ICSC Spoke 10 - Quantum computing: advances in hardware and software components

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Italiadomani
PIANO NAZIONALE DI RIPRESA E RESILIENZA

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Goals and activities

1. the development of hardware and softwares for the programming of quantum computers
   - IFN: photonic quantum computing chip
   - INO: atomic programmable quantum processor
   - ISC: quantum walks via Thouless pumping (perspective)
2. the development of scalable quantum processors
   - IFN: photonic quantum computing chip (perspective)
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3. the development of applications employing quantum computing
   - ISC: quantum walks via Thouless pumping

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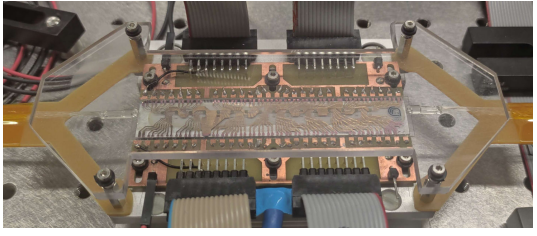
Photonic quantum computing chip

High-level scheme of a photonic quantum computer

Photonic circuit implementing a unitary transformation
between states of light from input to output

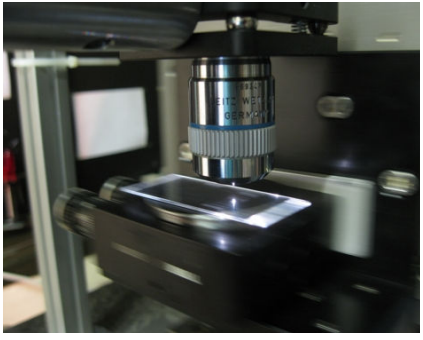


8-mode photonic chip:

- 8 input ports, 8 output ports
- 56 programmable elements for the implementation of arbitrary unitary transformations
- room temperature operation

Correspondent: Roberto Osellame, IFN (roberto.osellame@cnr.it)

Fabrication by femtosecond laser writing



- direct inscription of integrated photonic circuits in glass by focused ultrashort laser pulses
- precise control of the circuit parameters, fast prototyping, and low insertion losses with optical fibers
- reconfigurability achieved with thermal shifters

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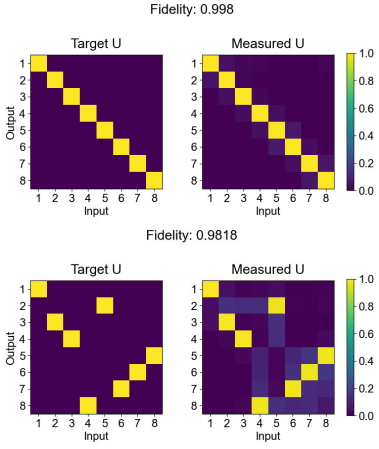
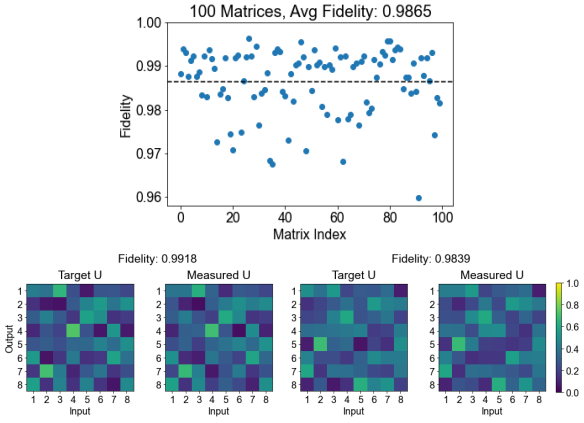
8-Mode photonic chip: validation

Example of operation: ROUTING



Example of operation: DIALLING A RANDOM UNITARY



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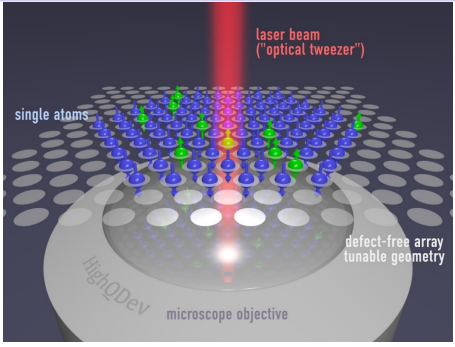
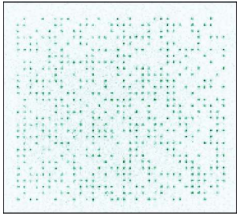
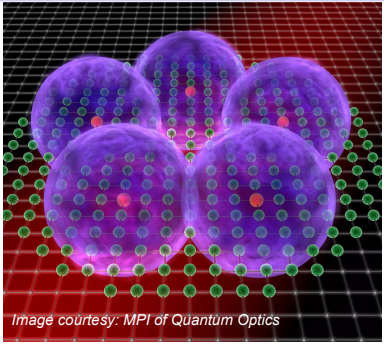
Atomic programmable quantum processor







- isolated, individually addressable atomic qubits ($5 - 10\mu m$ separation)
- real-time reconfigurable geometry
- scalable system with up to $> 100s$ atomic qubits
- fast experimental cycle (< 1s)

interaction between neighbouring tweezers via strong Rydberg-Rydberg interaction (blockade) for multi-qubit gates

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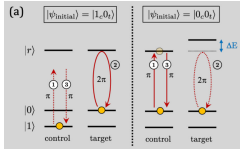
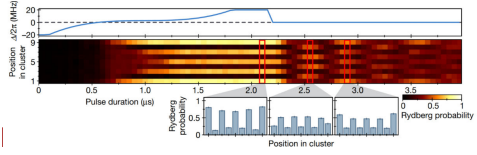
Atomic programmable quantum processor

Programmable Quantum Coprocessor for algorithms with inputs & outputs managed by classical computer ⇒ new classical-quantum hybrid machines

Digital QC:
algorithm blocks are executed by quantum gates based on Rydberg blockade (fidelities > 99%)



Analog QC:
algorithms blocks are mapped on programmable spin models of Rydberg atoms



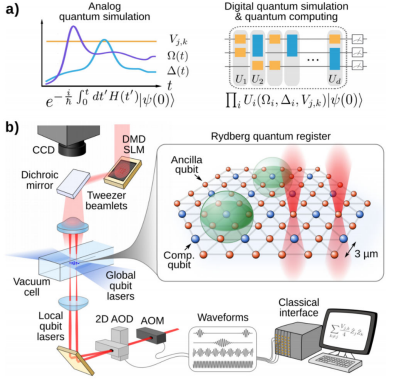


Image credits: M. Morgado, S. Whitlock, AVS Quantum Sci. 3, 023501 (2021)

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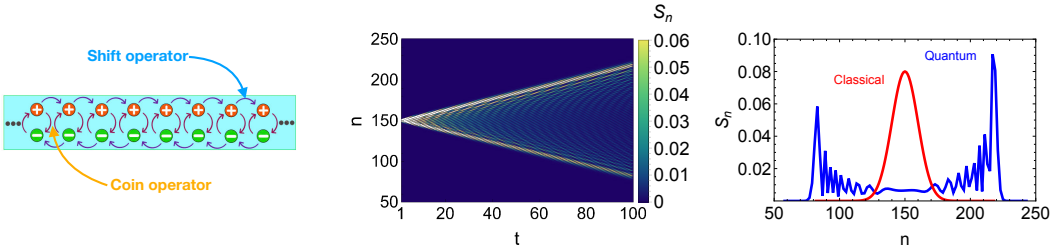
Quantum walks in photonic lattices via non-abelian Thouless pumping

Discrete time quantum walks:

- two levels $|+\rangle, |-\rangle$ system whose dynamics is given by alternating *coin* and *shift* operators
- quantum counterparts of classical random Markov chains



Applications:

K.Kadian *et.al.*, Comput.Sci.Rev. 41, 100419 (2021)

- search algorithms (*e.g.* Grover's algorithm)
- quantum information processing and evolutionary algorithms
- machine learning algorithms & quantum information processing

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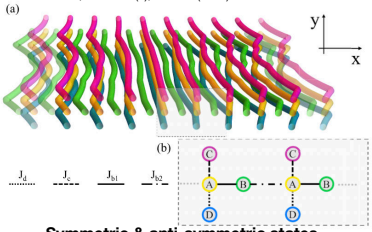
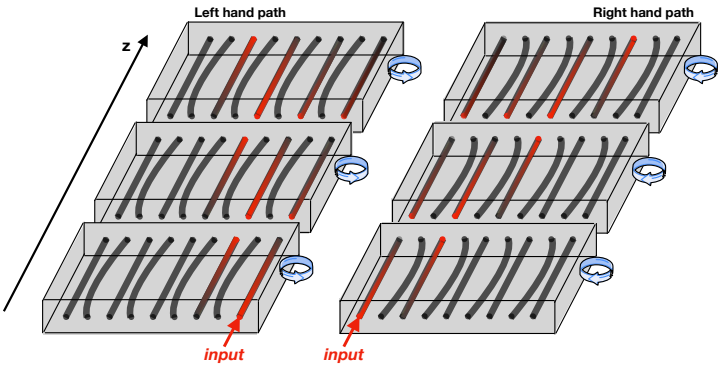
Quantum walks in photonic lattices via non-abelian Thouless pumping

Photonic lattice & Thouless Pumping

V.Brosco *et.al.*, PRA 103 (6), 063518 (2021)



Chiral quantum walk



Experimental realisation of Photonic Thouless Pumping

Y-K Sun *et.al.*, Nat.Phys. **18**,1080–1085 (2022)

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Perspectives

IFN – Photonic quantum computing chip

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- chip installed at Sapienza University for operations with single photon and quantum states of light
- implementation of quantum computing algorithms with up to 4 qubits
- development of a new generation of programmable photonic chips for 12 qubits operations

INO – Atomic programmable quantum processor

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- assembly of a new setup with neutral atoms (*e.g.* laser setups, vacuum chamber)
- realization of cold atomic gases to be trapped in optical tweezers
- realization of configurable arrays of individual atomic qubits

ISC – Quantum walks in photonic lattices via non-abelian Thouless pumping

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- scale from single photon to many interacting photons
- development of random quantum walks
- implementation of algorithm employing photonics quantum walks