QuantHEP

Quantum Computing Solutions for High Energy Physics

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QuantHEP

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Physics

- High Energy Physics - Experiment (**hep-ex** new, recent, search)
- High Energy Physics - Lattice (**hep-lat** new, recent, search)
- High Energy Physics - Phenomenology (**hep-ph** new, recent, search)
- High Energy Physics - Theory (**hep-th** new, recent, search)

- Quantum Physics (**quant-ph** new, recent, search)

AIM:
to develop Quantum resources for High Energy Physics

WHO

Partners:

- Portugal (coordinator): IT Lisbon - Yasser Omar
- Italy: INFN - Simone Montangero (PD) +
  Paolo Facchi (BA) & E.E. (BO)
- Latvia: ULatvia - Andris Ambainis

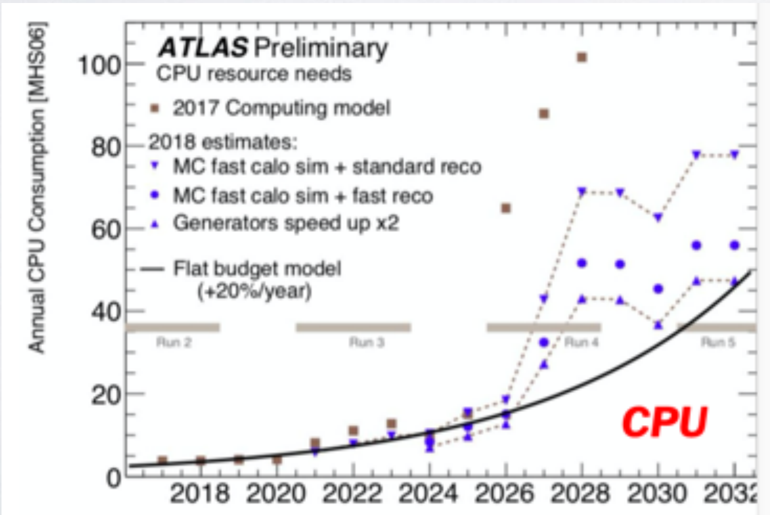
The goal of the project, *to harness the potential of quantum computation for particle-physics challenges*, is interdisciplinary in its very nature.

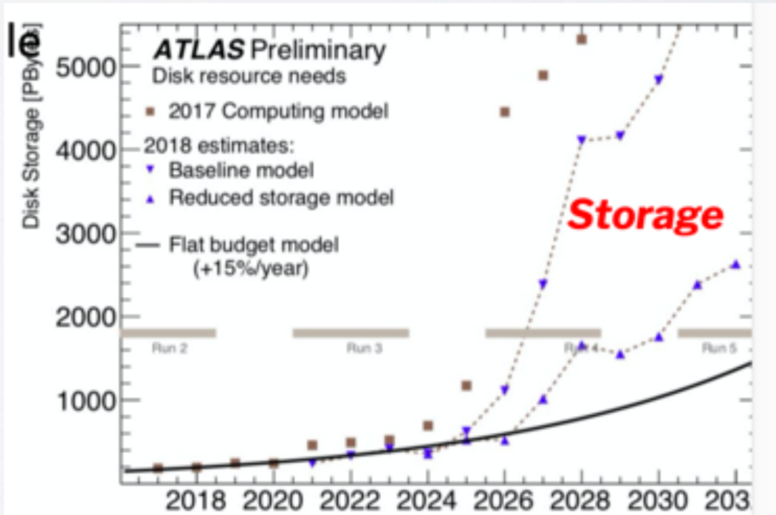
The expertise of the consortium embraces *quantum information theory* (with quantum algorithms and quantum analog and digital computing, quantum simulation and quantum control) and *high-energy physics* (with data analysis of scattering processes by state-of-the-art classical algorithms and neural network methods).

WHY

- For <u>fundamental physics</u>, gauge theories (pure or coupled to matter) represent THE paradigma, but their understanding still represents a formidable challenge, at quantum level

- <u>Experimental HEP</u>, especially the Large Hadron Collider (LHC) programme at CERN, is one of the most demanding activities in the world in terms of computing resources, a demand that will increase dramatically in the future





WHAT

- Present day HEP software, both for Monte Carlo simulations and data reconstruction and data analysis, still heavily relies on sequential coding

Solutions: - HPC
- massive parallelism
- machine learning

★ Can we exploit Quantum Computers?

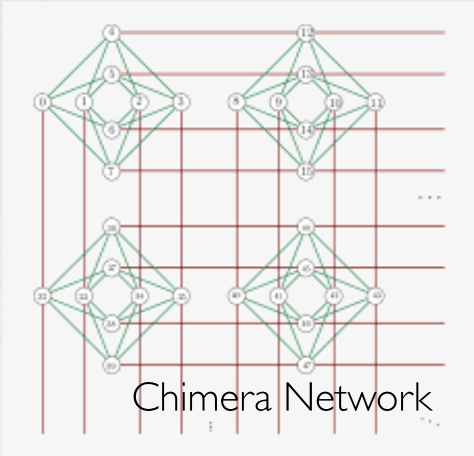
"Quantum Computing for High Energy Physics" (CERN, 2018)

- Address some crucial points in HEP analysis:
  - **Event reconstruction**
  - **Event selection**
  - **Simulation of scattering processes**

◉ **We deals with optimization and classification problems**

➡ *Quantum annealers*
➡ *General purpose (digital) quantum computers*
➡ *Atomic/Solid State quantum simulators*

➡ **Quantum annealers (D-wave)**

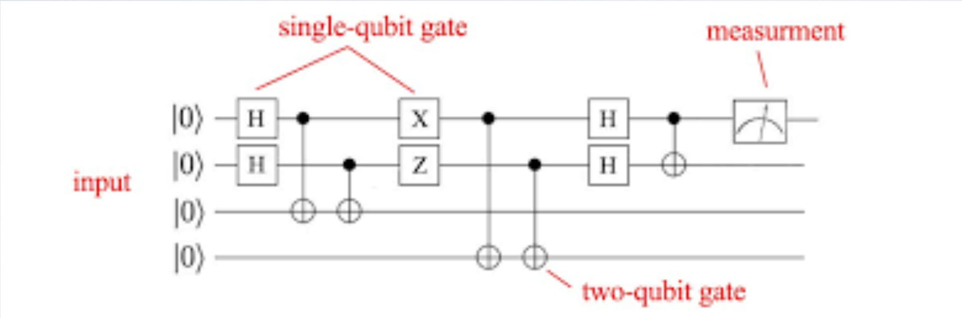


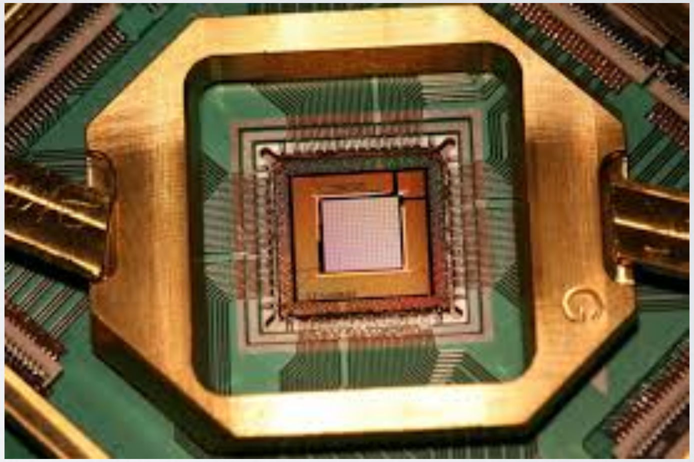
- Quantum variational algorithm based on Ising Model (non-universal)

✓ Ideal set-up for optimisation protocols

✓ Problems have to be embedded into the qubit connection architecture of the machine, a highly non-trivial task

➡ **Digital quantum computers (IBM, Google, Rigetti,…)**





- General-purpose and universal platforms

✓ Develop quantum algorithms and libraries for HEP processes

✓ By now, problems have to be analysed with few-qubits and middle-scale quantum processors only

➡ **Trapped Atom/Ion quantum simulators**

- Controllable qubits: initial preparation, dynamical evolution, measurements

✓ Mimic complex genuine quantum phenomena (lattice models)

✓ By now, only toy models with a limited number of qubits

WORKPACKAGES & TASKS

WP1 – Quantum Algorithms for HEP Data Processing Task 1.1 - Quantum algorithms for event selection Task 1.2 - Quantum algorithms for event reconstruction Task 1.3 - Small-scale analysis with real data using quantum algorithms
WP2 – Quantum Simulation of HEP Processes *Task 2.1 - Software libraries* *Task 2.2 - Quantum simulation of scattering processes and benchmarking* *Task 2.3 - Interface with classical HEP software frameworks*
WP3 – Management and Dissemination Task 3.1 - Scientific and financial management Task 3.2 - Communication and Dissemination

HOW

- Today quantum technologies allow only for simulations

with a small number of qubits and algorithms with a limited number of steps

1. Start with simplified problems (e.g. a small number of variables in event)
2. Starting from real data, identify the best protocol. i.e:
   - for quantum annealers, the best embedding in computer's architecture
   - for universal computers, the best optimisation quantum algorithm
3. Software solutions and libraries for quantum simulations of HEP processes:
   - embed the different elements (different particles / different interactions)
   - methods to implement constraints on the dynamics
   - time-dependent Schroedinger solutions
   - event reconstruction
   - scattering and particle production processes

- On-going analysis, which starts from simplified examples and moves towards more and more complex problems

Tests and benchmarks:

1. Proof of principle simulations on classical (HP) computers and dedicated simulation techniques (such as Tensor Network)
2. Tests on classical emulators of quantum processors
3. Hybrid classical/quantum algorithms
4. Quantum algorithms for few qubits and middle-scale quantum processors, to accomodate the expected development of the latter

THANK YOU