Poznańskie Centrum Superkomputerowo-Sieciowe
Poznan Supercomputing and Networking Center

Open QBench: An Application-Driven Perspective on Quantum Computing Benchmarks

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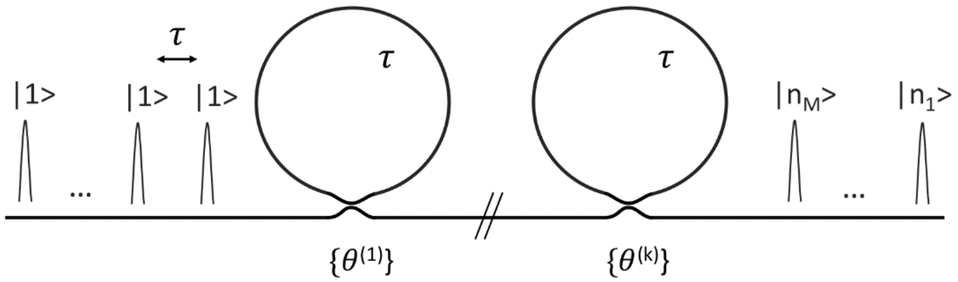
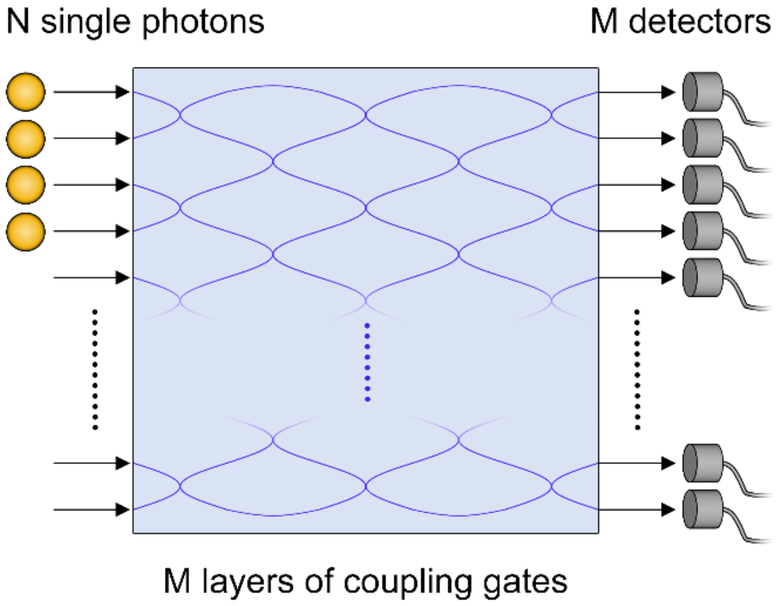
3rd International TQCI Seminar on Quantum Computing Benchmarks - June 24-25, 2025

Quantum Computing at PCSS

Photonics

- Two ORCA PT-1 photonic quantum computers were purchased during the EuroHPC PL project.
- Each one has 8 qumodes and 14 programmable parameters



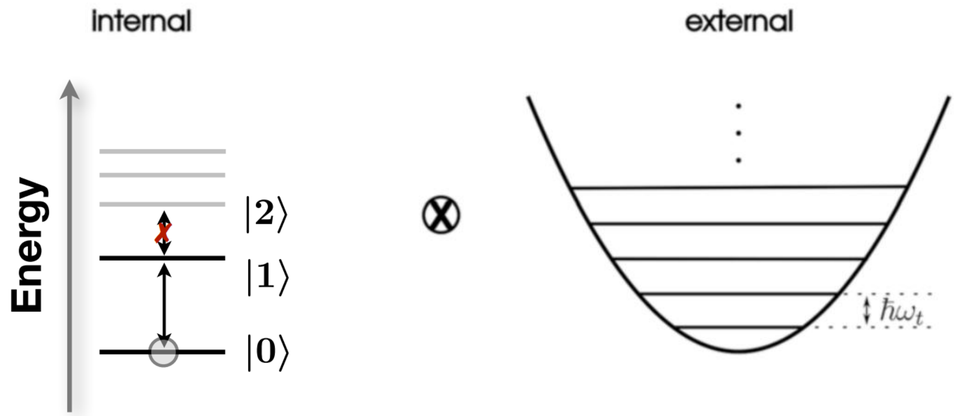


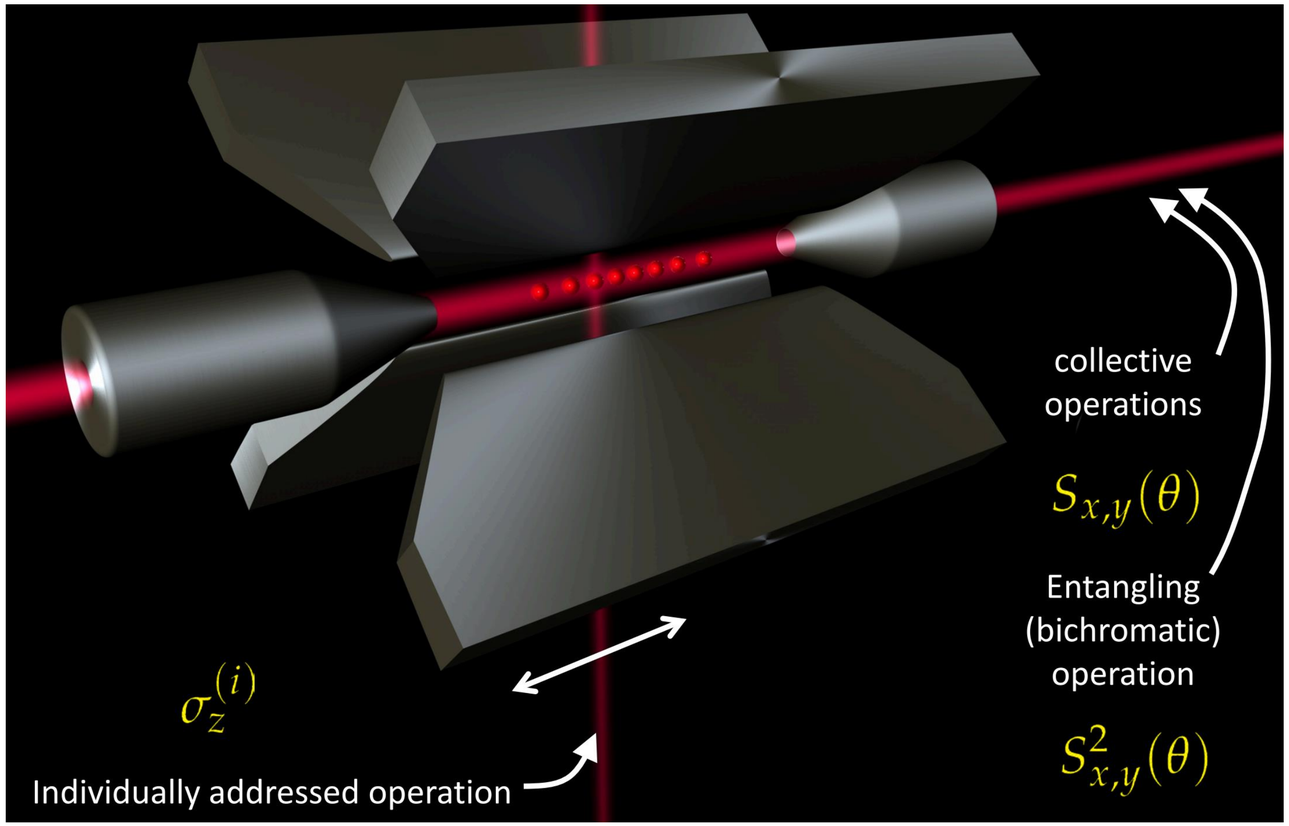
García-Patrón, R., Renema, J. J., & Shchesnovich, V. (2019). Simulating boson sampling in lossy architectures. Quantum, 3, 169.

Quantum Computing at PCSS

Trapped ions

- Procured by EuroHPC JU for the EuroQCS-Poland consortium
- Produced by Alpine Quantum Technologies (AQT) – a University of Innsbruck spin-off
- Officially launched yesterday (June 23)





Source: [Rainer Blatt]

Quantum Computing at PCSS

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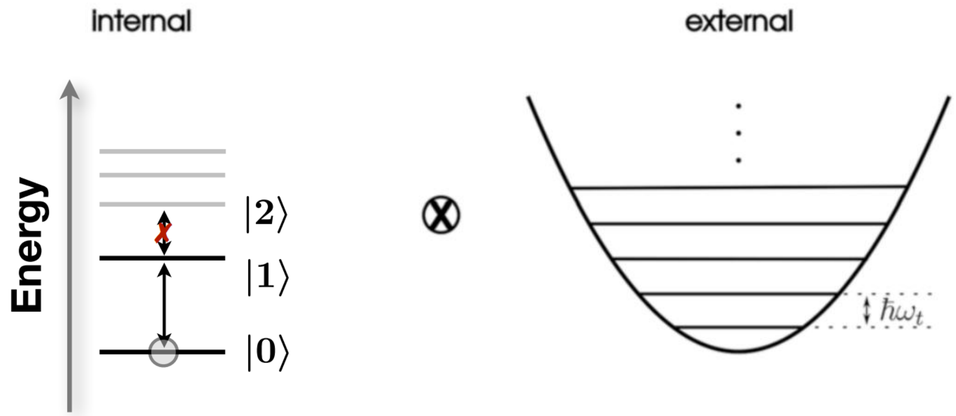
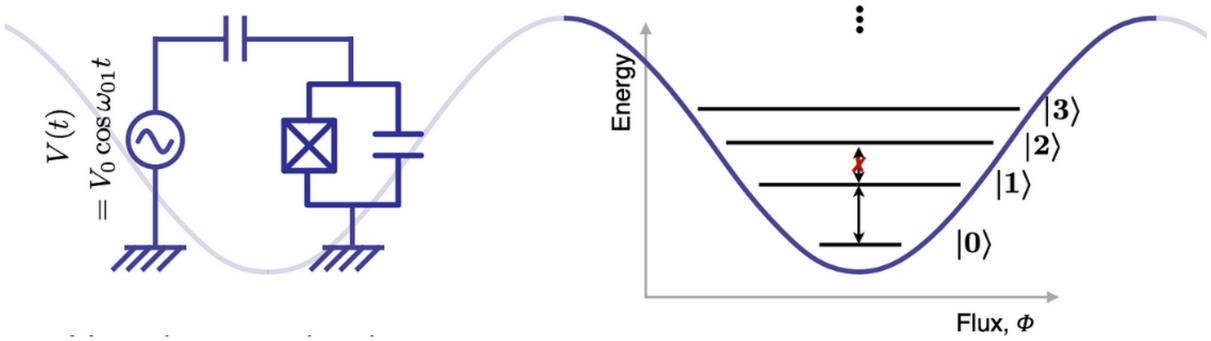


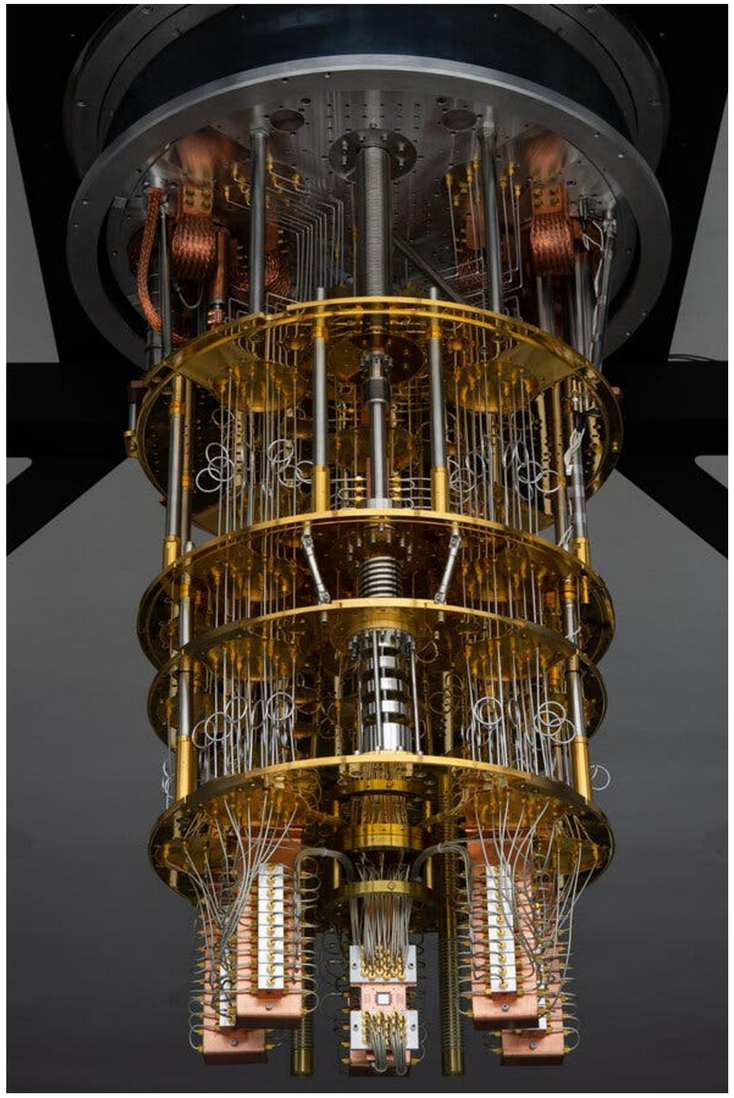
Quantum Computing at PCSS

Superconducting qubits

- PCSS is an IBM Quantum Innovation Center with cloud access to the latest superconducting quantum machines
- Currently 6 partner institutions working in different application areas

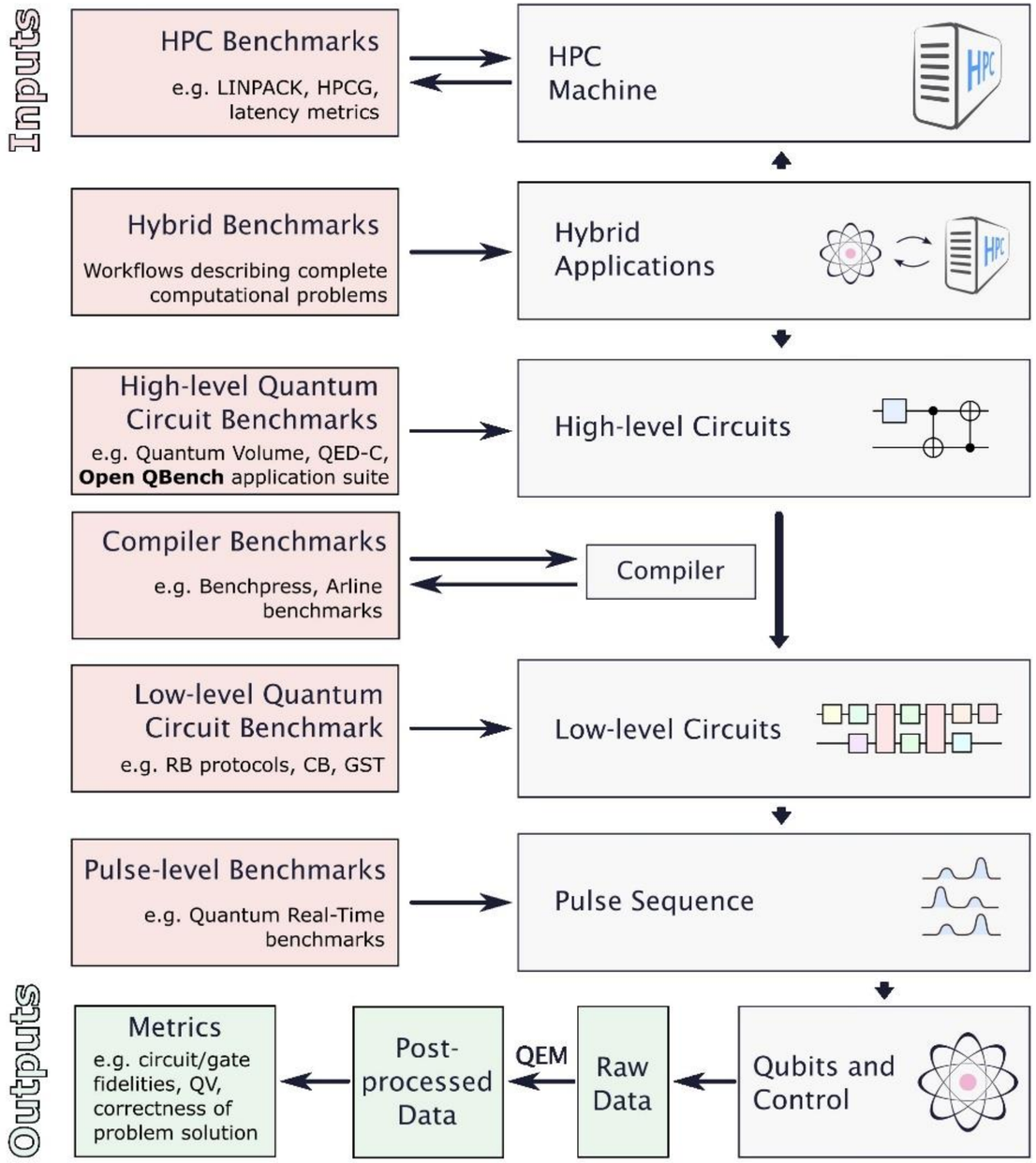


Source: Alexandre Blais



Source: James Estrin/The New York Times

The challenges of quantum benchmarking



Open QBench

Overview

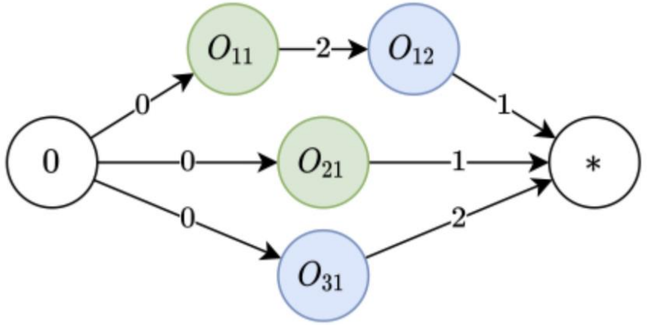
- Application circuits in OpenQASM format
- Implementations of benchmarking protocols in a unified form (Qiskit):
    - Reproducible results
    - Easy to extend
    - Open to contributions
- Qiskit-like APIs for constructing and running optical circuits
- Postprocessing routines for obtaining metrics and comparisons

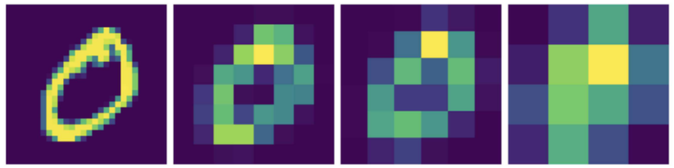
https://quantum.psnc.pl/openqbench/

Open QBench

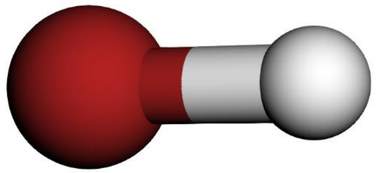
Application benchmarks

- Toffoli gate
- Grover's algorithm
- Quantum Fourier Transform
- Variational Quantum Eigensolver (VQE) – molecule ground state [1]
- Quantum Approximate Optimization Algorithm (QAOA) – Job Shop Scheduling [2]
- Quantum Support Vector Machine (QSVM) – MNIST classification [3]





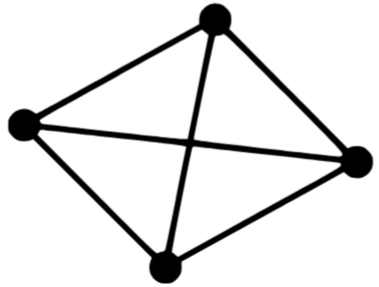
[1] Wojciechowski, K., Kurowski, K., & Mazurek, C. (2024). Chemical simulations of quantum systems using quantum computers – review of algorithms and their experimental verification. *Advances in Biochemistry* 70(2).
[2] Kurowski, K., Pecyna, T., Slysz, M., Różycki, R., Waligóra, G., & Węglarz, J. (2023). Application of quantum approximate optimization algorithm to job shop scheduling problem. *European Journal of Operational Research*, *310*(2), 518-528.
[3] Slysz, M., Kurowski, K., Waligóra, G., and Węglarz, J. (2023). Exploring the capabilities of quantum support vector machines for image classification on the MNIST benchmark. In *International Conference on Computational Science*, pages 193–200. Springer.



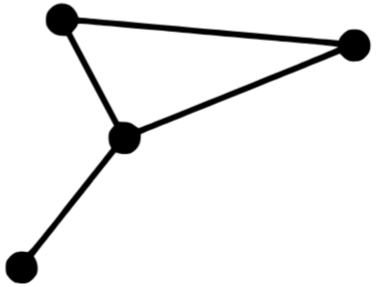
Open QBench

Binary Bosonic Solver

- Hybrid quantum-classical algorithm for solving combinatorial optimization problems by leveraging Boson Sampling devices
- Cost function encoded as a QUBO matrix
- Max-Cut used as a representative problem class



(a) 6 edges for the single-loop



(b) 4 edges for the double-loop

Slysz, M., Kurowski, K., & Waligóra, G. (2024). Solving Combinatorial Optimization Problems on a Photonic Quantum Computer. *arXiv preprint arXiv:2409.13781*.

Results

Gate-based machines

Application Benchmark	Number of Qubits	Normalized depth
Toffoli gate	5	n/a
Grover's algorithm	3	28
QFT	4	34
VQE	3	56
QAOA (JSSP)	7	24
QSVM	8	19

Device name	Grover	QAOA	QFT	QSVM	Toffoli	VQE	Time [s]
ibm_algiers	0.80	0.66	0.62	0.58	0.26	0.59	~ 1
ibm_auckland	0.88	0.69	0.52	0.80	0.34	0.73	~ 1
ibm_brisbane	0.91	0.85	0.71	0.49	0.40	0.80	~ 2
ibm_cairo	0.84	0.81	0.66	0.69	0.19	0.68	~ 1
ibm_cusco	0.89	0.58	0.68	0.66	0.21	0.72	~ 2
ibm_hanoi	0.90	0.69	0.68	0.78	0.40	0.77	~ 1
ibm_nazca	0.81	0.77	0.61	0.73	0.25	0.74	~ 2
ibm_sherbrooke	0.87	0.79	0.80	0.79	0.41	0.75	~ 1
ibm_torino	0.91	0.81	0.74	0.84	0.41	0.76	~ 1
ibmq_kolkata	0.93	0.82	0.71	0.75	0.16	0.81	~ 1
ibmq_mumbai	0.83	0.82	0.71	0.75	0.24	0.73	~ 1
AQT IBEX	0.90	0.79	0.81	0.83	0.49	0.73	~ 100
IQM Garnet	0.85	0.72	0.59	0.80	0.33	0.65	~ 1

Results

Boson samplers

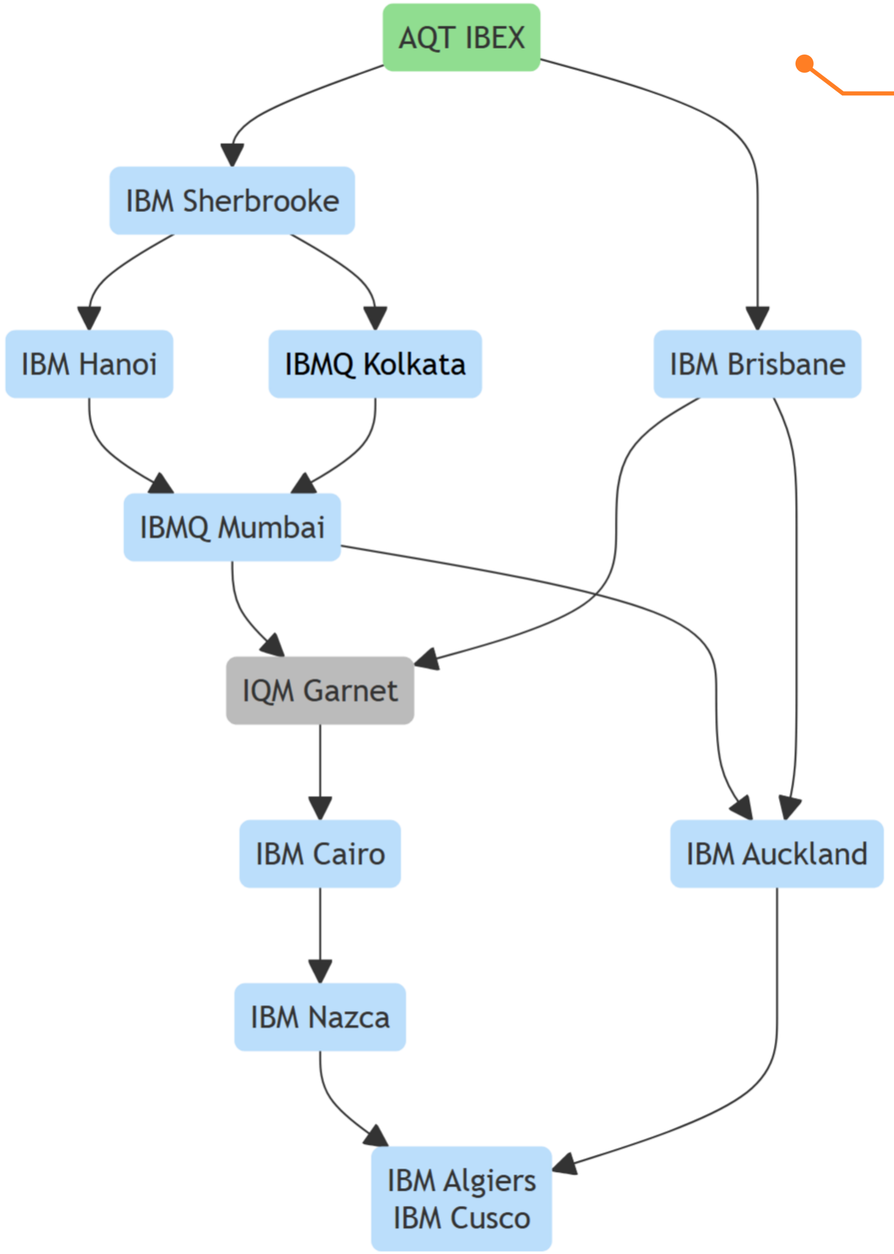
- 4 qumodes used
- 6 graph edges for single-loop configuration and 4 edges for double-loop

Device name	single-loop BBS	double-loop BBS	single-loop BBS Time [s]	double-loop BBS Time [s]
ORCA PT-1 System A	0.52	0.32	~ 166	~ 599
ORCA PT-1 System B	0.51	0.30	~ 23	~ 48

Results

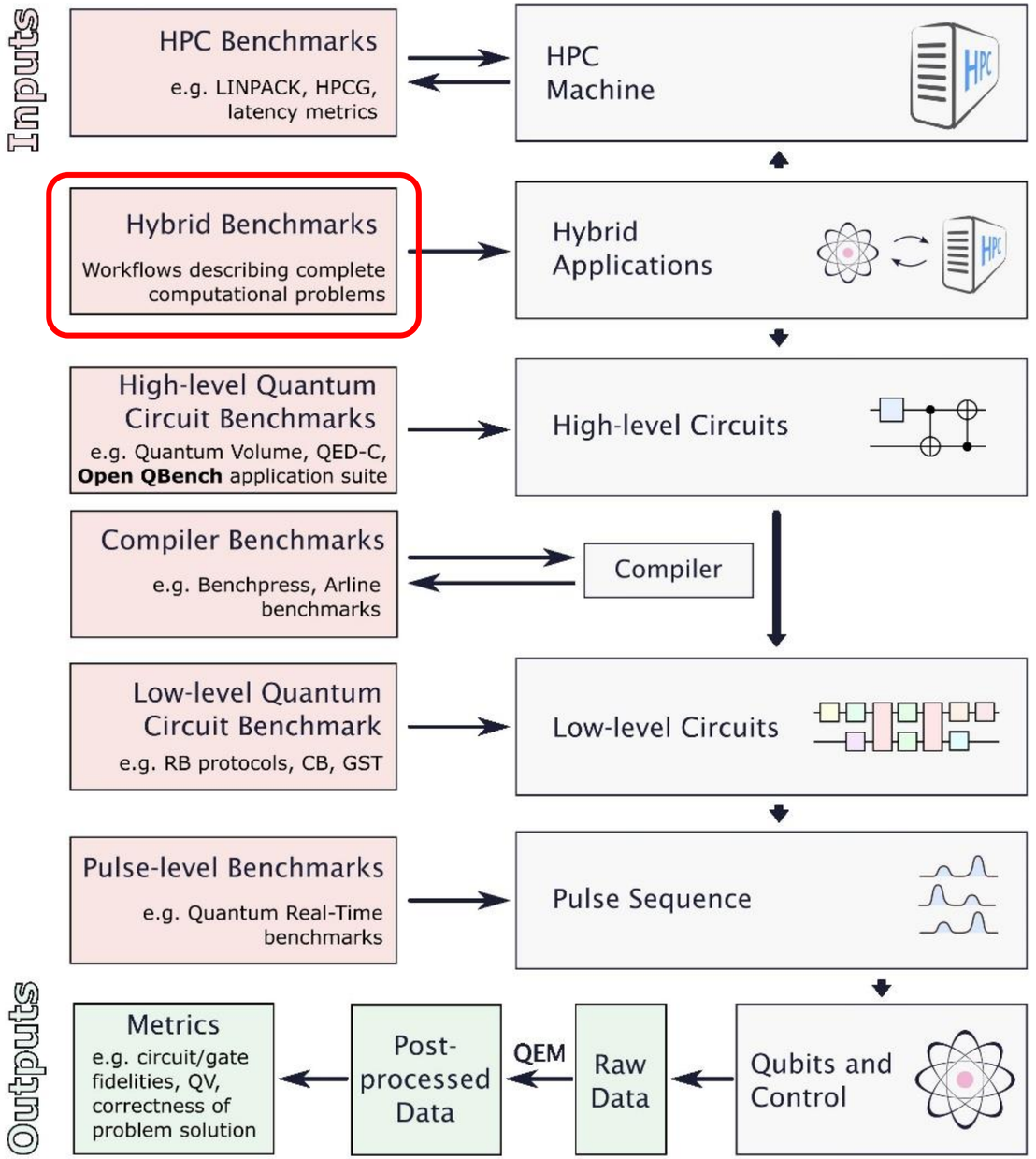
Aggregating fidelities

- Different Multiple-critiera decision analysis (MCDA) methods can be used to aggregate benchmark results
- We used ELECTRE III to generate a partial ranking represented on a graph
- This can be utilized to show relationships between different machines in terms of quality



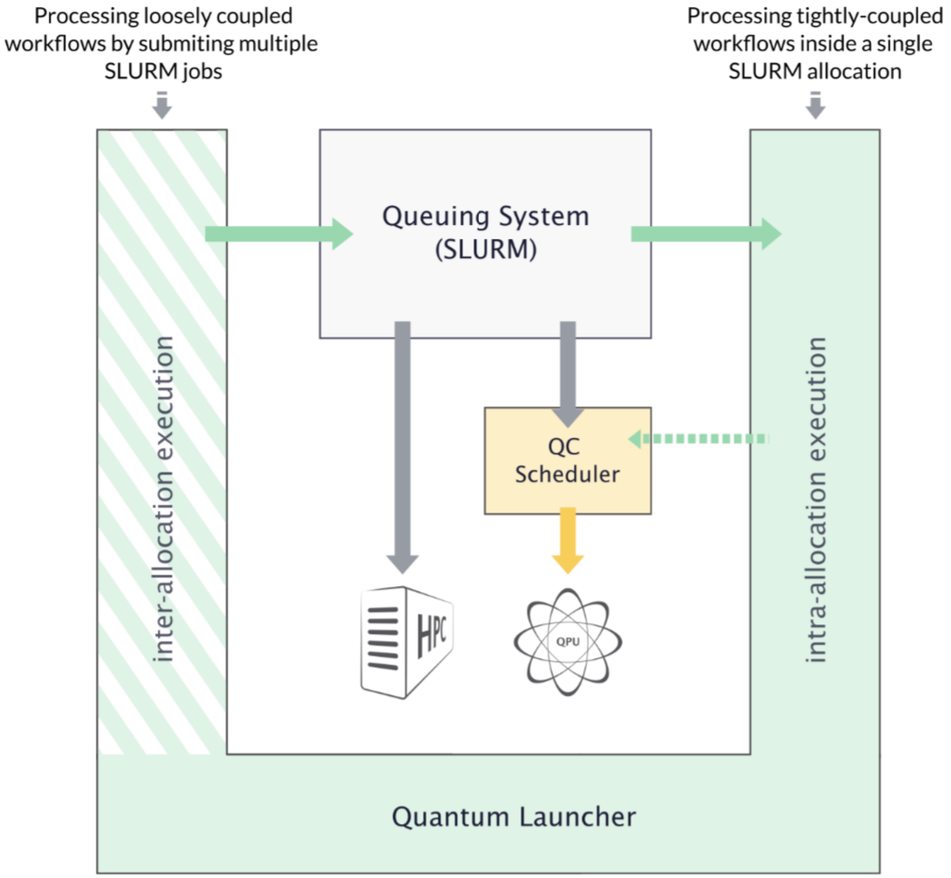
Conclusions and future work

- Good benchmarks are essential for characterization, tracking improvements and driving progress
- With quantum application benchmarks will need to be scalable
- The most popular benchmarks usually describe performance using a single metric
- Current efforts in HPC-QC integration will most likely lead to new (**hybrid**) benchmarks



Hybrid benchmarks

- For hybrid benchmarks we will use QLauncher developed at PCSS: https://gitlab.pcss.pl/quantum/psnc-sdk/launcher
- This will serve as a testbed for our integration efforts with the ORCAs and the EuroHPC trapped-ion machine (AQT)
- Good initial workflow candidates: chemistry (SQD), error mitigation (TEM), hybrid ML



Pecyna, T., Siera, D., & Bosak, B. (2024, September). QCG-QuantumLauncher: A Modular Tool for Quantum Scenarios. In International Conference on Parallel Processing and Applied Mathematics (pp. 351-360). Cham: Springer Nature Switzerland.

Thank you for your attention

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