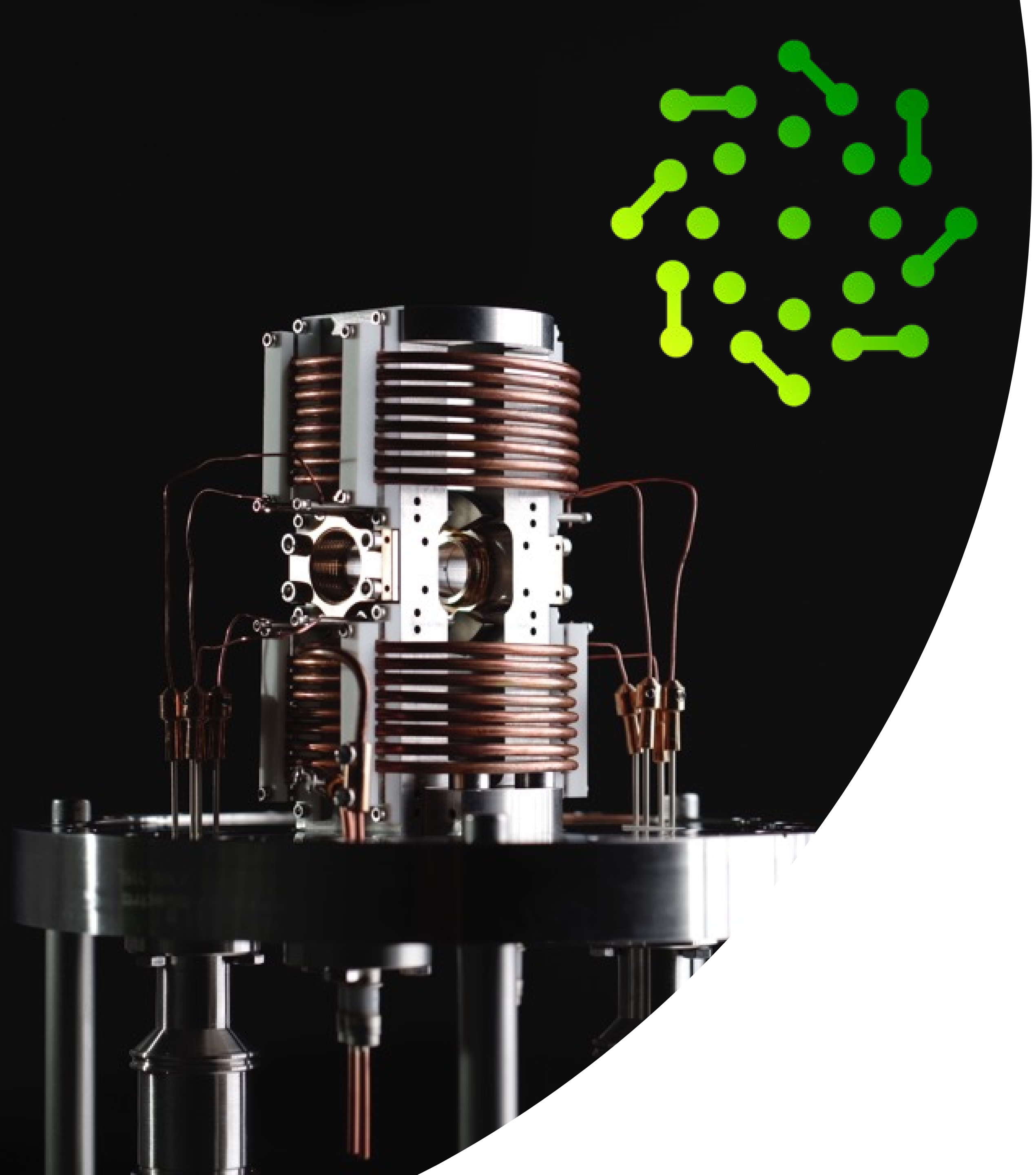
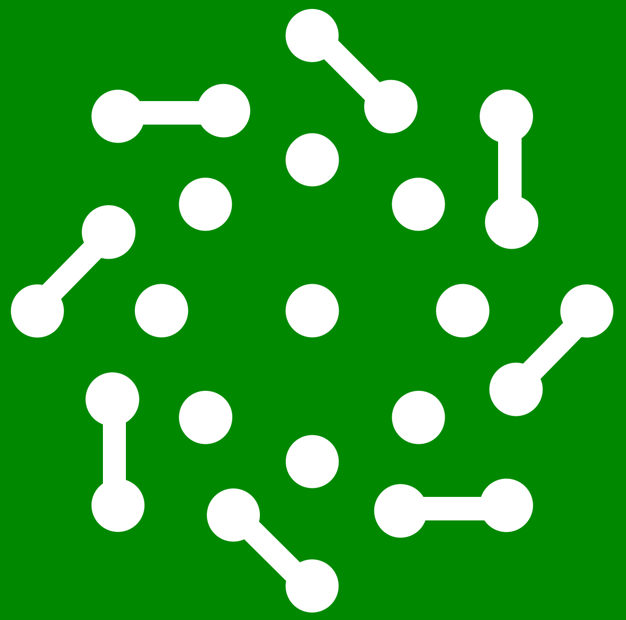


PASQAL

First scaling quantum processors and their applications

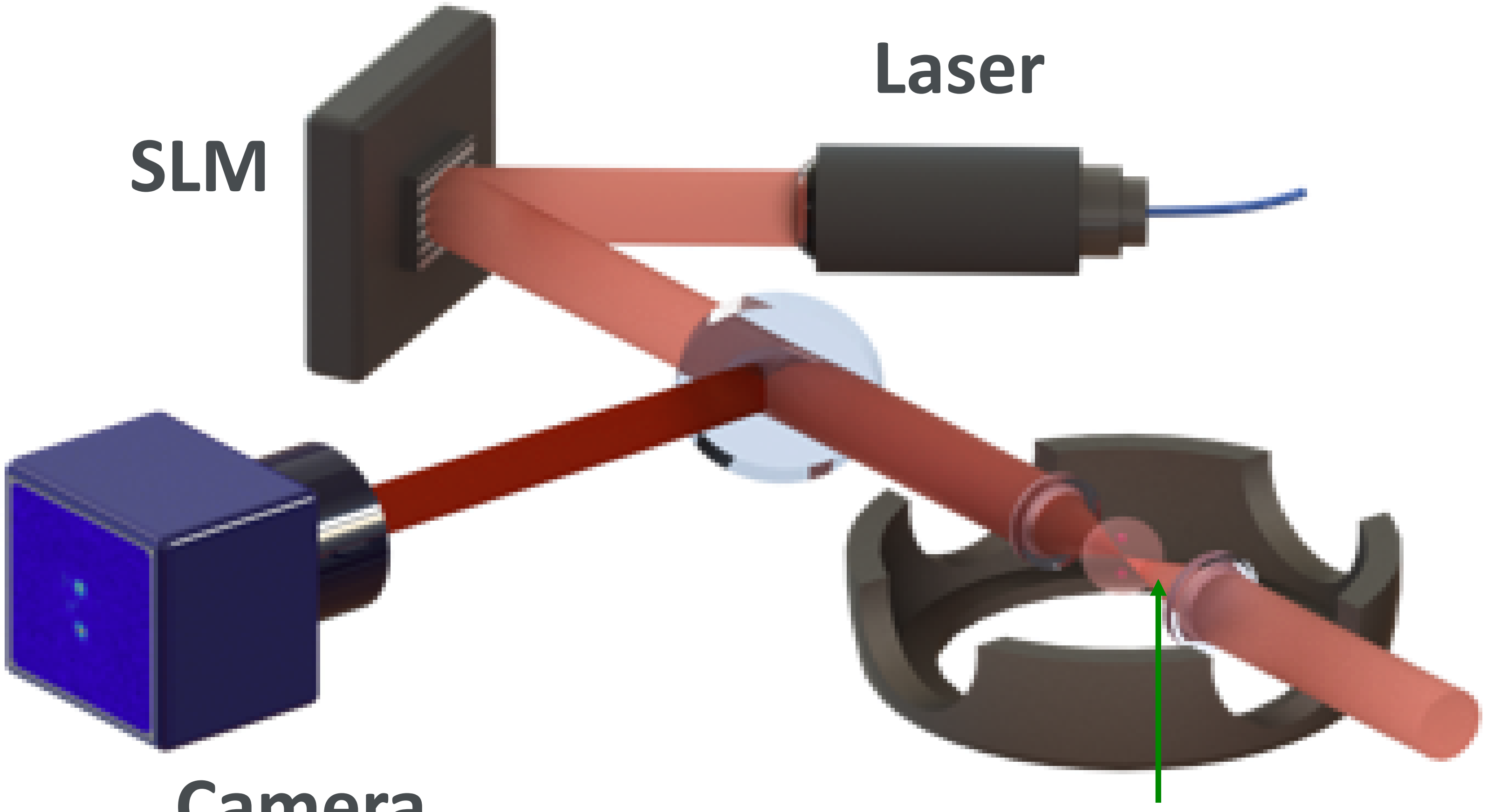
Agenda

- Neutral atoms for quantum computing: a blueprint for a 1000 qubits processor in 2023
- Applications
- Pasqal’s short term perspectives

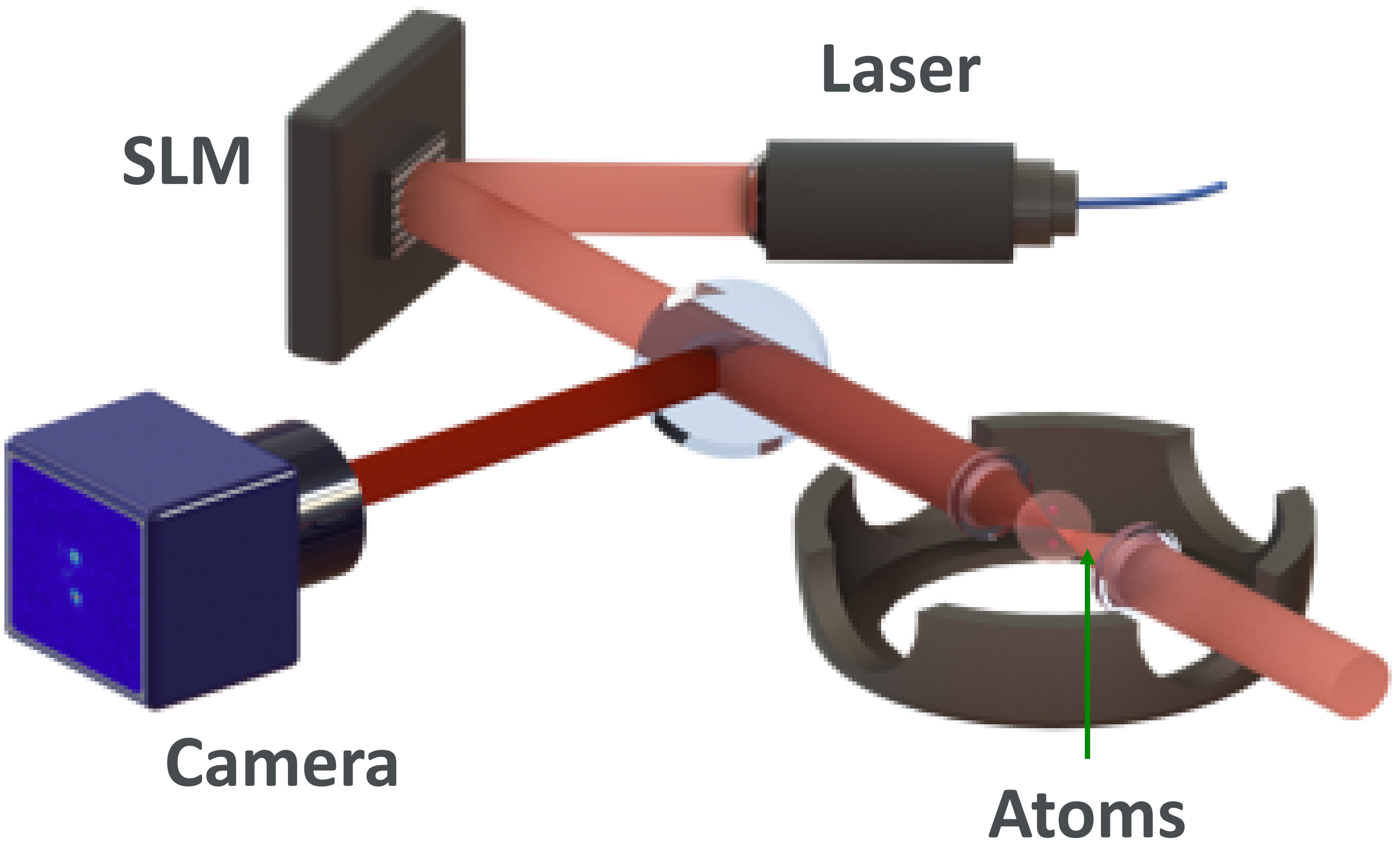


Neutral atoms for quantum computing

Atoms in arrays of optical tweezers



Atoms in arrays of optical tweezers



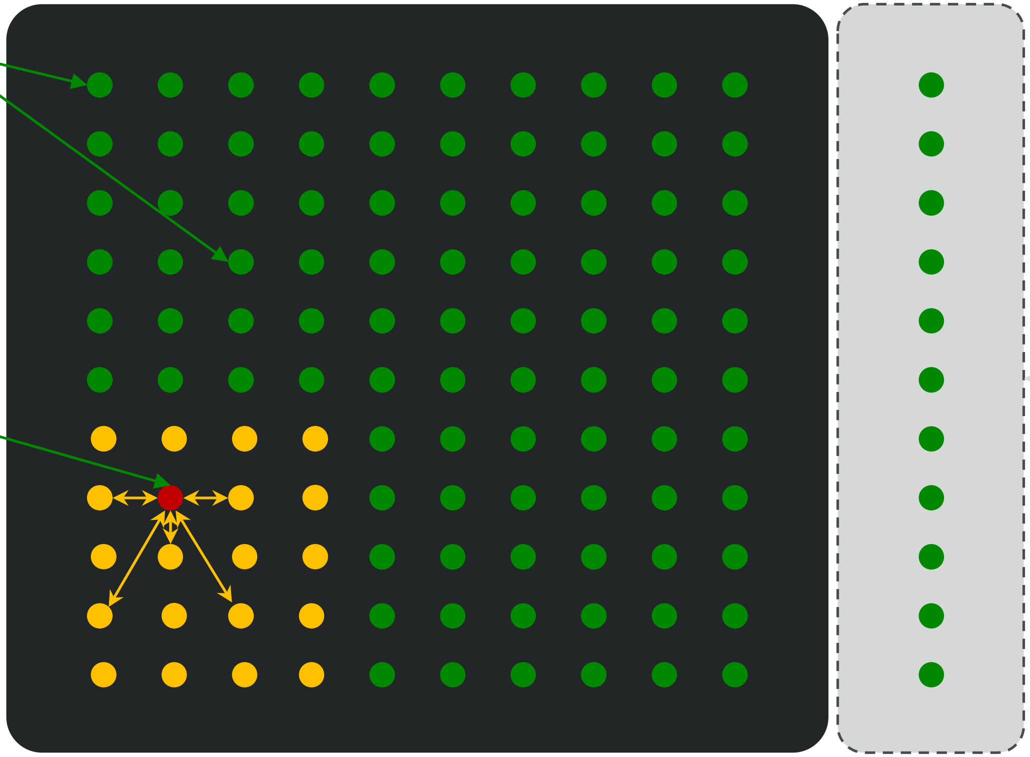
Operation at room temperature

Pasqal's processor is designed to offer scalability for a wide range of algorithms

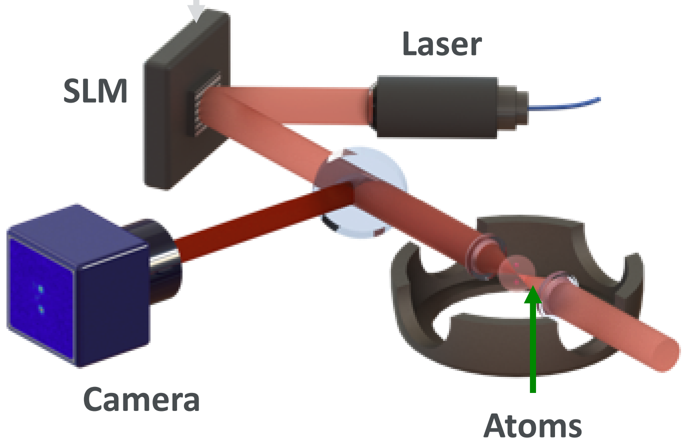
100 Qubits processing unit

1 atom = 1 qubit

The entire sub-register can be in an entangled state, providing the exponential computational power

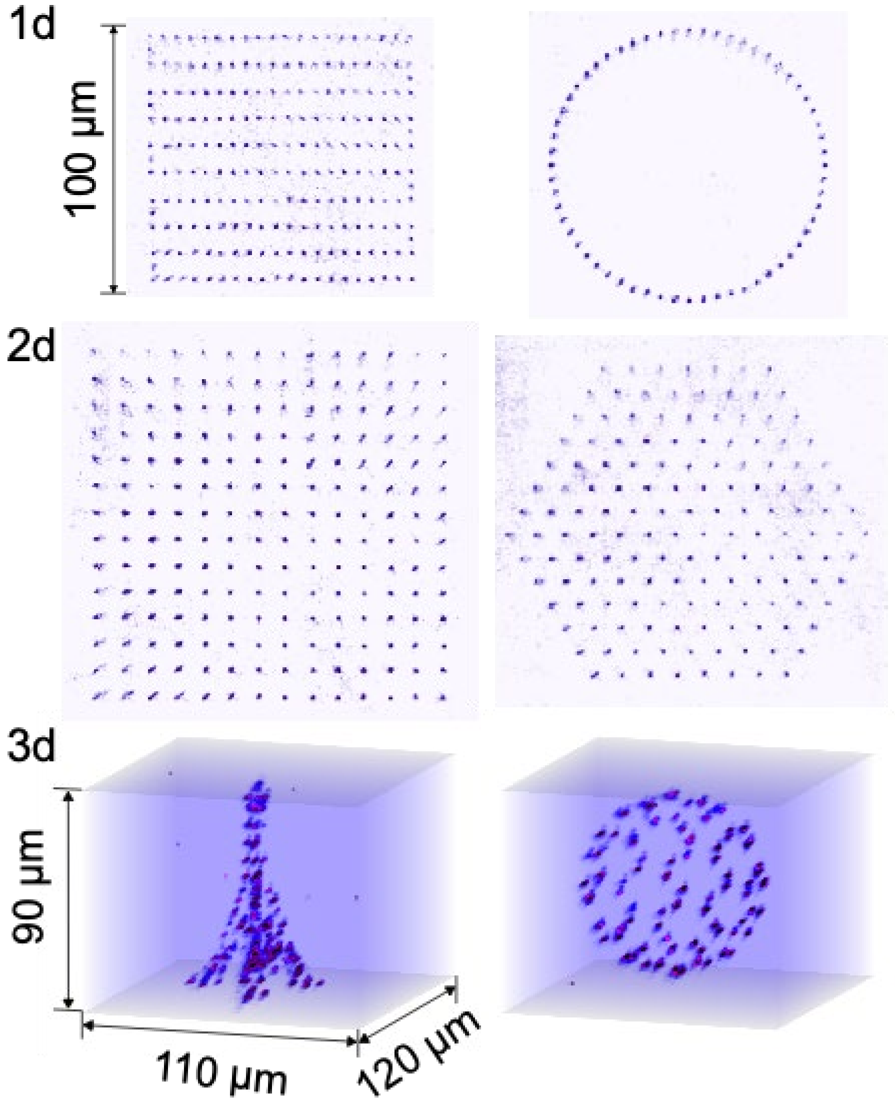


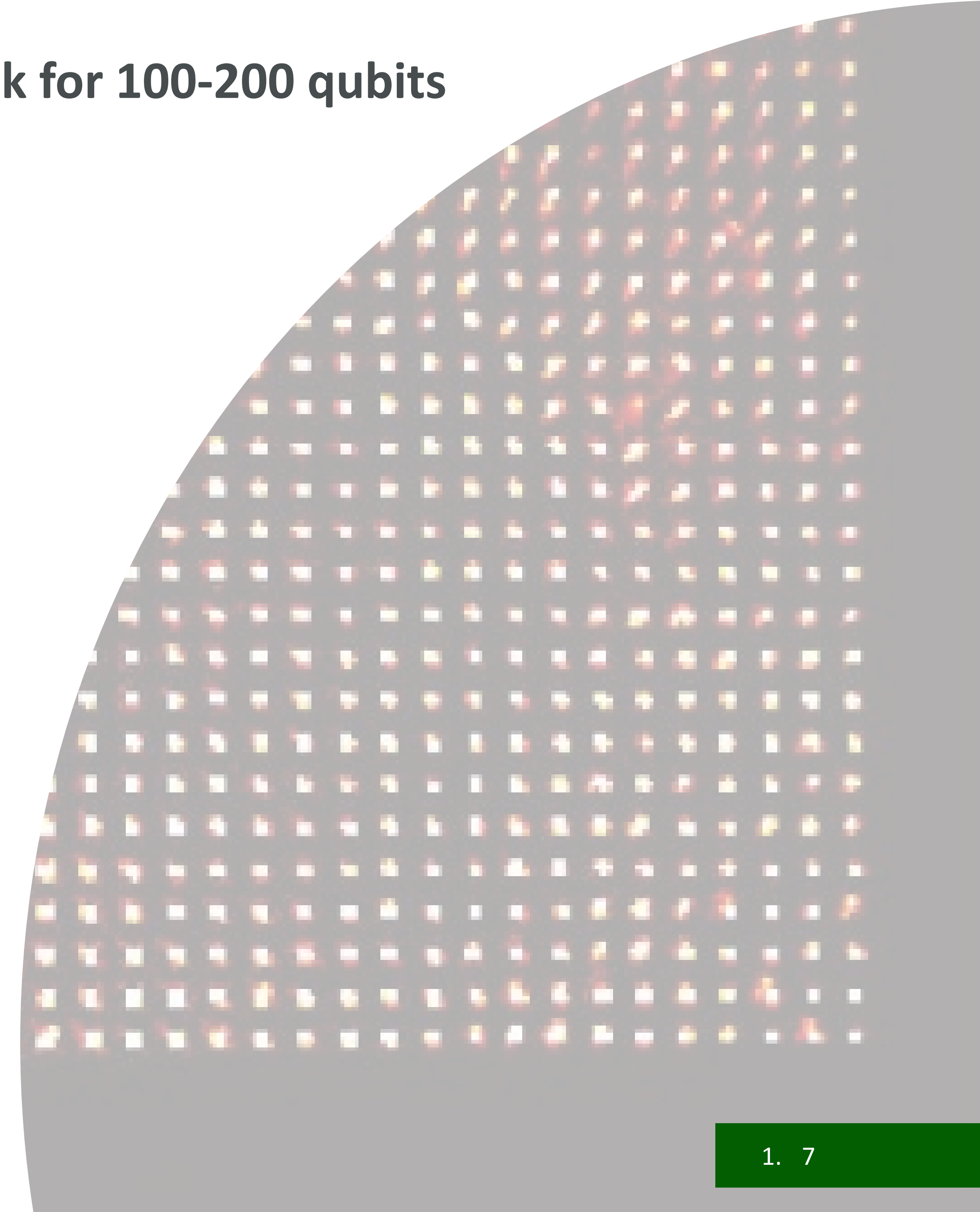
Atoms are trapped in a laser and the use of a Spatial Light modulator opens the way to add more and more lines of qubits



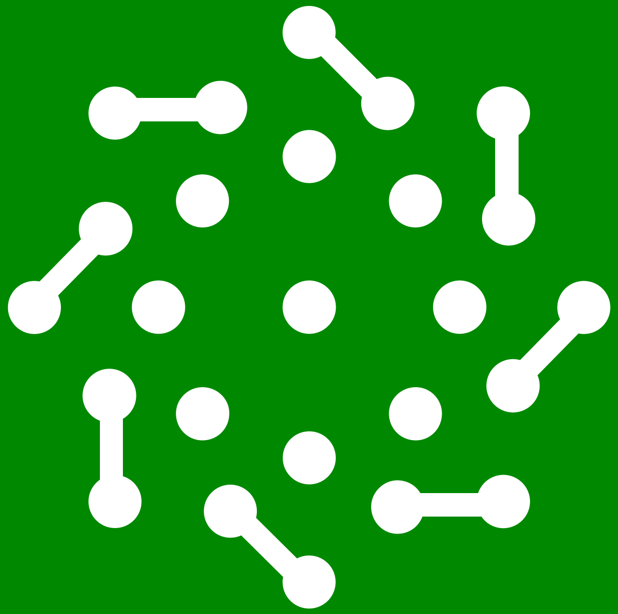
Neutral atoms give the possibility to arbitrarily entangle Qubits with the highest connectivity (reducing the need for ancilla gates), and easily add more and more qubits which are the two key factors to increase processing power.

A few examples of quantum registers: on track for 100-200 qubits processors



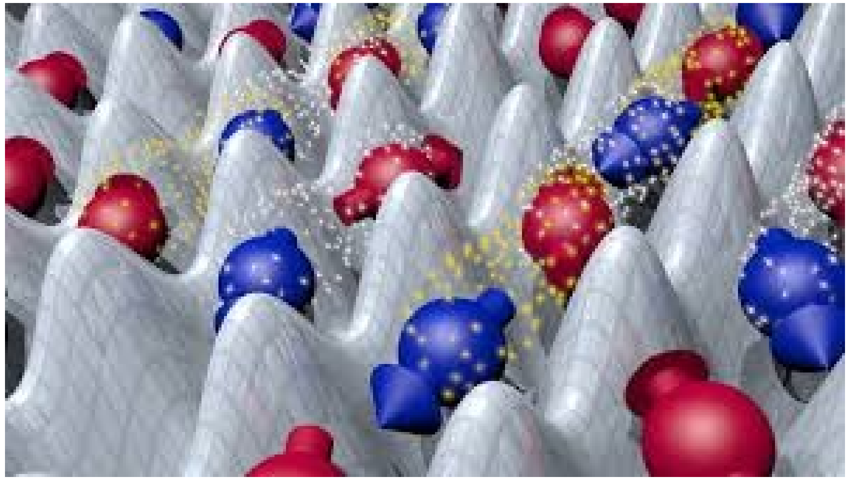


Applications



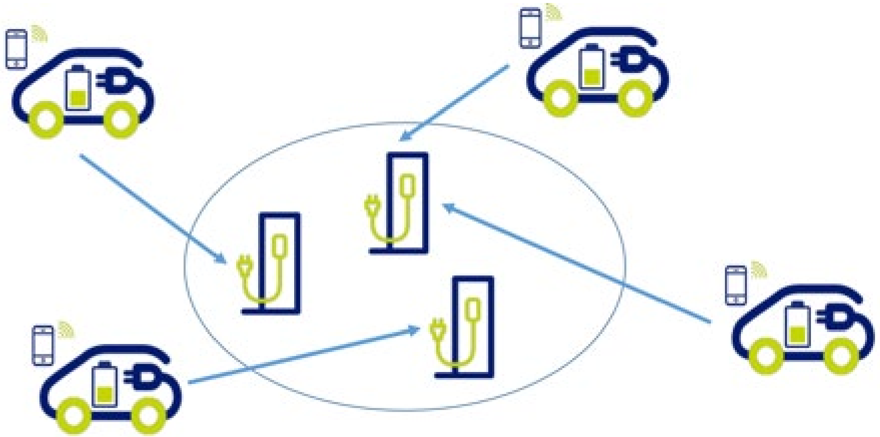
Applications

- Quantum Simulation[1] : artificially recreating in the experiment models of interest for scientific discovery



  - Many-body quantum physics
  - Chemistry, drug discovery
  - High-energy physics

- Hard computational problems



  - Approximate optimization
  - Quantum-enhanced machine learning
  - Resolution of non-linear PDEs

[1] A. Browaeys, T. Lahaye, Nature Physics 16, 132 (2020)

Controls

Quantum resources can be used in two different modes

Analog control

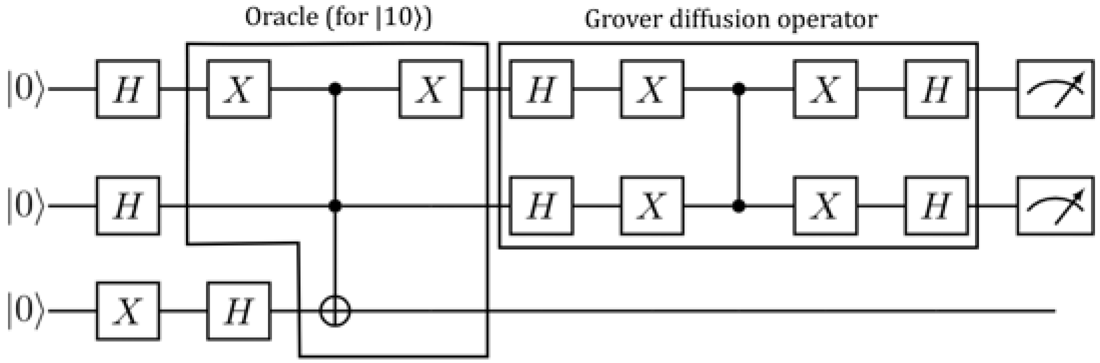
Programming a Hamiltonian sequence

$$H = \sum_j [\hbar\delta(t)\ \sigma_j^z + \hbar\Omega(t)\ \sigma_j^x] + \sum_{i,j} U_{i,j}\ \sigma_i^z \sigma_j^z$$

The Hamiltonian faithfully describes the dynamics of the physical system. Parameters can be tuned continuously. This computation mode is **not universal** but offers **better performances** in the near-term.

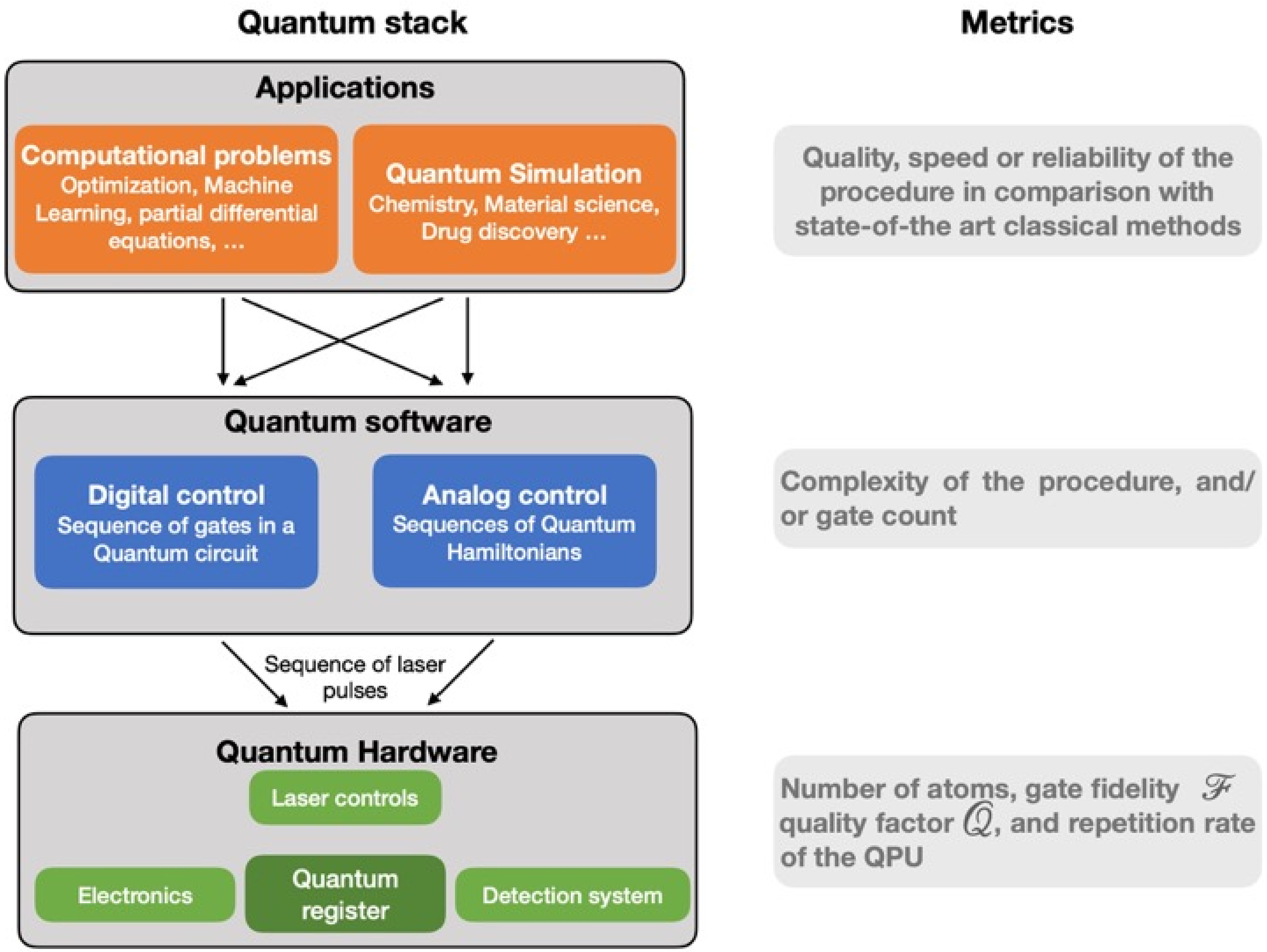
Digital control

Programming a quantum circuit with digital quantum gates



Elementary operations are discrete digital quantum gates, that can act either on individual qubits, or on several qubits at the same time. This computation mode is **universal**.

Quantum Software stack

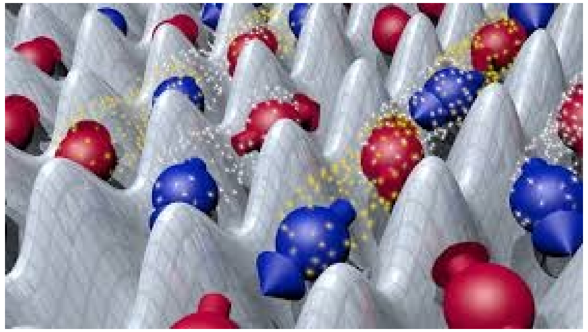


Quantum Simulation of Ising models

- Ising-like models (relevant in Quantum magnetism, and for Quantum Material Engineering)

$$H = \sum_j \frac{\hbar\delta(t)}{2}\,\sigma_j^z + \frac{\hbar\Omega(t)}{2}\,\sigma_j^x + \sum_{i,j} U_{i,j}\, n_i n_j$$

- Pasqal processors can implement this model in 1D/2D (3D) with 200+ particles, where state-of-the-art approximate classical methods are unpractical.



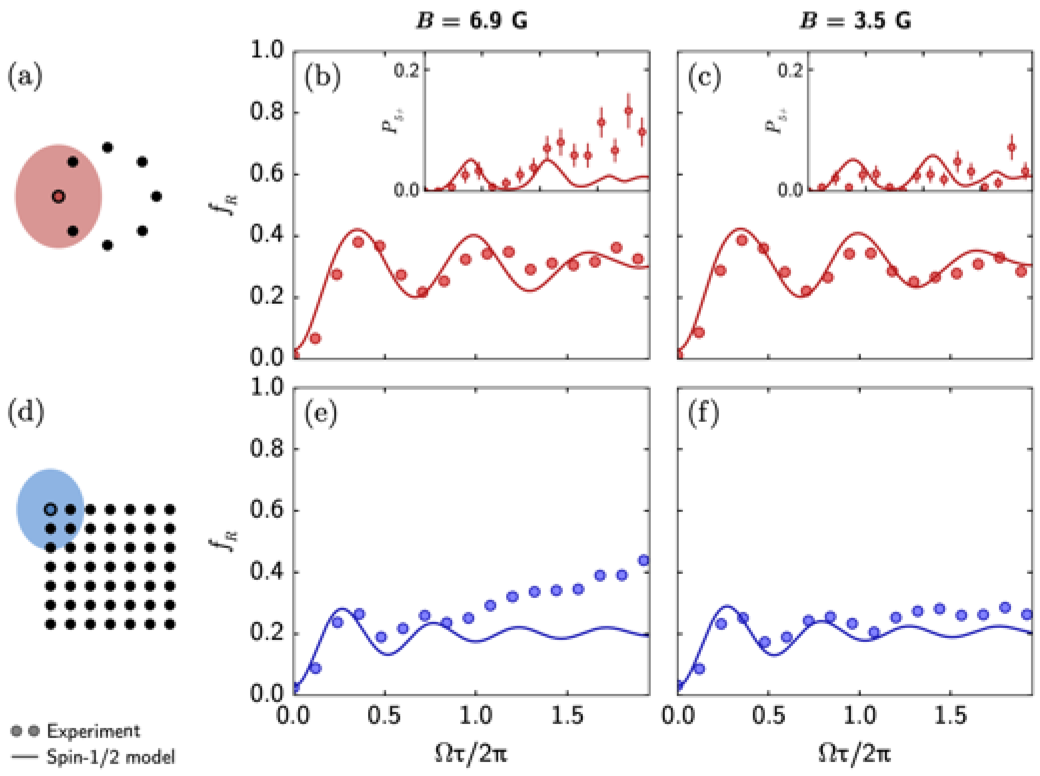
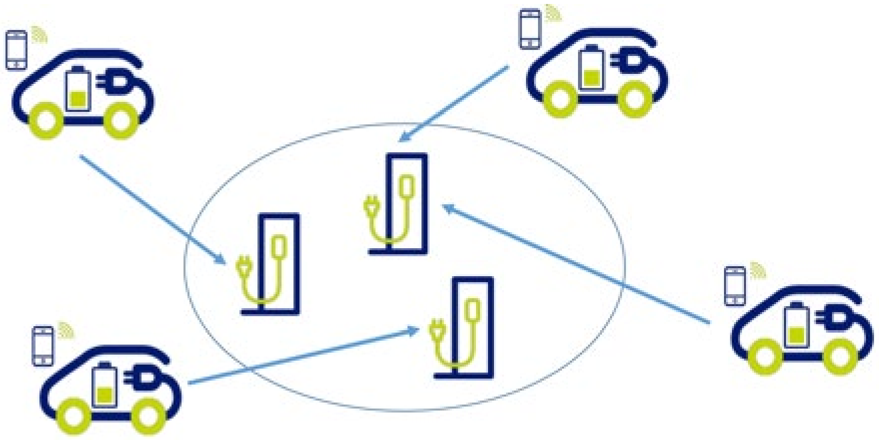


Fig. Non-equilibrium dynamics(1) of the quantum Ising model in 1D and 2D. Since this publication in 2018, the maximum number of atoms in the platform has been multiplied by 4.

(1) De Léséleuc et al. PRL 120 (2018)

Solving computationally hard problems: scheduling/decision problems



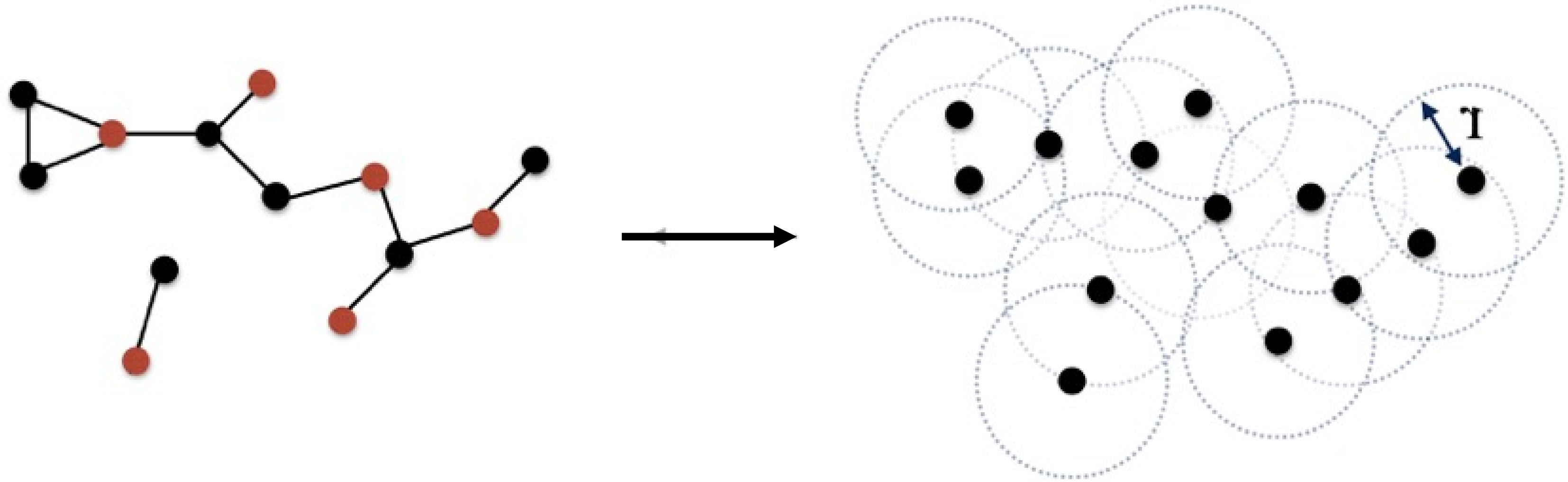
One seeks to maximize the total number of loads, with the following constraints:

- Loads that overlap in space and time cannot be achieved (charging stations can accommodate only one vehicle at a time).
- Loads are organized in groups, and we enforce that at most one load in each group is completed. This condition is often used in situations of resource scarcity and it enables a more balanced allocation.

Under these conditions, the problem can me mapped onto a MIS (Maximum Independent Set) problem.

Solving graph problems with Pasqal devices

- An independent set of a graph is a subset of vertices such that no pair is connected by an edge.



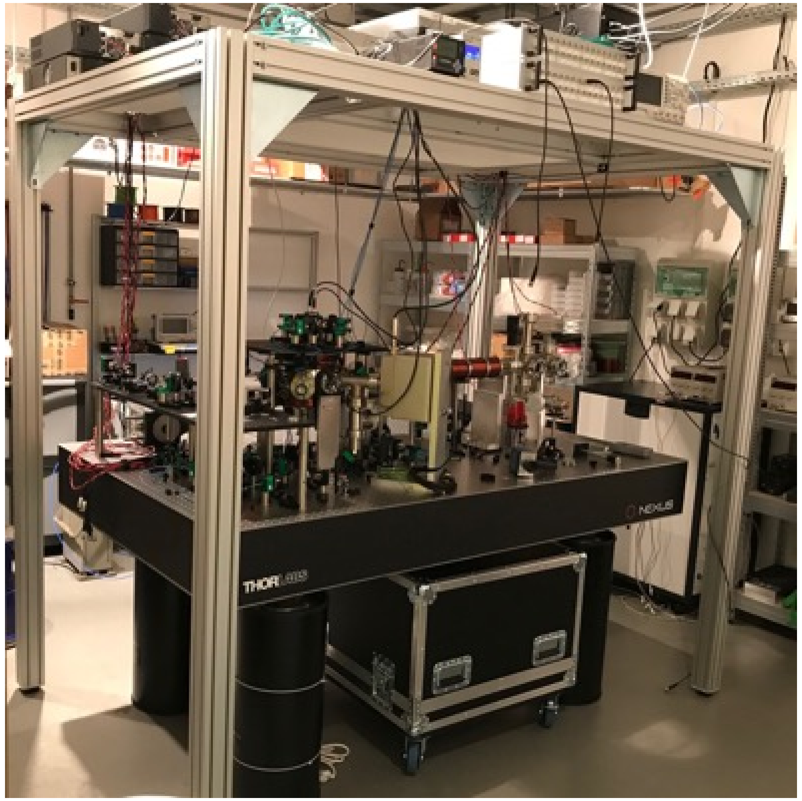
This approach should outperform **classical approximation schemes on supercomputers** in the 800-1200 qubits range – *Atos, arxiv.org:2006.11190.* **Attainable by Pasqal Gen 2 devices**. Gen 1 might already bring an advantage if cost/energy considered.

Applications for: scheduling problems, graph-based decision making, communication networks etc…

Pasqal’s short-term perspectives

Next steps

- Pasqal is building its first processor, 100+ qubits
  - In operation in analog mode by end of 2020 – beginning 2021,
  - Digital in 2021
- We can already work on your use-cases
  - Strong team dedicated to applications
  - Emulator for gauging the performances of the solution
  - Prototype for implementation: remotely in 2021 and cloud in 2022
- We are developing a second generation of processors to reach 1000qubits in 2023



Programming quantum circuits with Cirq

Cirq as a front-end of Pasqal devices

- Python framework developped by Google for digital quantum computing[1]
- Enables a large control over the operations realized on the hardware

Cirq

- Working locally on your laptop
- Compatible with other python packages for applications (openfermion, tensorflow-quantum)

Quantum circuit →

← Measurement results

PASQAL QPU

PASQAL classical emulator

[1]https://cirq.readthedocs.io/en/stable/

Conclusion

- Neutral atoms in arrays of optical tweezers is a very scalable and flexible platform for quantum computing
- Its analog control mode addresses applications for both quantum simulation and optimization, in the short term
- We are developing the HW and SW to implement these solutions in the most efficient way

Pasqal was awarded the Grand Prize of the I-Lab innovation Challenge, organized by the French ministry of “*Enseignement Supérieur, de la Recherche et de l’Innovation*”, in partnership with BPI

Public support:

VC & techno:

Customers & industrials: