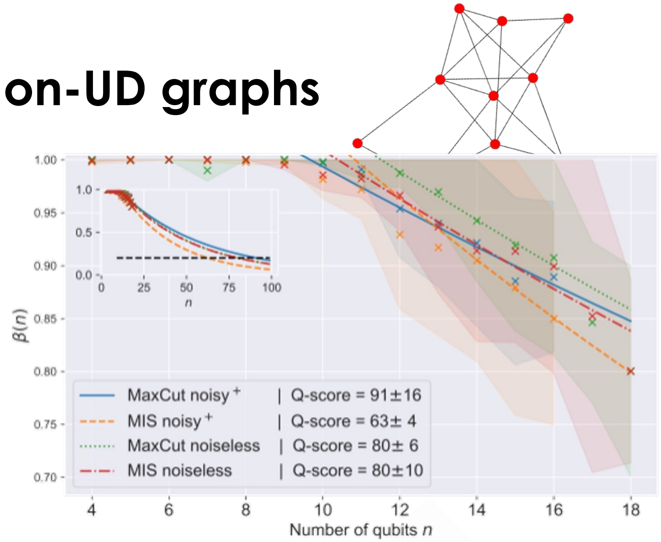


arXiv:2207.13030

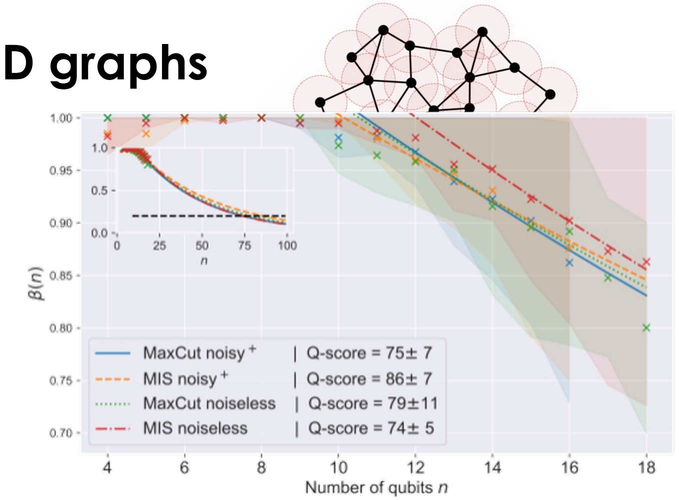
Results and conclusion

Pasqal

Non-UD graphs



UD graphs



Conclusion

- We could solve MaxCut and MIS problem even on non-UD graphs
  - Better results for MaxCut on non-UD graphs
  - Better results for MIS on UD graphs
- The supervised ML can learn how to predict good pulses for both graph problems
  - Not dependent on the graph size/order
  - Need a "good" training data set
- Embedding Strategies could improve for some graph classes

Persepectives

- Refine the model
  - Improve training dataset
  - Train on (mixed emulation-)QPU results
- Extend to other algorithms and/or problems

arXiv:2207.13030

QUANDELA

Experimentation Campaign on QPUs Using Q-score Metric

Vassilis Apostolou *(Quandela)*

4 June 2024

Teratec LNE THALES

STRATÉGIE NATIONALE QUANTIQUE

MetriQs France

FRANCE 2030

anr agence nationale de la recherche

QUANDELA

Q-score using Single Photons and Linear Optics

Teratec TQCI Benchmark

Ana Filipa Carvalho – Quantum Applications Engineer
June 2024

Quandela's implementation and results for Q-score:

Index

Atos' Q-score metric

Benchmarking method "application-centric, hardware-agnostic and scalable to quantum advantage"

"The Q-score measures the maximum number of qubits that can be used effectively to solve the Max-cut combinatorial optimization problem".

Conditions for a proper benchmark:

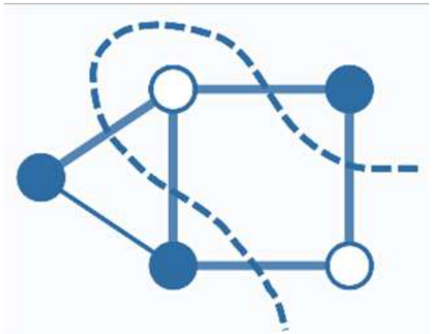
1. Application-centric
2. Hardware-agnostic
3. Scalable

Q-score measures the maximum number of quantum bits that a quantum computer can use to solve a combinatorial optimization problem—the Max Cut problem—significantly better than a classical random algorithm.

Atos' Q-score metric

Max-cut problem

- Graph G(V, E) of V vertices and E edges.
- *Goal*: find a partitioning (cut) of V into V_1 and V_2 s.t the number of edges not belonging to either of the induced subgraphs $G_1(V_1, E_1)$ and $G_2(V_2, E_2)$ is maximum.
- The set of edges $E/(E_1 \cup E_2)$ is called a cut, so MAXCUT is simply the problem of finding a cut of maximum cardinality.
- NP-complete

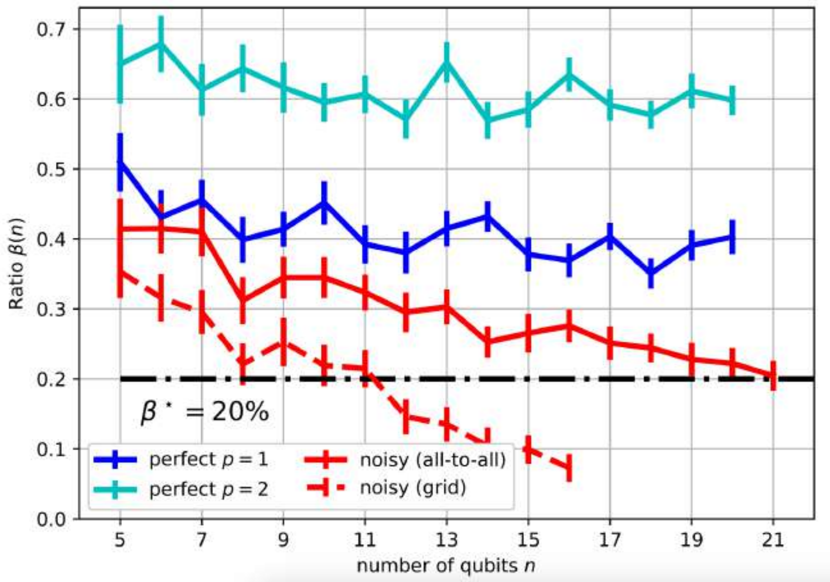


Atos' Q-score metric

Quantum algorithm for the Max-cut problem

Core of the benchmarking technique:

1. Fix some p.
2. Work with QAOA for MAXCUT on random graphs of n vertices, whose average number of solutions is known.
3. An ideal quantum device can solve with accuracy $a\%$ on average this problem.
4. Choose an accuracy $b\% < a\%$ and define Q-score as the largest n for which the noisy quantum device can solve MAXCUT using QAOA on random graphs with accuracy $b\%$.



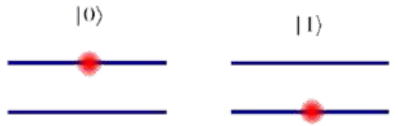
Optical Quantum computing
Quandela's vision

MAIN INGREDIENTS

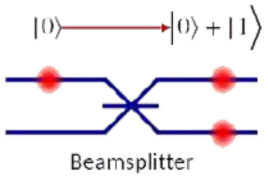
Type	Discrete variables: single photons
Encoding	Dual rail: integrated photonic Time: fibre loops & delay
Scheme	KLM: linear optical circuits – NISQ (up to tens of qubits) MBQC inspired: operation on cluster states, fusion gates – towards fault-tolerant
Approach	Efficient modules interconnected by ultra-low loss fibre links

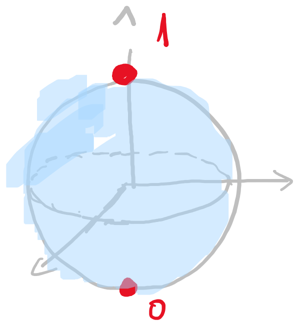
PHOTONIC QUBITS

Qubit encoding

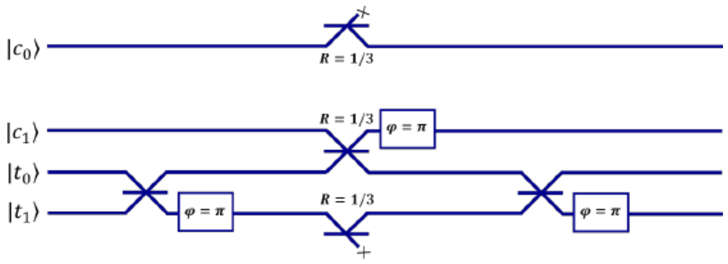


1-qubit gates





2-qubit gates



The Knill–Laflamme–Milburn (KLM) scheme

Dual rail encoding

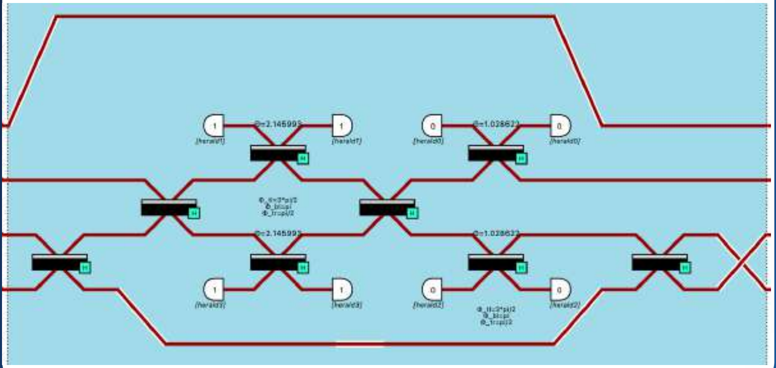
- We could end up detecting 2 photons in the modes of the qubit 0…
  - But this can’t be interpreted as a qubit output!
  - When this happens, we just ignore the run and try again → post-selection
  - Thus 2-qubit operations are probabilistic (KLM-scheme)
- KLM is a problem for the scalability of the approach
  - E.g. Try performing 50 operations each of which succeeds with say probability ½…
  - Ultimately, we will need a different model of computing – a more clever way to instantiate qubits with photons

The best (known) success probability of a CNOT-gate is 1/9 (post-selected), 2/27 (heralded)

Max-Cut problem:
Low level analysis of photonic Implementation

Variational Quantum Algorithms
Naive qubit translation

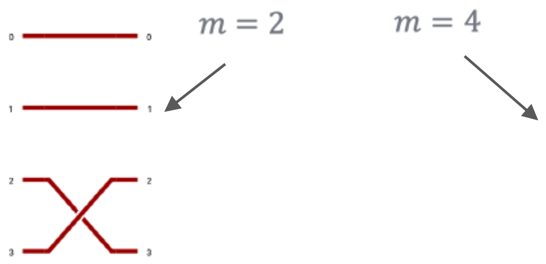
VQA
- Variational Quantum Eingensolver – VQE
- Quantum Approximate Optimization Algorithm – QAOA
- Variational Quantum Linear Solver - VQLS

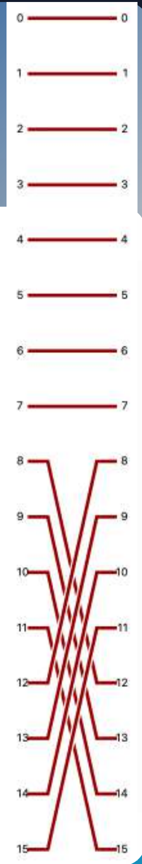


Hyper Encoding scheme:
Qubit Logic On Qudits (QLOQ)

Deterministic gates by different spatial encoding scheme.

KLM scheme with QLOQ encoding.

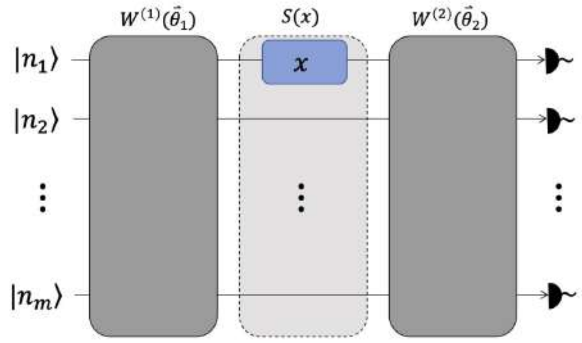




Photonic VQA [1], VBS

VQ circuit designed as an equivalent to neural networks;

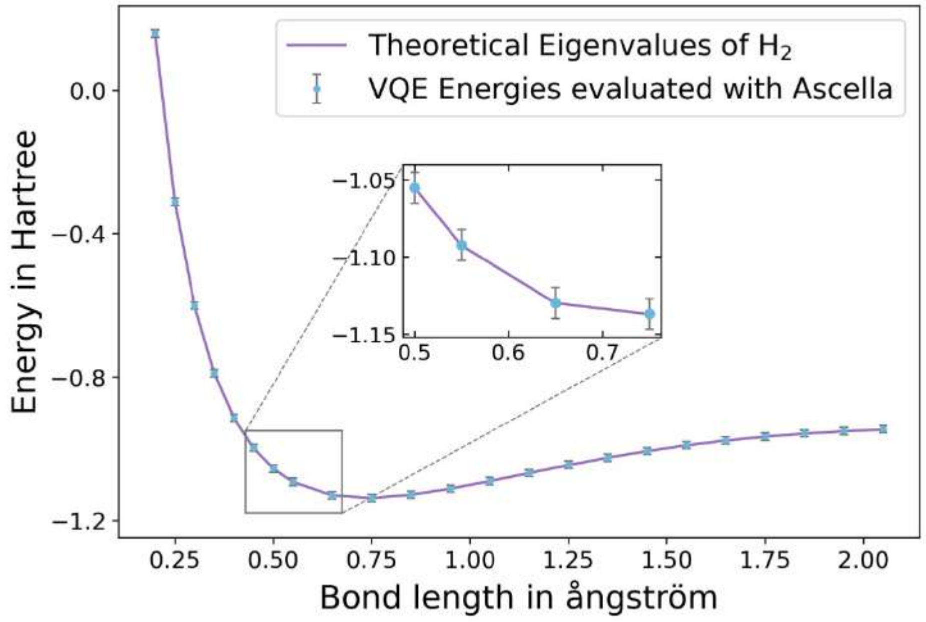
Data encoding operation S(x)
Parametrized operations W(Θ): train over Θ



[1] Gan et al., EPJ Quantum Technol. 9, 16 (2022)

Variational Quantum Eigensolver:
Better tailored to photonic hardware

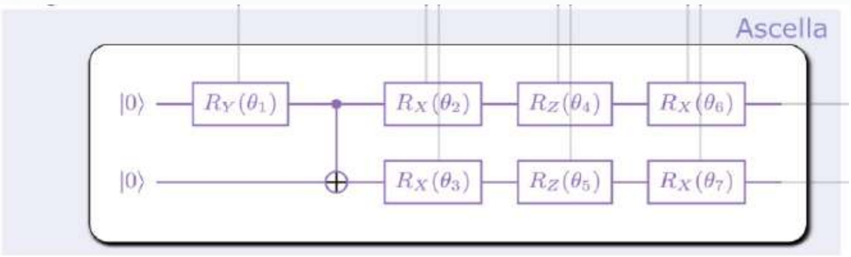
Goal: Find the ground state energy of a molecule given the coordinates of its nuclei. An example in Quandela's toolbox is the H_2 molecule.

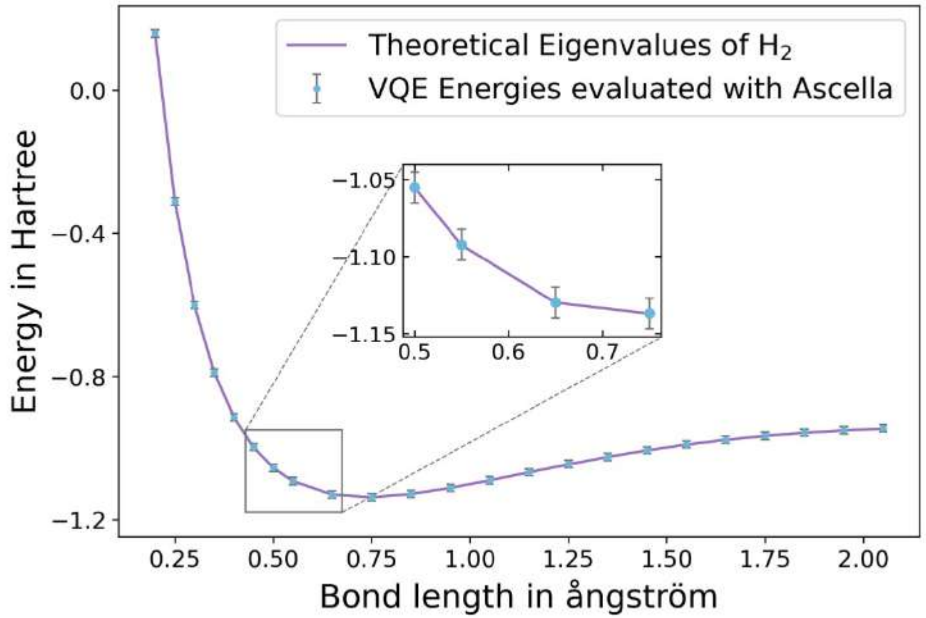


Variational Quantum Eigensolver:

Better tailored to photonic hardware

Goal:	Find the ground state energy of a molecule given the coordinates of its nuclei. An example in Quandela's toolbox is the H_2 molecule.
Step 1:	We prepare an ansatz for the quantum state with a circuit that has variational parameters.
Step 2:	The chemical problem is converted into a qubit Hamiltonian. Our circuit measures this qubit Hamiltonian and adds up averages of each measurement to gain an approximation of the ground state.

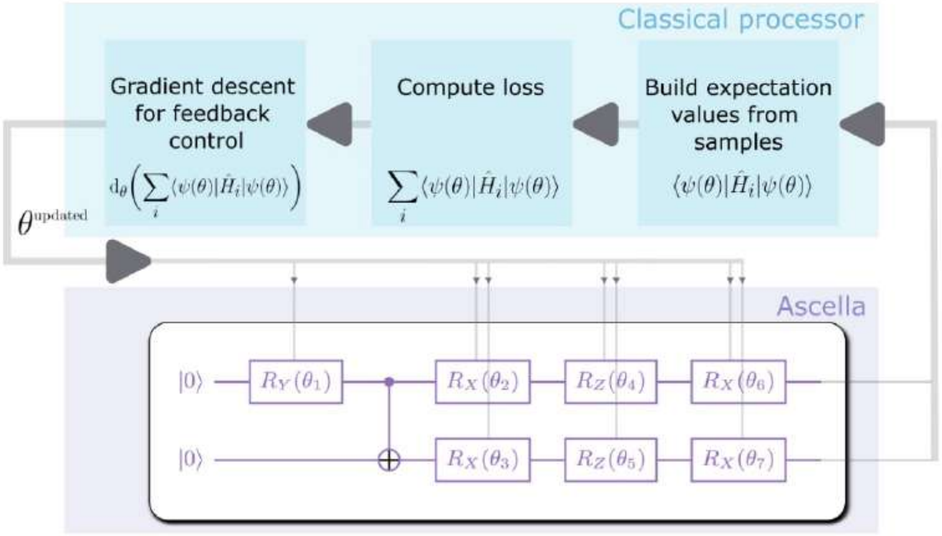


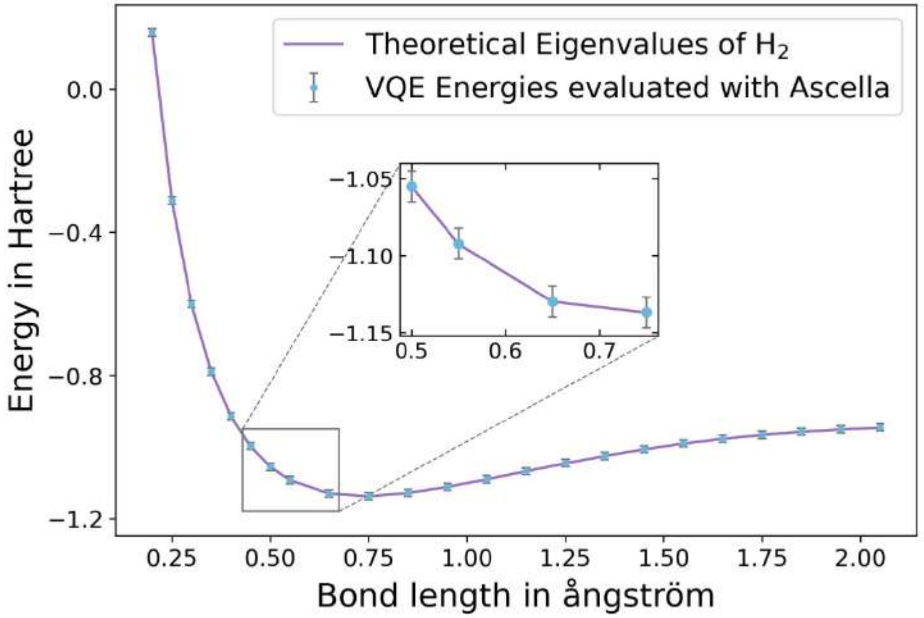


Variational Quantum Eigensolver:

Better tailored to photonic hardware

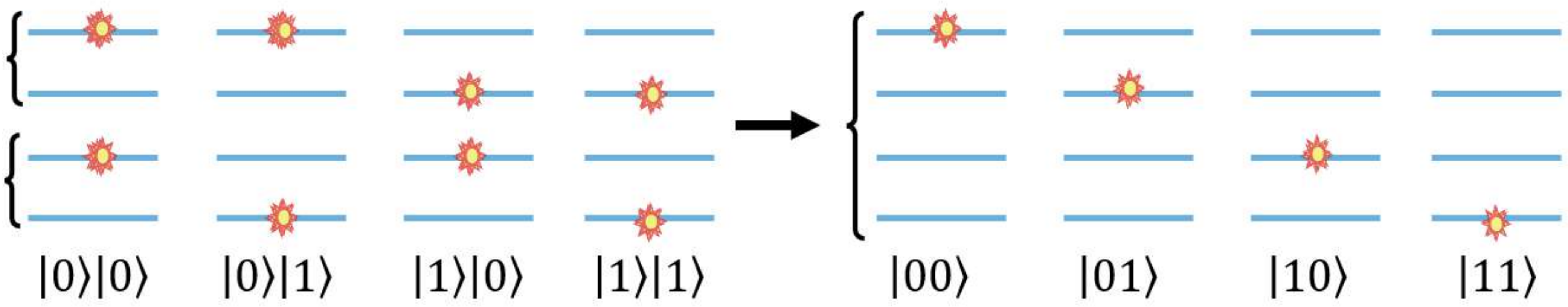
Goal: Find the ground state energy of a molecule given the coordinates of its nuclei. An example in Quandela's toolbox is the H_2 molecule.





Qubit Logic On Qubits (QLOQ) encoding: Core concept

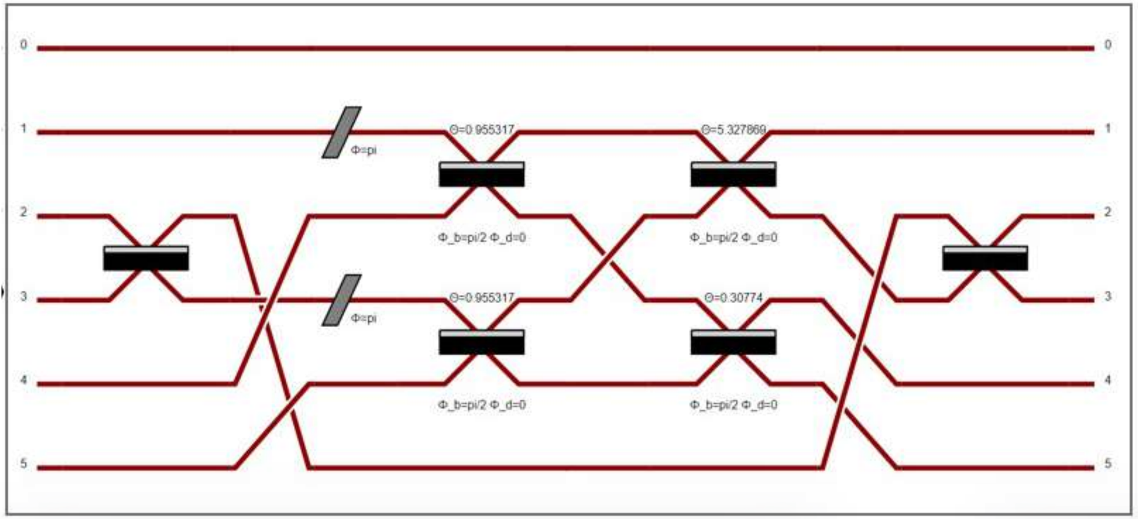
Divide a circuit into groups of qubits and map each group to a physical qudit.



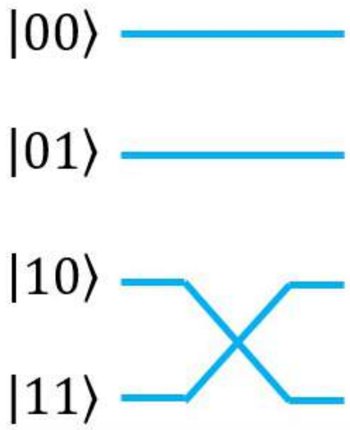
Qubit Logic On Qubits (QLOQ) encoding: Core concept

Divide a circuit into groups of qubits and map each group to a physical qudit.

Advantage #1: Entagling gates between qubits in the same group become local (single-qudit) operations!



Knill CNOT
$^2/_{27}$ success probability with 2 heralding photons needed



Local QLOQ CNOT
Deterministic with no heralding photons needed

Faster optimization:

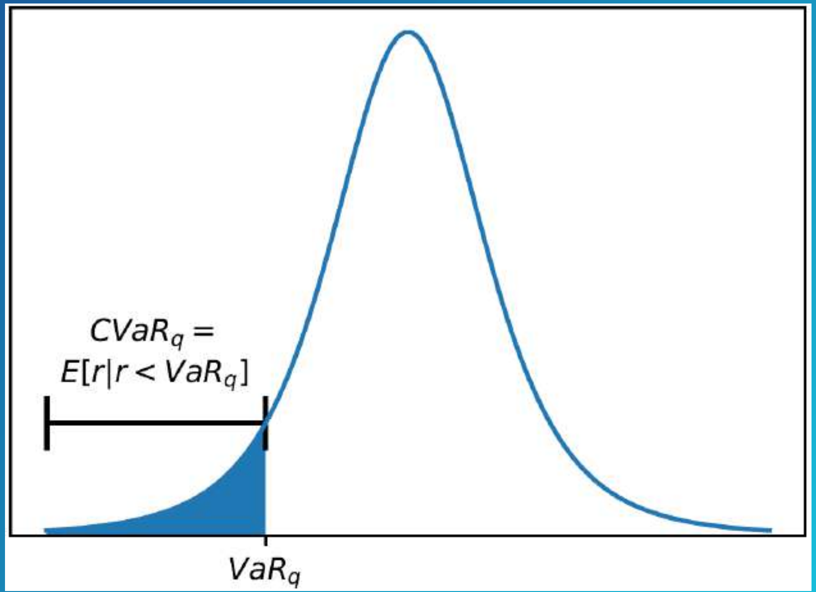
Conditional Value at Risk (CVaR) for faster convergence

Q: How to implementing a CVaR approximation to Generic VQE for QUBO? The user essentially defines a tail end to their probability distribution, a variable we call α.

Main points:

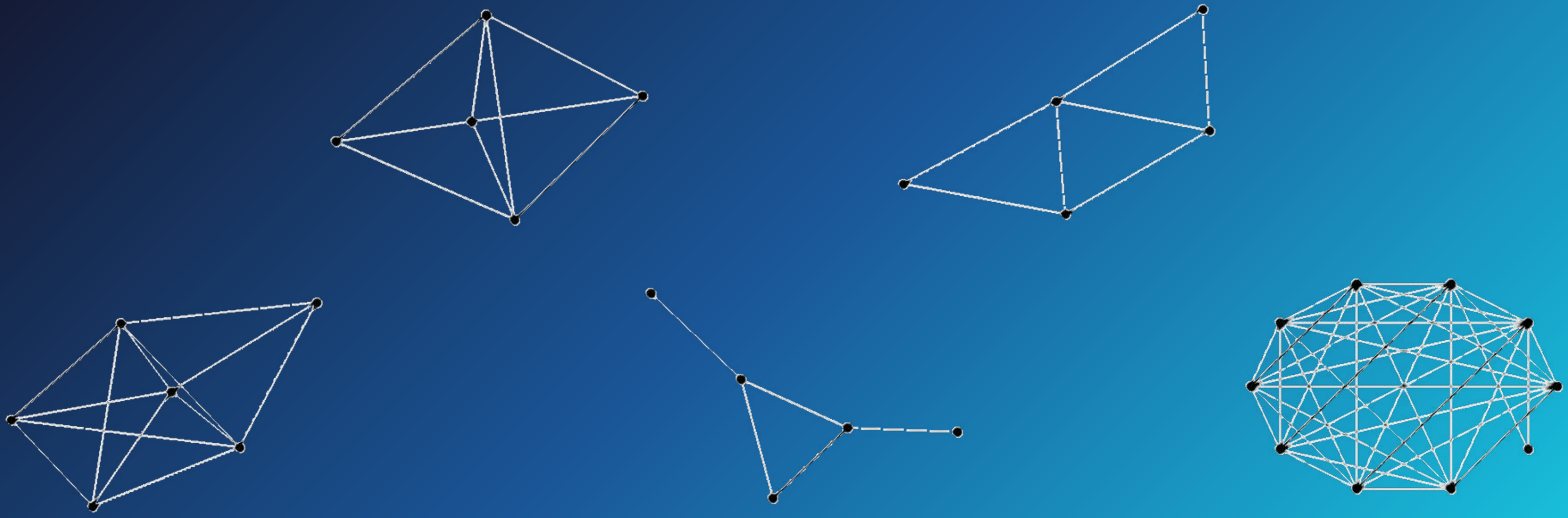
- Allows to *find results faster*.
- It has the *same qubit number requirements* as Generic VQE.
- *Resilient to noise*, both quantum and statistical unlike the generic version ⇢ less significantly less shots per run and indicating it will scale as our hardware grows.

$\alpha = 1$ ⇢ runs generic VQE on a standard optimization problem.
$\alpha < 1$ ⇢ takes a segment of the probability distribution, quicker convergence and reaches the optimal bitstring with higher accuracy.



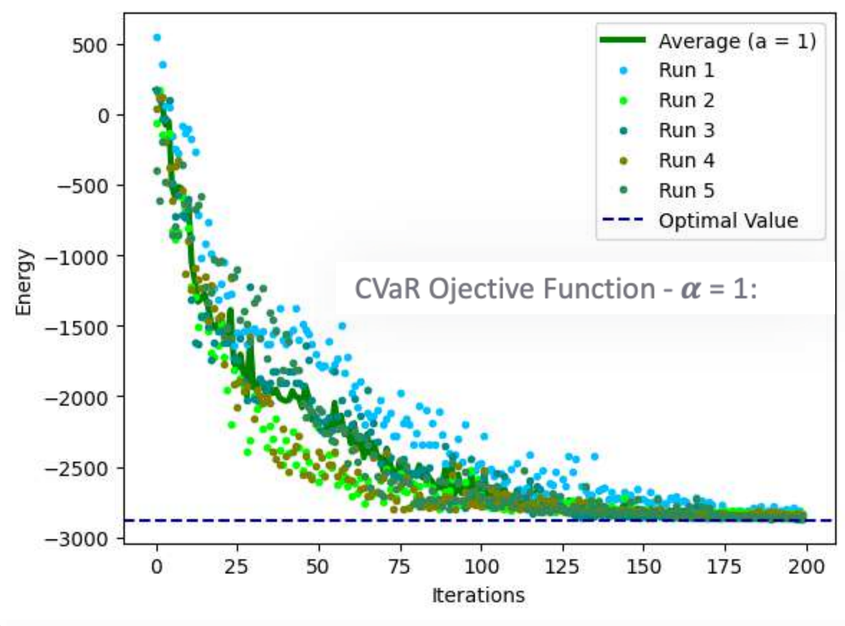
Numerics:

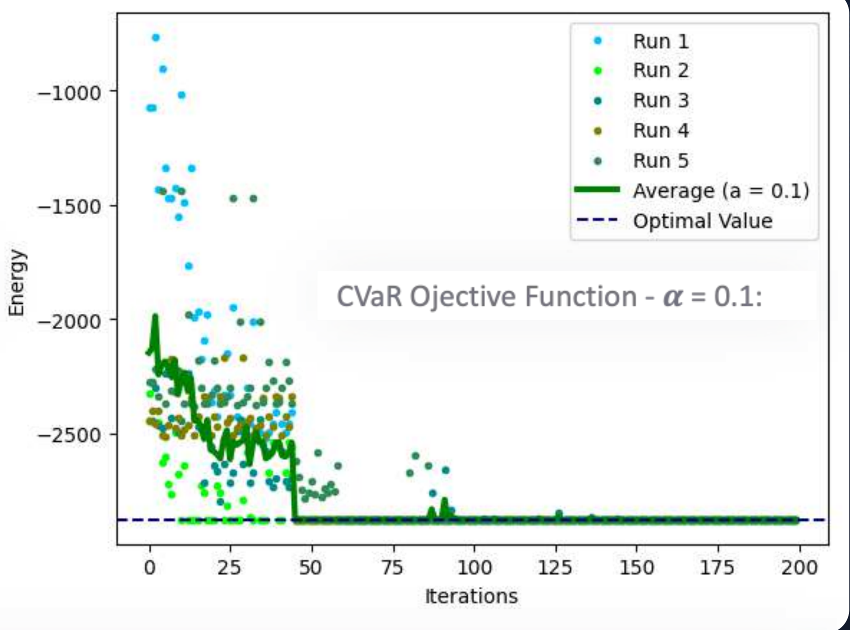
Implementation and results

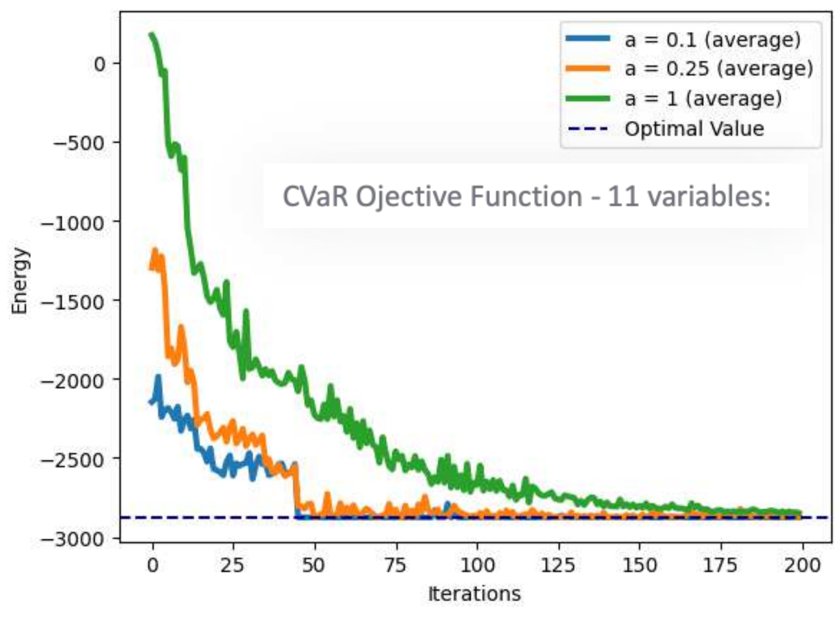


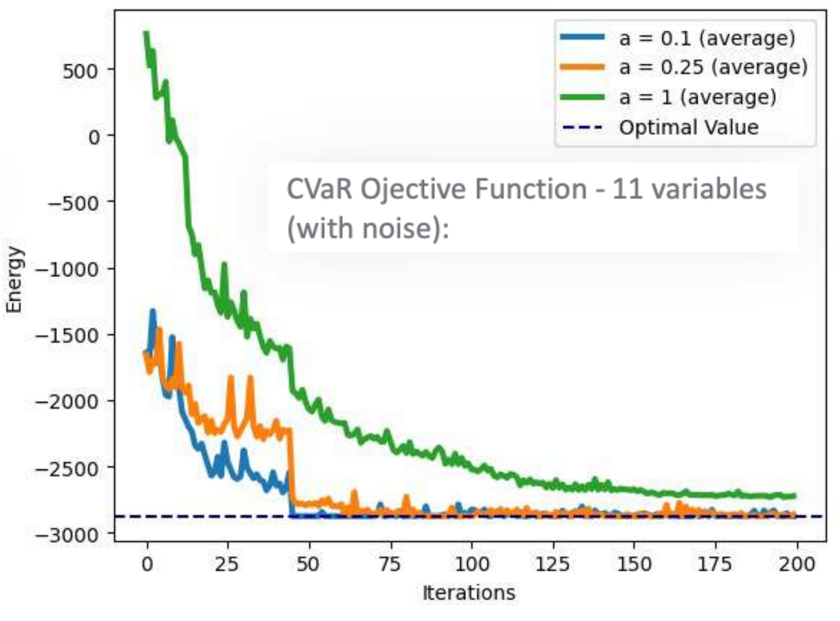
Results

CVaR-VQE versus VQE for Applications & Noisy Environment







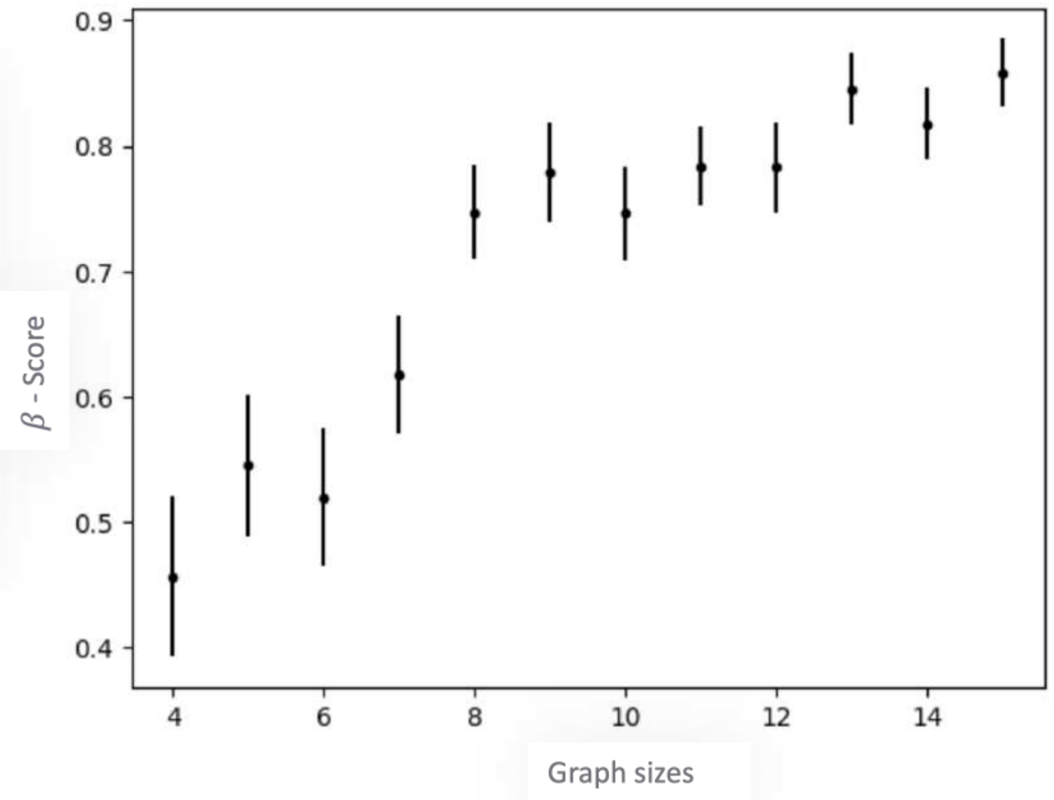


Atos' Q-score

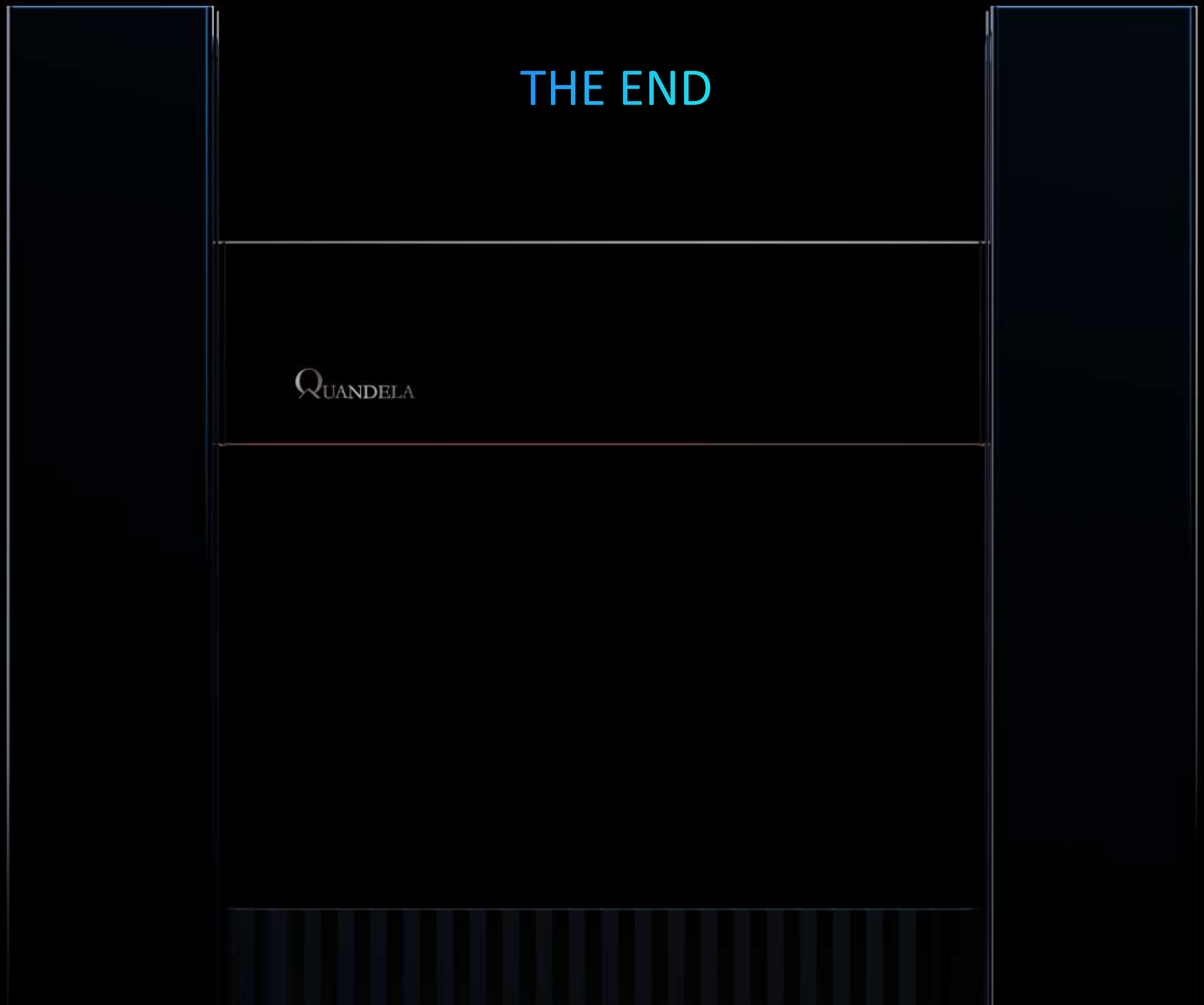
Results with CVaR-VQE implemented in Perceval

Results for Q-score with CVaR-VQE tailored for photonic technologies with QLOQ encoding.

Maximum size tested: 15 nodes.
Difficulty for larger tests: simulation runtime.



THE END



Experimentation Campaign on QPUs Using Q-score Metric

Ward van der Schoot *(TNO)*

4 June 2024

Showing the strength of Q-score as a framework

Ward van der Schoot MMath

Quantum at TNO

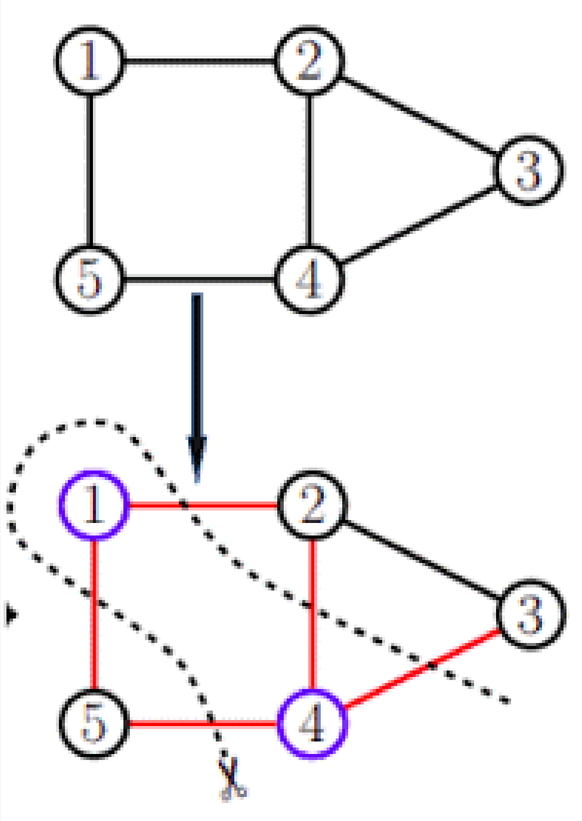
- The Netherlands Organisation for applied scientific research
- Mission:
  - To generate innovative solutions with provable impact for a safe, healthy, sustainable and digital society in the Netherlands and beyond.
- Quantum applications at TNO. Goal:
  - To enable **practical implementation** of relevant applications on current and/or near term quantum devices.

- Quantum benchmarking at TNO:
  - Goal:
    - Find the perfect device for a given application. Not for ourselves, but for industry
  - Considered many different application-level benchmarks
  - Focus on Q-score

Original Q-score by Atos

- Largest problem size *N* for which a device significantly outperforms a random algorithm at solving the Max-Cut problem

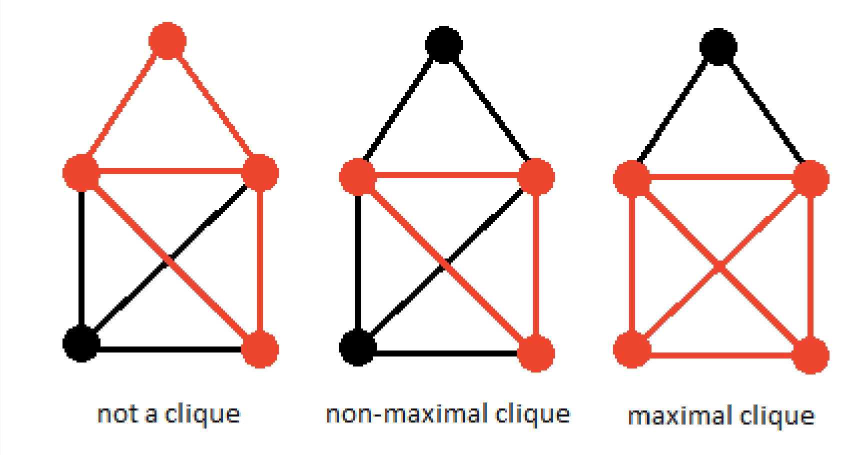
- Applicable on gate-based as well as annealing-based devices
  - Depends **not only** on the device
  - Also on the used algorithm, optimisations and resources



Extending Q-score framework: Q-score Max-Clique

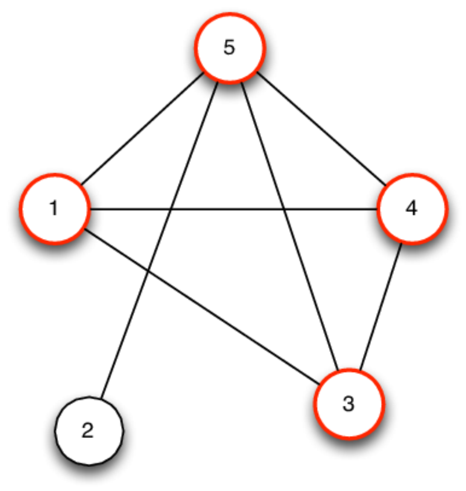
- Questions about the Q-score:
  1. Why do we specifically use the Max-Cut problem?
  2. What about other devices, such as photonic quantum computers?

- Q-score Max-Clique
  - Q-score with the Max-Clique problem
  - Find the largest clique: complete subgraph in *G*
  - Consider $\left(N, \frac{1}{2}\right)$ Erdös-Rényi graphs
  - Keep time constraint and optimisation as degrees of freedom



- → Q-score can be seen as a benchmarking framework with various degrees of freedom

Q-score Max-Clique



1. For increasing N, do the following steps:
2. Pick a collection of graphs of size N
3. Run a Max-Clique algorithm on each graph and compute average clique size $\mathrm{C}(N)$
4. Check whether clique size is 'good': $\beta(N) = \frac{C(N)-C_{rand}}{C_{max}-C_{rand}} = \frac{C(N)-1.6416325}{2\,\ln(N)-1.6416325} > \beta^* = 0.2$
5. Q-score Max-Clique is highest N satisfying this

- How do we estimate the max and random clique size C_{max} and C_{rand}?
- Random clique size:
  Adding nodes randomly until no clique yields $C_{rand} = \sum_{i=0}^{N} i(1-p^i)p^{0.5i(i-1)} \approx 1.6416325$
- Max clique size:
  Literature study plus quantum and classical brute force suggest $C_{max} = 2\ln(N)$

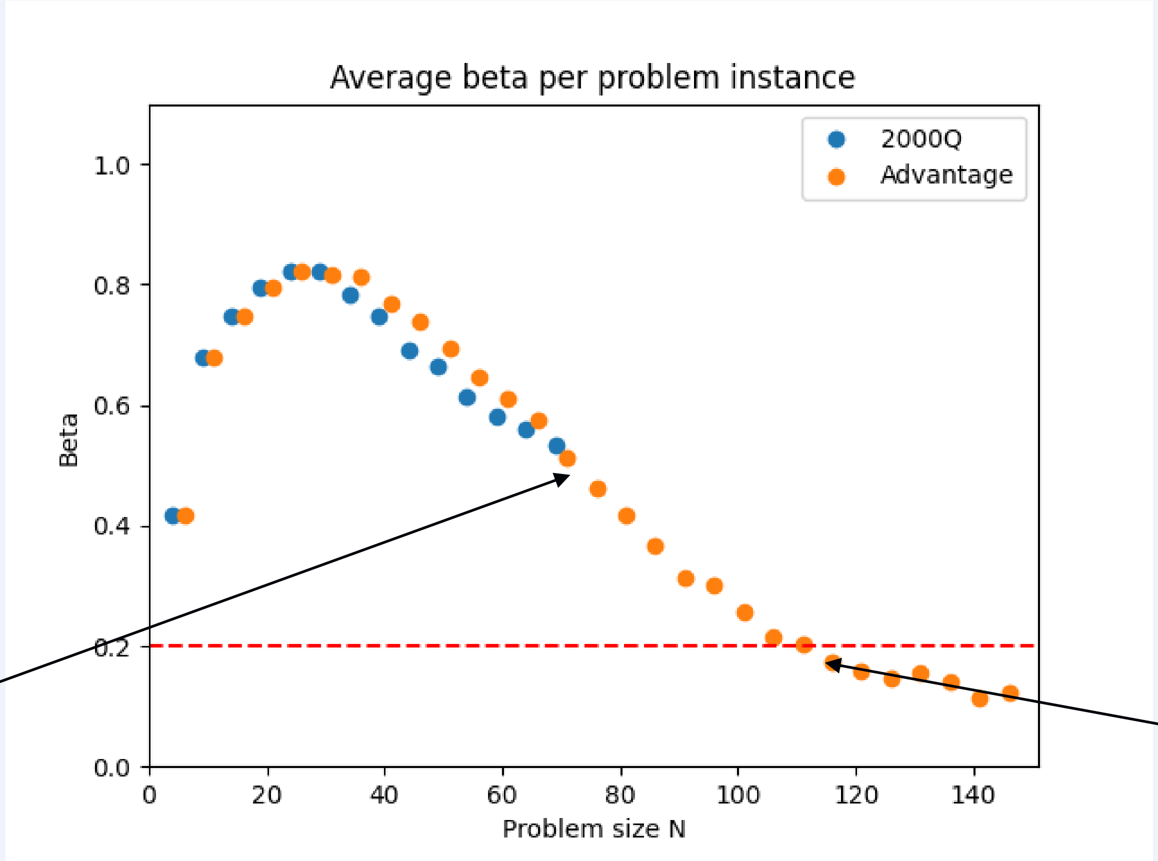
Experiments

- Calculate Q-score Max-Clique for following solvers
  - Quantum gate-based hardware IBM Guadalupe, Quantum Inspire Starmon-5
  - Quantum annealing hardware D-Wave Advantage, D-wave 2000Q
  - Quantum photonic hardware Quandela
  - Quantum photonic simulator Xanadu
  - Classical algorithms Simulated annealing, Tabu search
  - Hybrid quantum-classical solvers D-wave hybrid solver

- Extra constraints for specific metric instantiation:
  - Maximum calculation time: 60 seconds
  - Use out-of-the-box solvers:
    - Standard parameters
    - No extra optimisation allowed

Q-score Max-Clique Annealing Hardware

D-wave 2000Q
2048 qubits
6 qubit couplings



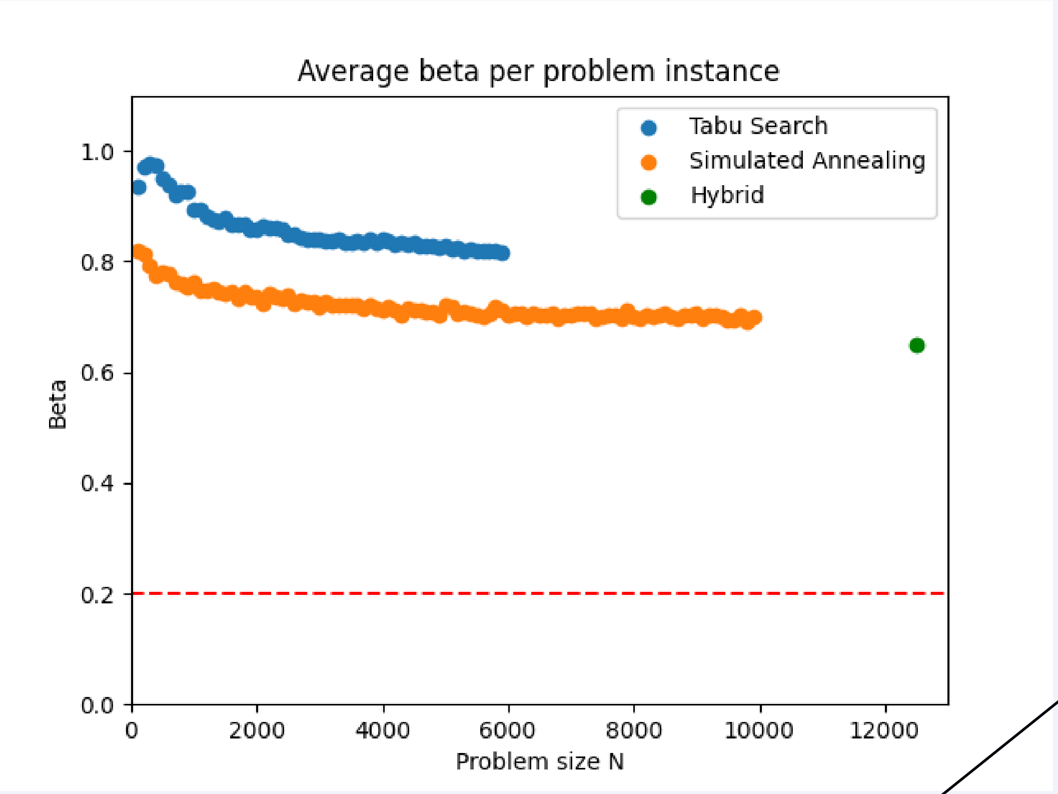
D-Wave Advantage
5640 qubits
15 qubit couplings

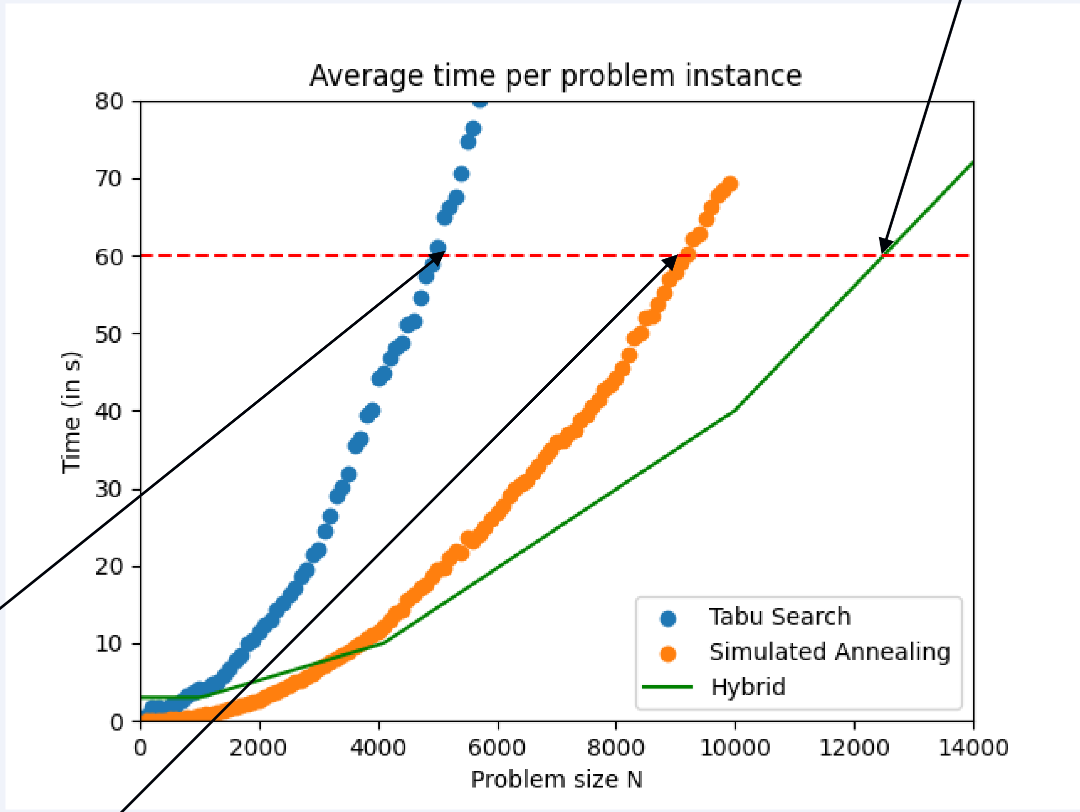
Q-score = 70

Q-score = 110

Q-score Max-Clique Classical & Hybrid Solvers

Q-score = 12,500





Q-score = 4,900

Q-score = 9,100

Results

Approach	Q-score
1. Tabu search	4,900
2. Simulated annealing	9,100
3. D-Wave Advantage	110
4. D-Wave 2000Q	70
5. Hybrid annealing solver	12,500
6. Quantum Inspire Starmon-5	5*
7. IBM Guadalupe	≥5*
8. Quandela Ascella	3
9. Simulated gate-based	13*
10. Simulated photonic-based	20*

- * = more than 60 seconds used

Conclusions

- Q-score yields a benchmarking framework to benchmark (quantum) devices in many ways:
  - Problem
  - Resources (time, optimisation, …)

- This work: Q-score Max-Clique
  - Allowing native solution for photonic quantum hardware

- Goal:
  - Suite of metrics with plug-and-play degrees of freedom
    - More degrees of freedom, e.g., KPIs (time, energy, accuracy, problem size, …)
    - See our talk later today – Quantum Application Score (Koen Mesman)
  - Matching between application(s) and device(s)

Thank you

Contact: ward.vanderschoot@tno.nl

innovation
for life

RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

EVIDEN

LABORATOIRE NATIONAL DE MÉTROLOGIE ET D'ESSAIS

LNE

Thank you for your attention

Damien Nicolazic (Eviden) – Jami Rönkkö (IQM) - Louis-Paul Henry (Pasqal) - Vassilis Apostolou (Quandela) - Ward van der Schoot (TNO)

4 June 2024

Teratec LNE THALES

STRATÉGIE NATIONALE QUANTIQUE

MetriQs France

FRANCE 2030

anr agence nationale de la recherche

CONFIDENTIAL LNE