Quantum Computing for HEP

The CERN QTI

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High-Level Objectives

Computing

- Assess the potential and role of QML in HEP workloads, work on optimization and more robust mathematical formulations
- Build expertise in the state-of-the-art of the software stack (simulators, compilers, programming models/languages/tools)
- Work on quantum systems simulators (FPGA?)
- Set up a distributed QCS platform

Communications

- Explore possible applications of QKD
- Comms+sensing for detectors?
- European Quantum Network/Internet

Sensing

- Ion/particle traps as computing/sensing devices
- Mass/charge/gravity sensors
- Quantum clocks
- Nanowires/nanodots for particle tracking/calorimetry
- Rydberg calorimetry

Theory

- Simulation of quantum systems
- Quantum gravity
- Information processing, error mitigation/correction strategies

Multiple “pieces”

Testbeds for developers

Algorithms/Applications

Classical quantum simulation platforms

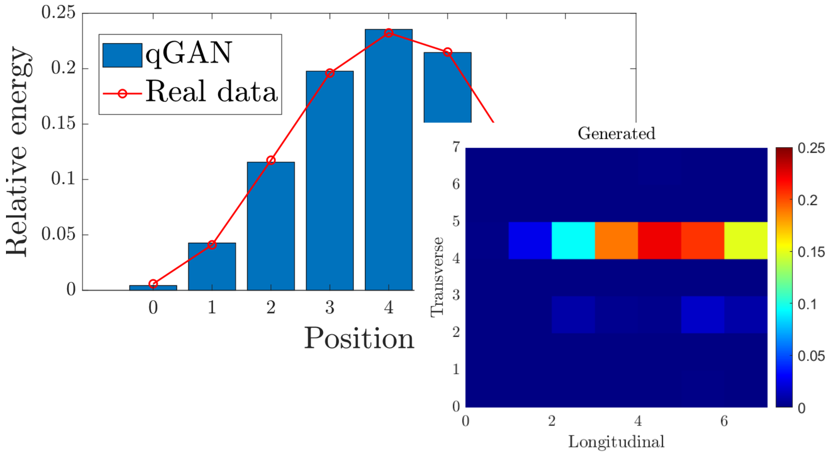
Access to quantum hardware

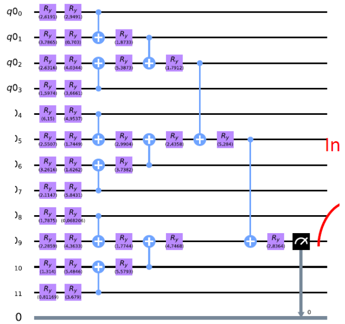
Algorithms and applications

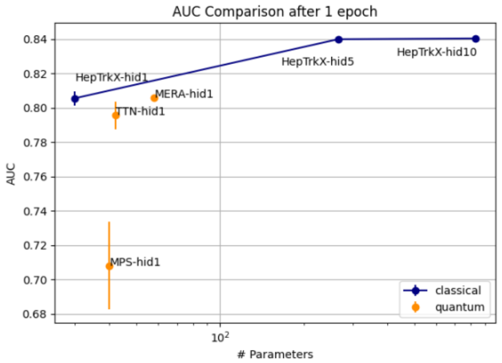
- Understand what HEP applications **can profit** from a quantum approach
  - Start from **understood use cases**
  - Constraints, challenges and best strategies
- Algorithms **design** and/or **optimisation**
  - Input **data representation/ data loading**
  - De-quantization tests / **circuits characterization**
  - Different types of hardware / **hardware-aware computations**
  - Noisy Intermediate-Scale Quantum (**NISQ**) hardware

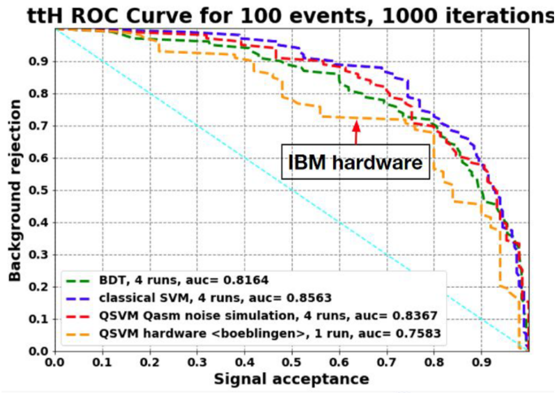
Algorithms and applications (II)

- So far most algorithms under study are **Quantum Machine Learning**
- Applications in **all fields** of data processing







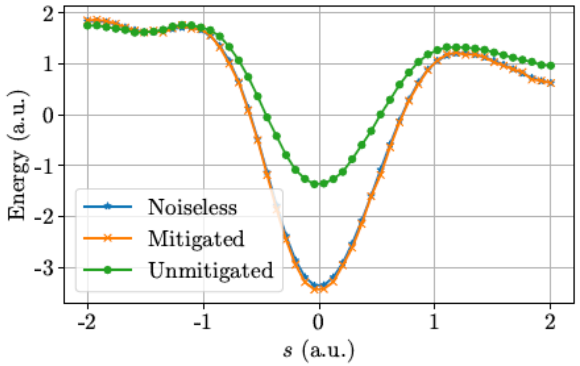


- Quantum Computing scope is broader
  - Accelerate **optimisation problems**
  - **Direct quantum simulation**

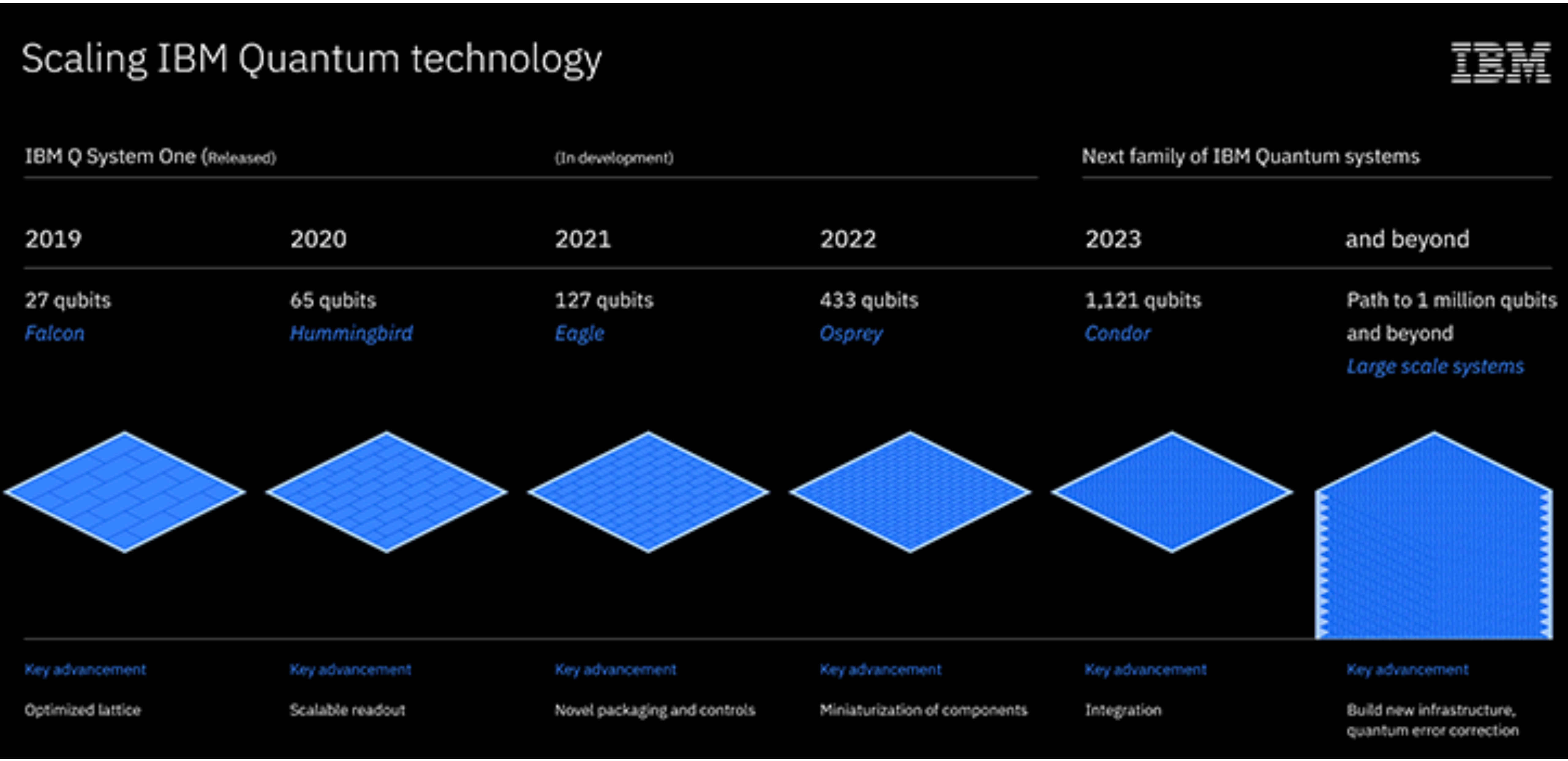
Links to other branches (Theory, …)

Near-term hardware

arXiv:2010.08520v1



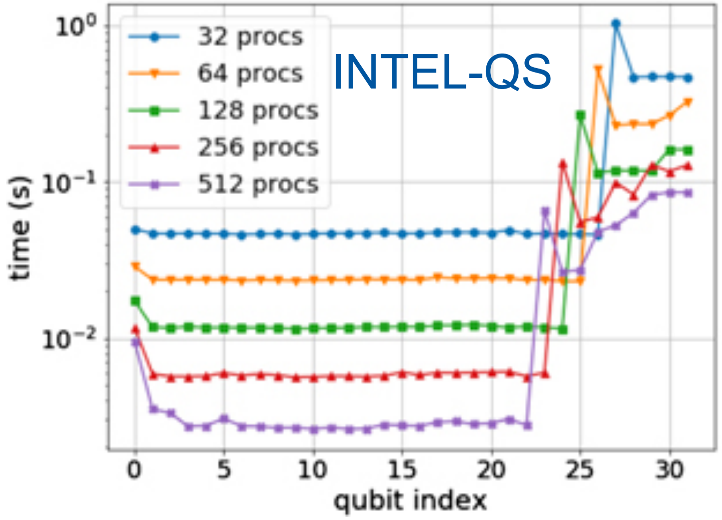
- **NISQ**
  - Short coherence time, noise
  - Limited number of qubits
  - Limited topology
- Development of **error mitigation** techniques and **error robust** circuits
- **Hybrid strategies** (variational approaches) are most popular today
- **Quantum volume**
- Require detailed **noise simulation**
- **Collaboration with quantum hardware experts**



https://www.ibm.com/blogs/research/2020/09/ibm-quantum-roadmap/

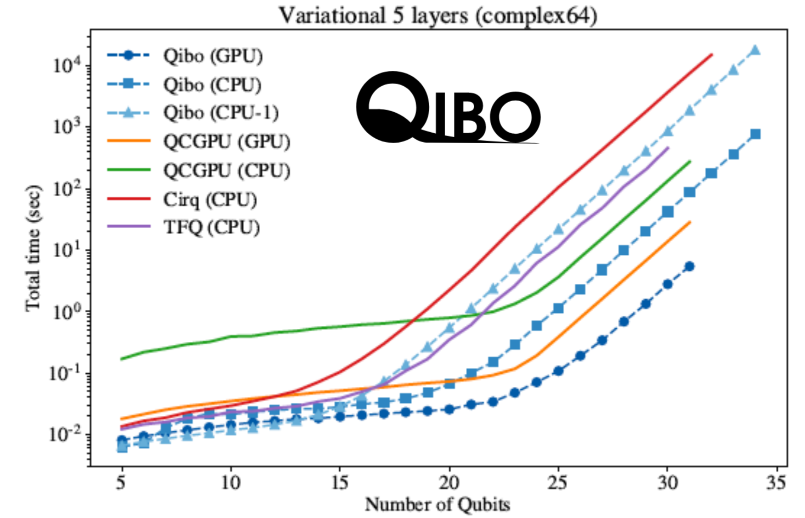
Classical simulators

doi: 10.1088/2058-9565/ab8505
https://github.com/iqusoft/intel-qs



- Computational cost **scales exponentially** with n_{qubit}
  - Large memory systems
  - Low latency / fast communication
  - HPC/Cloud/ accelerators
- Large number of **simulators**
  - https://quantiki.org/wiki/list-qc-simulators
  - Wide range of features/implementations/performance
  - Move toward **hardware-agnostic**?
  - Compiler style? Circuits optimisers?
- Interest in simulators development?

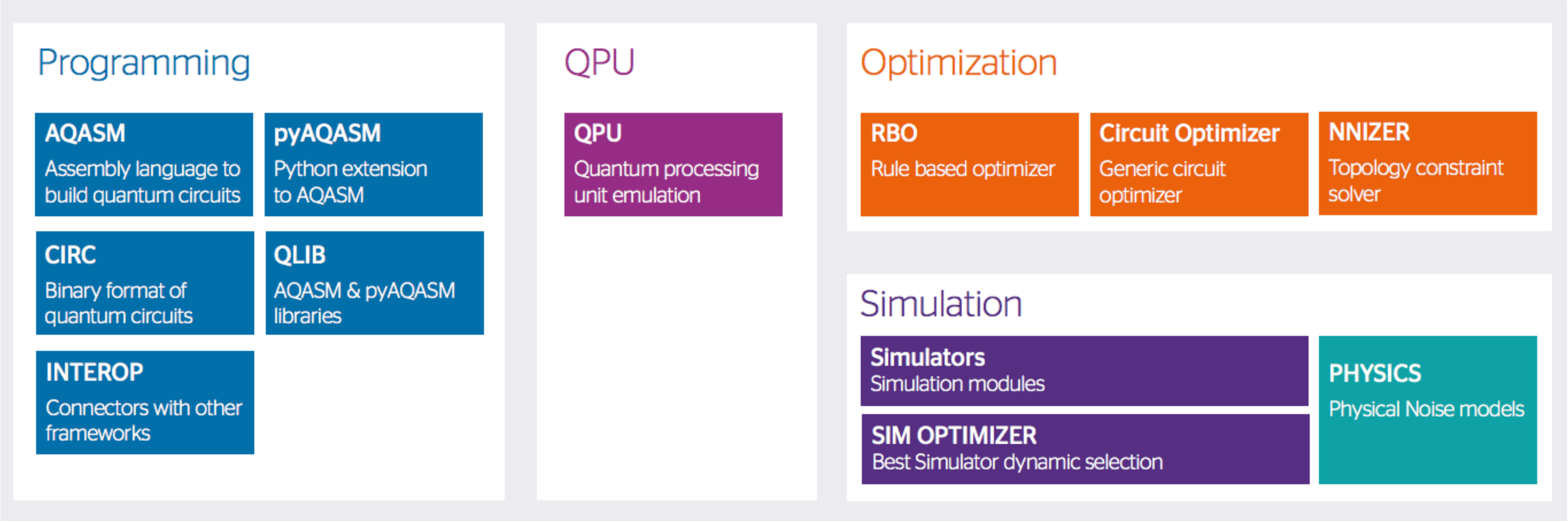
arxiv:2009.01845
https://github.com/Quantum-TII/qibo



Developers testbeds

- **Custom clusters** (accelerator-based) on site
- **Appliances** Ex. ATOS QLM

Atos QLM software stack



- Cloud resources (some providers offer quantum simulation services) ?

QC Simulation Platform

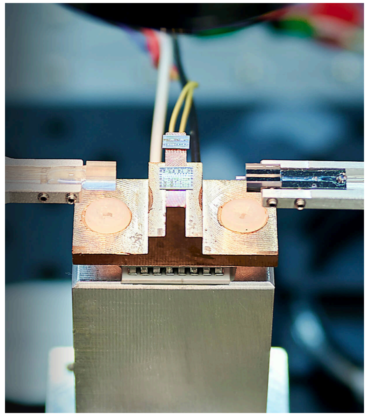
Critical to build skills and **start R&D work**, both as a preparation to real H/W and to explore “quantum-inspired” computing

“**Standardized” access** to different simulators, hardware, tools, libraries (e.g. pre-packaged containers, Jupyter notebooks, GitHub, etc.)

Multiple participating sites, capitalizing on CERN world-level expertise in operating **distributed infrastructures**

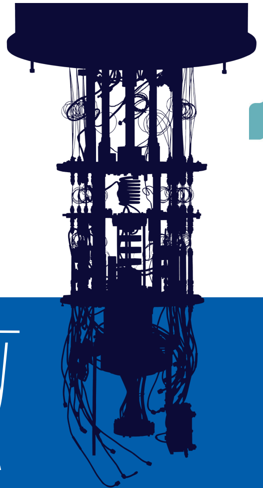
Access to quantum hardware

XANADU



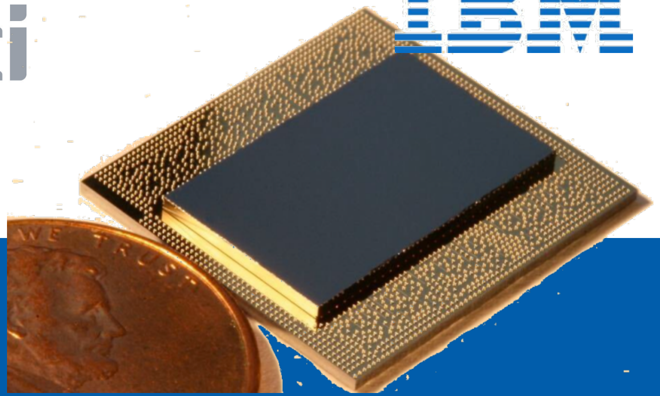
- Today most quantum hardware is **available on cloud**
  - “Quantum” companies (IBM, Google, Rigetti, Xanadu,..)
  - General cloud providers (AWS, Microsoft)
- **Streamline/organize** access
- **Direct access** through quantum networks (IBM)?

Google

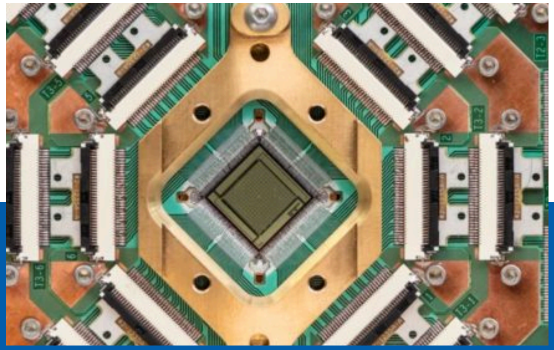


rigetti

IBM



D:Wave
The Quantum Computing Company™



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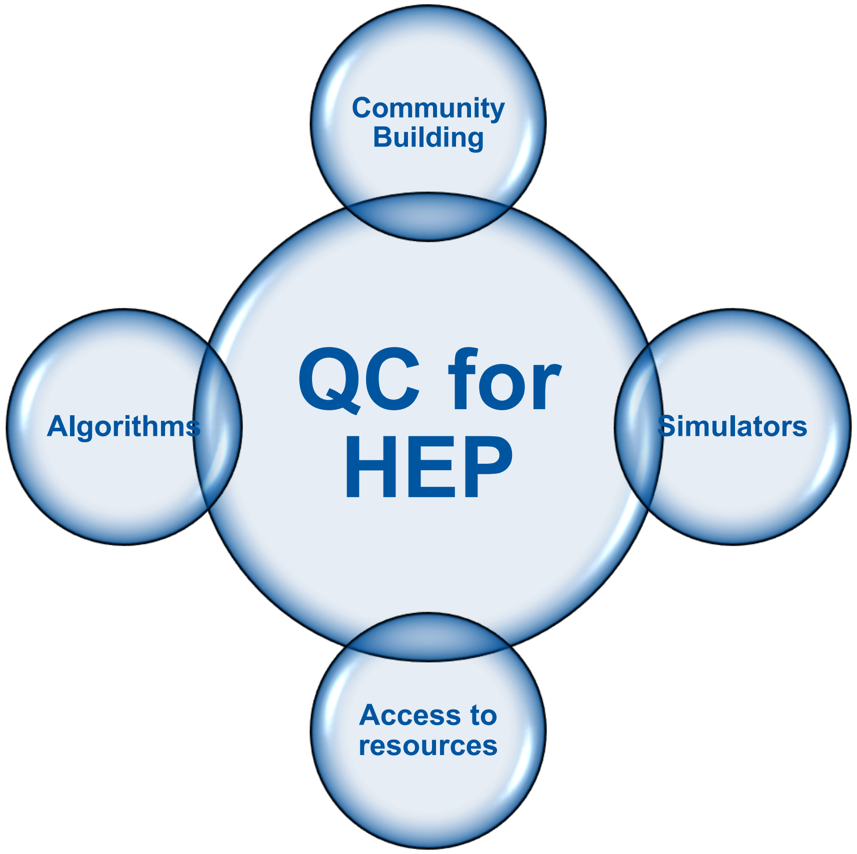
Summary

- « Practical » **quantum computing** requires **synergies** and **collaborative efforts** across disciplines/applications
  - A thin line between theory and experiment
- Algorithm design/optimisation is « **transversal issue** »
  - Same challenges across different practical applications
- Collect **priorities** and define a **roadmap** according to interests and expertise



Let’s get to work!

Comments/Remarks/Questions

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https://quantum.cern/