IQM

WE BUILD QUANTUM COMPUTERS

Benchmarking @ IQM

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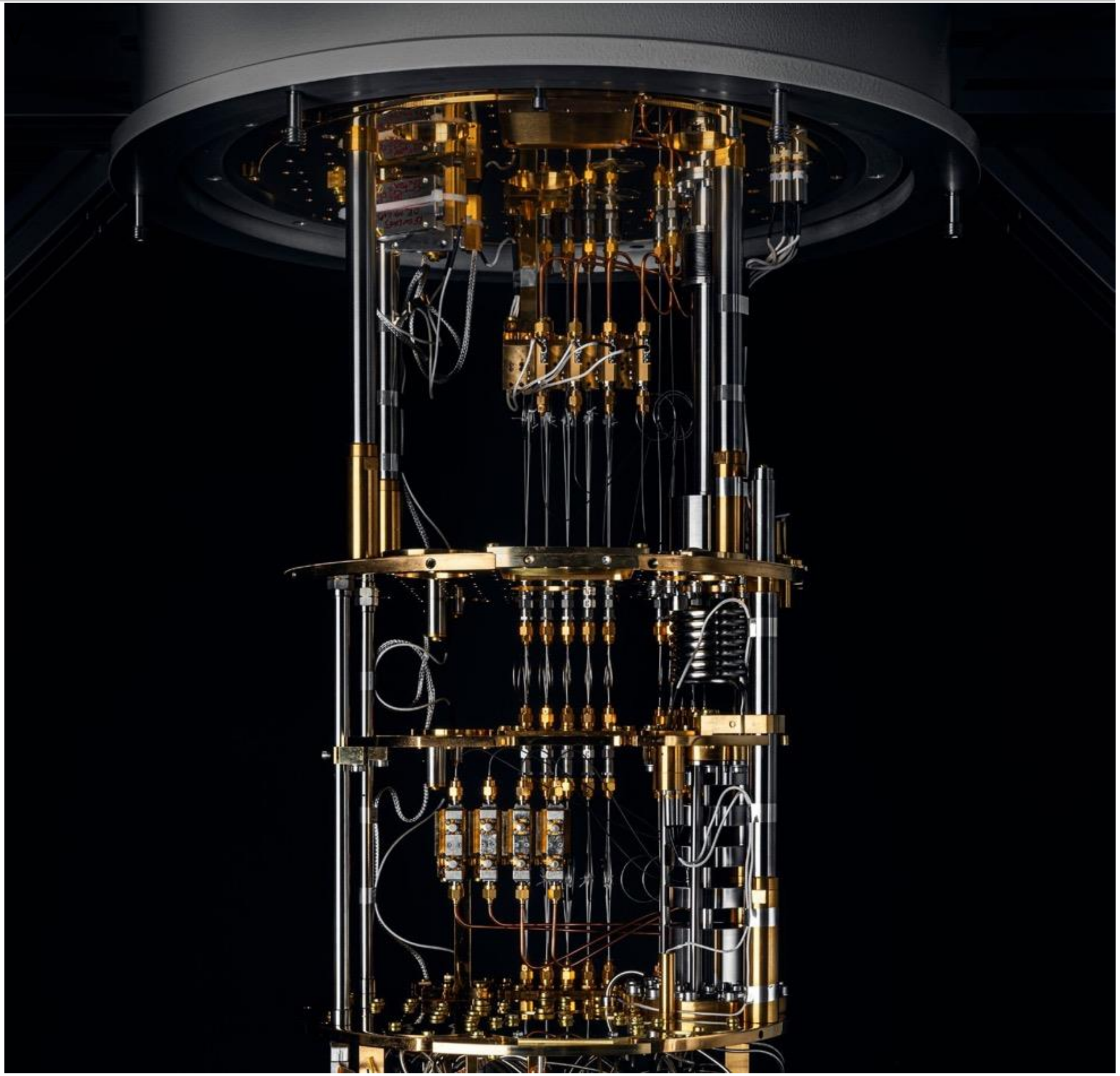


Different levels of benchmarks
for different purposes

- **Component**
- **Processor**
- **Fundamental physics**
- **Application**
- **Speed**

Component level

- IQM has started in 2018 as a hardware company
  - Focusing first on experimental physics: qubits, couplers
- Need to better understand the physics of the device
  - Coherence times
  - Single- and two-qubit gate fidelities
  - Time to pass a gate

- **Randomized benchmarks**
  - Implementing large sequences of Clifford operations
    - ➔Estimate the average error rates
    - ➔Characterize the type of noise
  - Better scaling than tomography

Processor level

- Need to better understand how the different qubits are working together (« system » view)

- **Volumetric benchmarks**
  - As a generalization of the « square » Quantum volume
- **Mirror randomized benchmarks**
  - Implementing large sequences of Clifford operations **using mirror circuits** to allow for more complex circuits with multiple qubits
    - ➔Gives more information on interactions between qubits (crosstalk errors)
    - ➔Allow to understand where bad things, such as problematic coupling, are happening

Fundamental physics level

- Need to demonstrate <u>quantum physics capabilities</u>

- **Entangled state generation**
- **Non contextual inequalities**
- (In the future for networks, Bell inequalities)
- **Cross-entropy**, such as the Google experiment - it is not exactly demonstrating fundamental physics, but fundamental capabilities (similar approach)
  - ➔Prerequisites to do useful things
  - ➔But don't tell you what is going wrong

Application level

- Randomized benchmarking gives a sort of average over all possible algorithms, whereas it is necessary to know performance on specific tasks
- Need for well-defined <u>performance results on specific tasks</u>

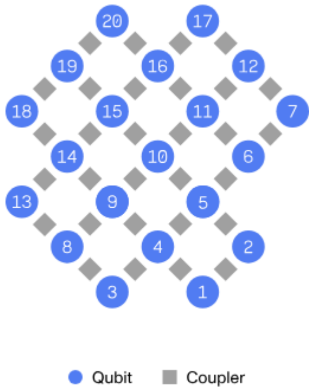
- **Q-Score**
  - ➔ Best approach for applications so far
  - ➔ But too limited in terms of scope, and methodology could be better defined
  - ➔ Need governance from an independent oraganisation
- **Munich Quantum Toolkit**
  - Select the benchmark, run it, get the result as a bitstring
    - ➔ Nice compilation of tasks, but now we need to find ways to combine them and generate good benchmarks out of them. In summary a good toolkit, but not yet a full benchmark
    - ➔ Does not tell you how well you performed

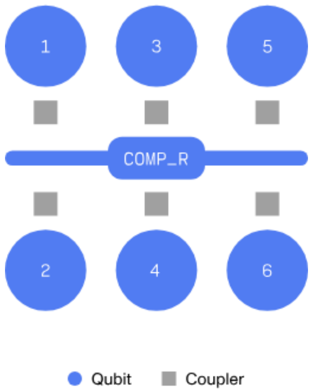
Speed level

- Need to know how fast a benchmark is run, whatever the level
- Speed used to be less considered as fidelity was a limiting factor to create large circuits
  - It is evolving, in particular when you want to apply Error Mitigation techniques that require to complexify the initial circuit
- **Circuit Layer Operations per Second (CLOPS)**
  - Based on Quantum Volume (QV)
    - ➔ Taking into account only part of the processor (QV is using square circuits)
    - ➔ Biased as it is focusing on some types of delays
    - ➔ Not holistic, wall times would be more useful for application benchmarks
    - ➔ For application benchmarks, maximum execution time could be useful as well, but for the moment it is better to measure the speed separately until it is properly included in the application benchmarks
- **Internal speed benchmarks**

We publish benchmark results for our cloud QPUs

- On https://resonance.meetiqm.com two QPUs are available
  - Garnet: 20 qubits in a square-lattice topology
  - Deneb: 6 qubits in a star-shape topology with a central resonator
- We will publish soon Garnet detailed results on https://iqmacademy.com





BENCHMARK	METRIC	RESULT
Quantum Volume (QV)	QV	32
Circuit Layer Operations Per Second (CLOPS)	CLOPS	2594
GHZ State Creation	largest N (fidelity)	20 (0.6)
MQT Bench	Hellinger distance	see below
Q-Score	Qubits	15

Conclusion and take-aways

- Benchmarks were initially developed and used for internal purposes
  - To have a reference and monitor our progresses
- Nowadays, they are becoming more and more important for business purposes to compare against competition
  - E.g., EuroHPC tenders required a heavy benchmark activity
- Application benchmarks are expected to cover more and more domains with some industry-focused benchmarks
- They should include also some well-defined methodology and how to read results, including execution times, with governance from an independent organisation
  - E.g., by providing open-source implementation commonly agreed
  - This is not only a matter of running some circuits
- Buyers should care about benchmarks
- IQM is part of several initiatives and is happy to bring expertise in that field

Thanks!

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