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Quantum Simulators

physics, technologies, applications

Dario Gerace

Dipartimento di Fisica, Università di Pavia

Congresso di Dipartimento - 13 Settembre 2018

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QUANTUM PHOTONICS

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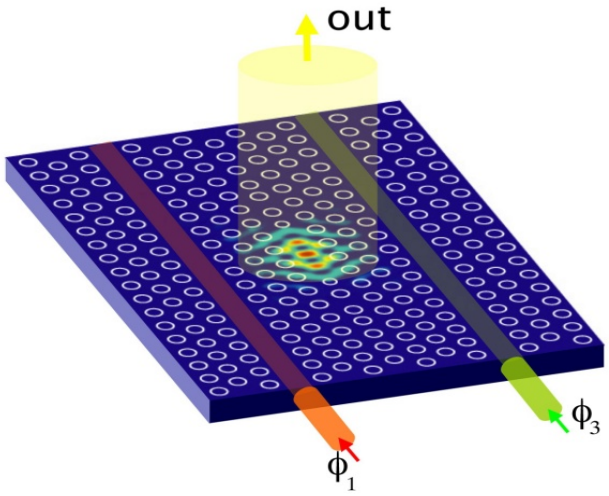
Single-photon sources

- Modelling and realizing single photon devices on-chip



- Combination of complex electromagnetic modelling, quantum optics, nanostructures, materials science

Ultimately: engineering single-photon devices (transitors, diodes…)

D. Gerace, et al. *Nature Physics* **5**, 281 (2009)

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QUANTERA

ERA-NET Cofund in Quantum Technologies

221 projects submitted

26 projects funded

CUSPIDOR

CMOS Compatible Single-photon sources based on SiGe Quantum Dots

2018-2021

JOHANNES KEPLER UNIVERSITY LINZ	Johannes Kepler University Linz	T. Fromherz
UNIVERSITÀ DI PAVIA	Università degli Studi di Pavia	D. Gerace
CORK INSTITUTE OF TECHNOLOGY	Cork Institute of Technology	L. O'Faolain
MASARYK UNIVERSITY	Masaryk University Brno	P. Klenovský
Tyndall National Institute	Tyndall National Institute	F. Murphy

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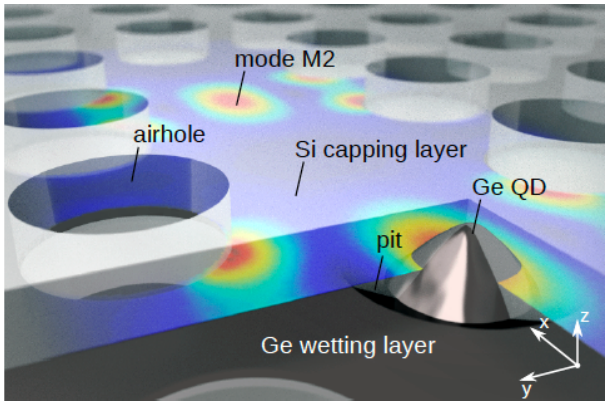
Targets

- SiGe QD based single photon source
- Electrically driven
- Room temperature operation

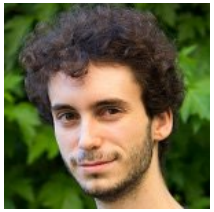


Complementing activities within *Dipartimento di Eccellenza*

People

Experimental activity

Matteo Galli



Marco Clementi (PhD)

To be hired (24 months)

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QUANTUM SIMULATIONS

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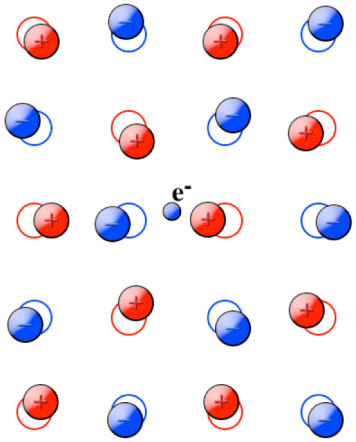
Problem: Simulating complex manybody systems



- Metals
- Semiconductors
- Insulators
- Superconductors
- Ferromagnetic
- Ferrimagnetic
- Ferroelectric
- …

Quantum description of the system evolution

$$i\hbar \frac{d}{dt} |\varphi\rangle = H|\varphi\rangle$$

The amount of required memory resources and computational time on a classical computer grows **exponentially** with the number degrees of freedom.

General solution

$$|\varphi(t)\rangle = \exp\{-i\hbar H t\}|\varphi(0)\rangle$$

→ **Untractable**

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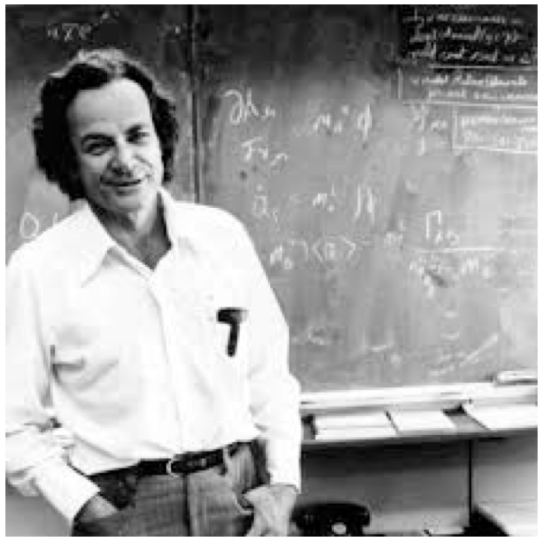
What is a quantum simulator?



"…there is to be an exact simulation, that the computer will do exactly the same as nature"

R. Feynman, 1982

"Let the computer itself be built of quantum mechanical elements which obey quantum mechanical laws."

The Quantum Computer is a Universal Quantum Simulator

Seth Lloyd, Science **273**, 1073 (1996)

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The Quantum Computer as a Universal Quantum Simulator

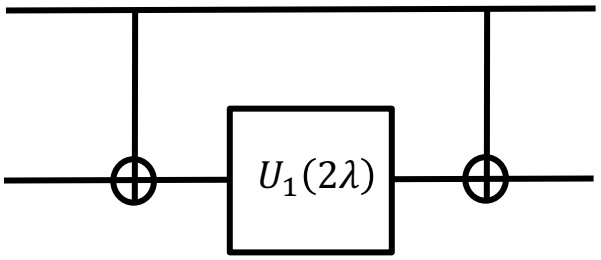
- Map the model Hamiltonian into $H = \sum_{l=1}^{M} H_l$

IF $[H_l, H_{l'}] = 0$ THEN $U = \prod_l \exp\{-i\hbar H_l t\}$ is EXACT

- Then $U(t)$ can be translated into a sequence of single and two qubit gates applied on the initial state (like in a pentagram)

Example: evolution on two qubits

$e^{-i\lambda\sigma_1^z\sigma_2^z} =$



IF $[H_l, H_{l'}] \neq 0$ THEN SOLVE FOR $U = (\exp\{-i\hbar H \Delta t\})^{t/\Delta t}$

whereby $U(\Delta t) \approx \prod_l \exp\{-i\hbar H_l \Delta t\}$ for $\Delta t \to 0$ **(Trotter)**

S. Lloyd, Science **273**, 1073 (1996)

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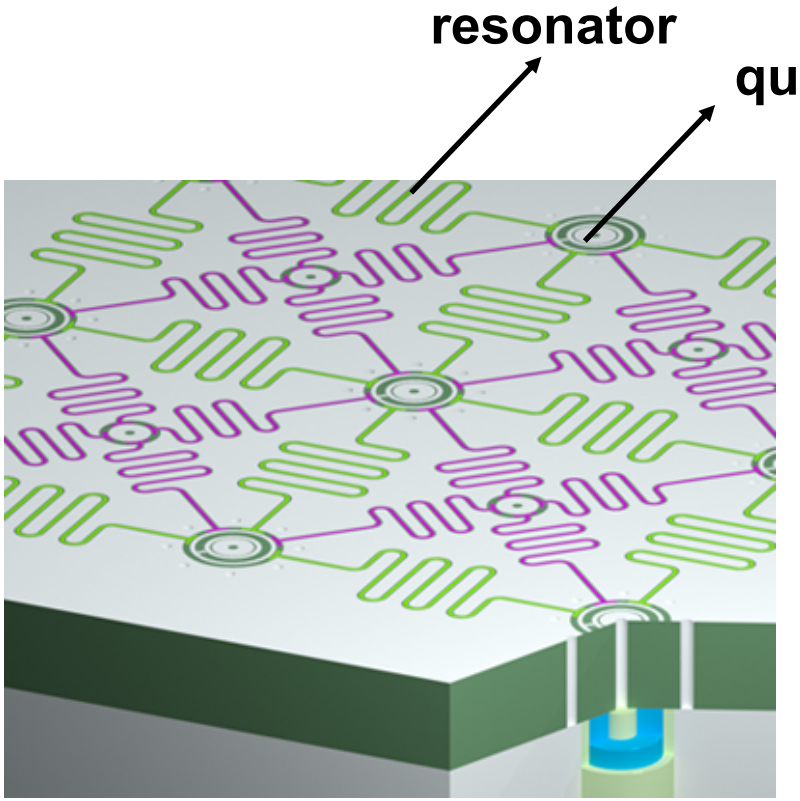
Practical quantum simulators

A **quantum simulator** is practically made of **qubits**, i.e. any system that can be initialized and/or read out in **a|0>+b|1>**

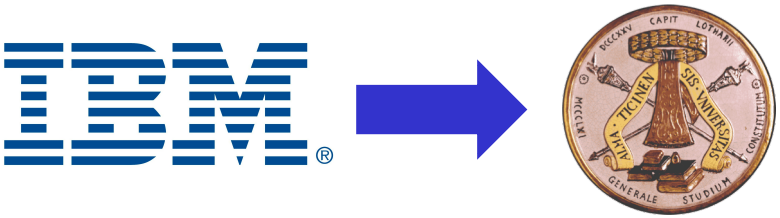


Superconducting circuits

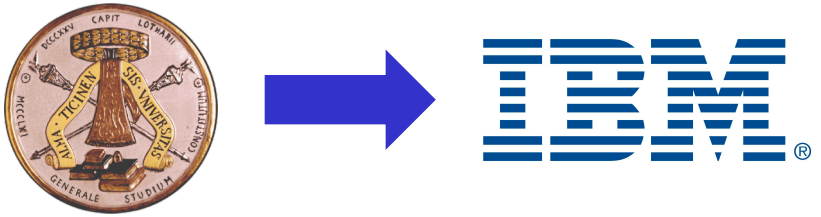
- Operational frequencies
  1-10 GHz
- Operational temperatures
  ~10 mK
- Coherence times
  ~100 μs

The collaboration with IBM (D. Rebuzzi)

- **Ph.D. Executive (Michele Grossi)**



- **Project LM+**



Currently the only available for cloud quantum computing

- **5-qubit chips** (ibmqx2, ibmqx4) & **16-qubit chip** (ibmqx5) **on line** for the **Quantum Experience** (free)
- **20 qubit** chip already available to partners
- **50 qubit chip** (to be announced 2018)

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People

Univ. Pavia

F. Tacchino

FUTURO IN RICERCA

NUOVO BANDO PRIN
Progetti di ricerca di Rilevante Interesse Nazionale

Univ. Parma

S. Carretta

IBM

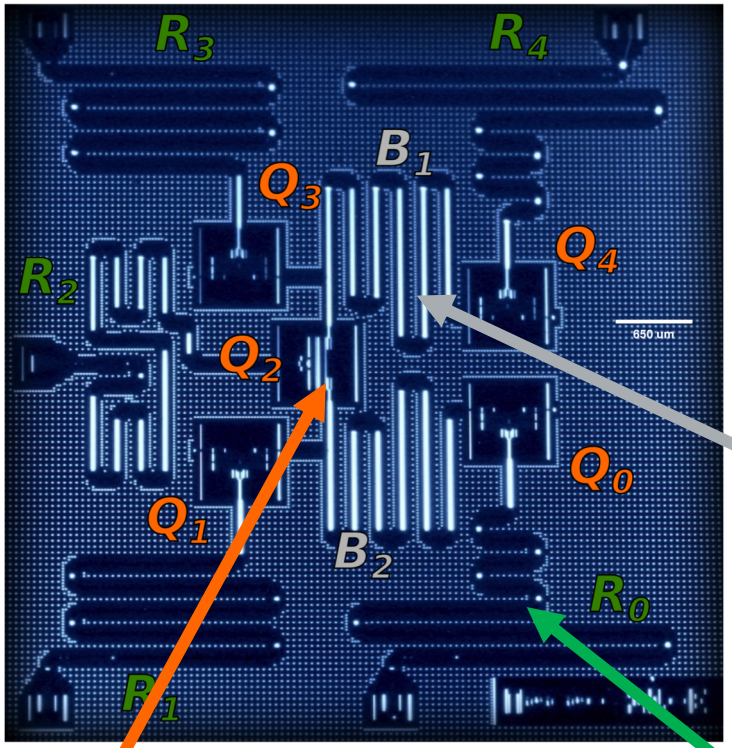
I. Tavernelli

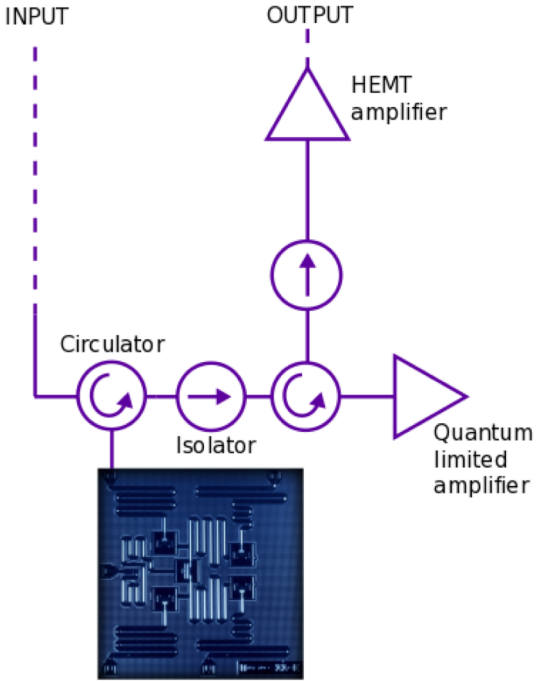
M. Grossi

The IBM Qx4 (RAVEN) chip

Freely available on cloud

→ can be used for testing quantum algorythms





$T_1 \approx 50 - 60\ \mu s$

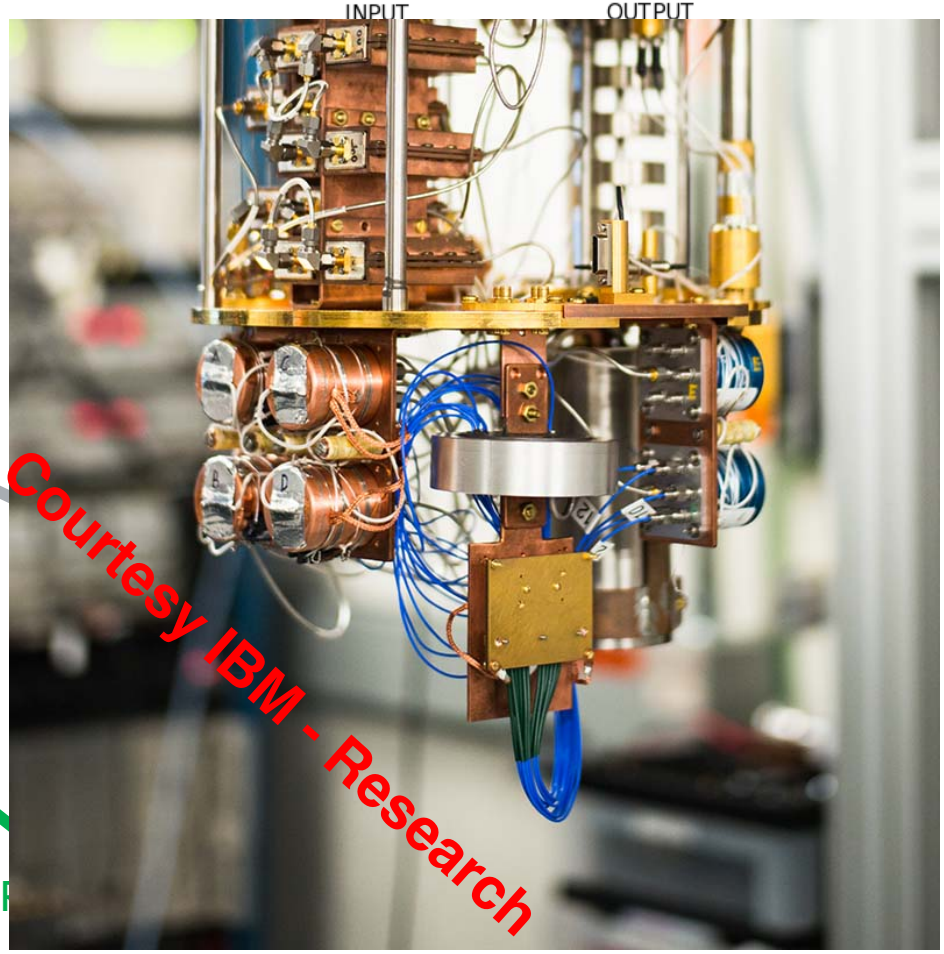
$T_2 \approx 50 - 80\ \mu s$

See more on GitHub https://github.com/QISKit/ibmqx-backend-information/tree/master/backends/

The IBM Qx4 (RAVEN) chip

Freely available on cloud

→ can be used for testing quantum algorythms



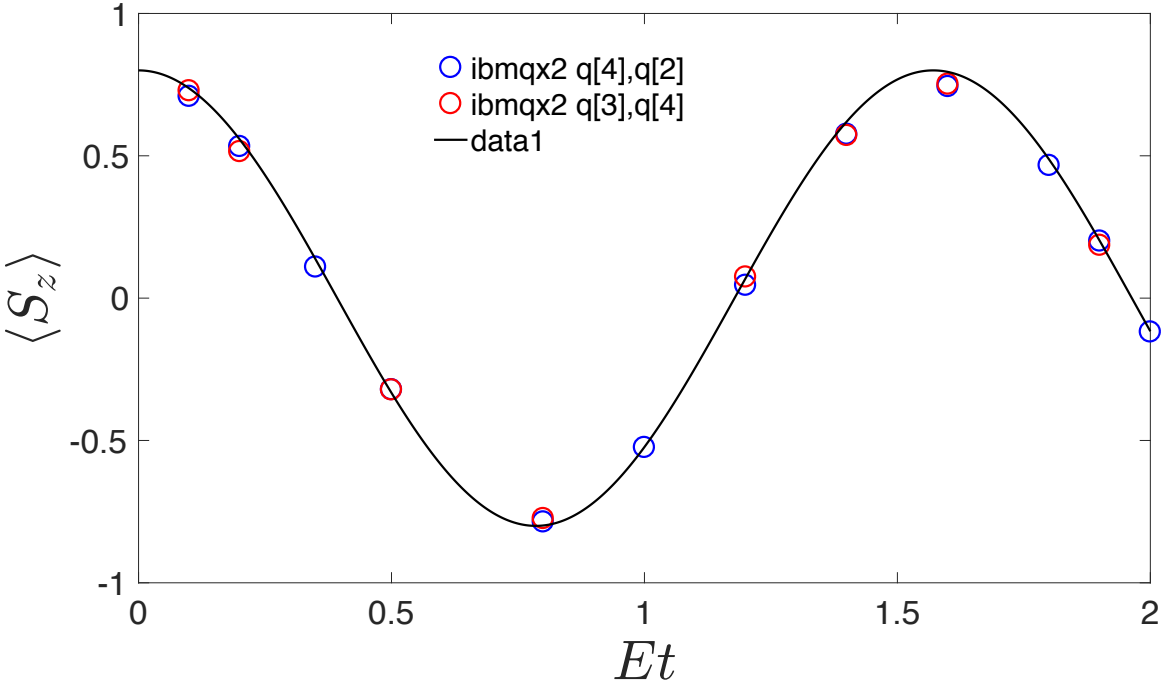
See more on GitHub https://github.com/QISKit/ibmqx-backend-information/tree/master/backends/

First test of digital quantum simulation: tunneling of S=1

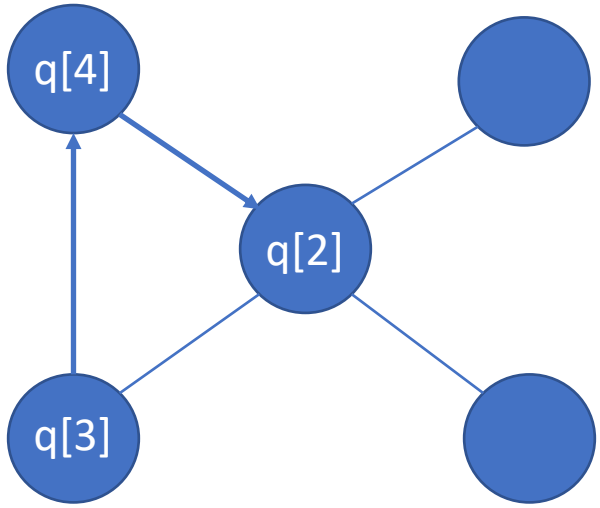
target model

mapped model

$$\mathcal{H} = DS_z^2 + E\left(S_x^2 - S_y^2\right) \; S = \frac{\sigma_1}{2} + \frac{\sigma_2}{2} \Longrightarrow \mathcal{H} = \frac{D}{2}\sigma_{z1}\sigma_{z2} + \frac{E}{2}\left(\sigma_{x1}\sigma_{x2} - \sigma_{y1}\sigma_{y2}\right)$$



Comparison of q4 controlling q2 *vs* q3 controlling q4 sequences.



Ibmqx2 chip with the qubits involved in the simulations