PADUA QUANTUM COMPUTING AND SIMULATION CENTER

Simone Montangero
QUANTUM COMPUTING AND SIMULATION CENTER

Investment of 6 M€
National strategic partnerships
Trapped ion quantum computer
ECOSYSTEM

2020 World Class Research Infrastructure
Quantum@Unipd

quantum.dfa.unipd.it
PASQuanS
Programmable Atomic Large-Scale Quantum Simulation

Pilot Project
2018-2022

FPA - PASQUAN$\text{S}^2$
2023-2030
Quantum simulator with 10000 qubits!
QUANTUM COMPUTING AND SIMULATION CENTER

Infrastructure

Quantum Computation & Simulation
Quantum interfaces & Networks
Quantum & Classical software

Support

Education, Dissemination, & Technological transfer
Management & coordination
Analog quantum simulators with coupled photons and atoms

Exploring new dimensions for novel phases of light-and-matter in:

- Suspended atoms coupled to photonic waveguides
- Atoms trapped within photonic crystals

Image courtesy:
[2] Ravitej Uppu et al. PRL 126, 177402
Emulators for quantum computers

Quantum circuits

Quantum computing Platforms
Superconducting, Trapped ions, or neutral atoms

Quantum circuits emulator
- Quantum circuit as a tensor network
- Measurement of local observables
- Efficient sampling of the final state

Digital twin approach
1) Up to 8x8 atoms
2) Schedule native gates
3) Gates as pulses
4) Study crosstalk
5) Run simulation

Comparison and resolve errors per step: GHZ state

Quantum computing for industry

Contacts with new Industry partners

Mission planning for earth observation

Hard optimization problems

combinatorial optimization
(Knapsack problem)

from single satellite to constellations

- Identification of use cases in the field of mission planning
- Estimate (hybrid) QPU-specs for realistic problems
Quantum algorithms for simulating energy and charge transfer dynamics in molecular networks. Non-unitary dynamics of the open system via effective representations of the environment in the quantum circuit.

Quantum algorithms for electronic states of molecules in gas phase and in solution, their structures, and their optical properties.

Insight on the structure of the jets produced in proton-proton collisions at LHC. We are working within LHCb collaboration to investigate the b quark originated jets.

Dynamical systems for quantum computing, minimal representation and efficient simulations.
When do we really need a quantum simulation/computation?
State of the art in 1D (poly effort)

No sign problem

Extended to open quantum systems

Machine learning

Data compression (BIG DATA)

Extended to lattice gauge theories

Simulations of low-entangled systems of hundreds qubits!


\[ \hat{H} = - t \sum_{x, \mu} \left( \hat{\psi}_{x}^{\dagger} \hat{U}_{x, \mu} \hat{\psi}_{x+\mu} + h.c. \right) \]
\[ + m \sum_{x} (-1)^{x} \hat{\psi}_{x}^{\dagger} \hat{\psi}_{x} + \frac{g_{e}^{2}}{2} \sum_{x, \mu} \hat{E}_{x, \mu}^{2} \]
\[ - \frac{g_{m}^{2}}{2} \sum_{x} \left( \hat{U}_{x, \mu x} \hat{U}_{x+\mu x, \mu y} \hat{U}_{x+\mu y, \mu x} \hat{U}_{x, \mu y} + h.c. \right) \]
Quantum Matcha Tea
An efficient matrix product state simulator for quantum circuits
FUTURE STEPS AND CONCLUSIONS

➤ Atom/ion quantum computers are among the leaders of the QT transformation

➤ Tensor network algorithms can be used to benchmark, verify, support and guide quantum simulations, computations and communication

➤ Hybrid solutions will give the first results in

  ➤ Complex optimisation problems
  ➤ Machine learning
  ➤ Quantum sensing
  ➤ Optimized protocols
Website ready soon!