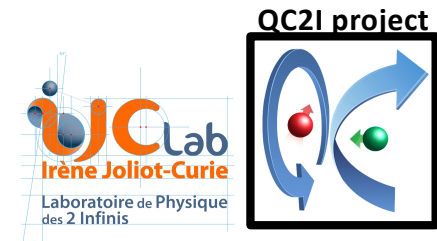# Quantum computing of atomic nuclei

Denis Lacroix (IJCLab-IN2P3)
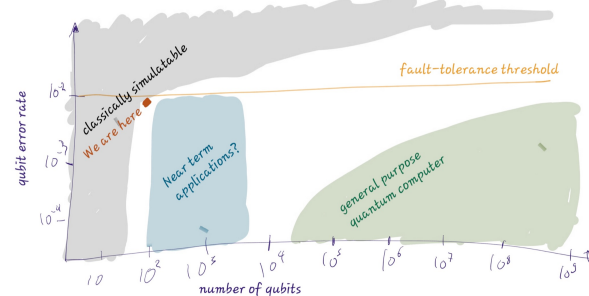
Contribution with:

G. Hupin (IJCLab), V. Somà (CEA-Saclay/DPhN)
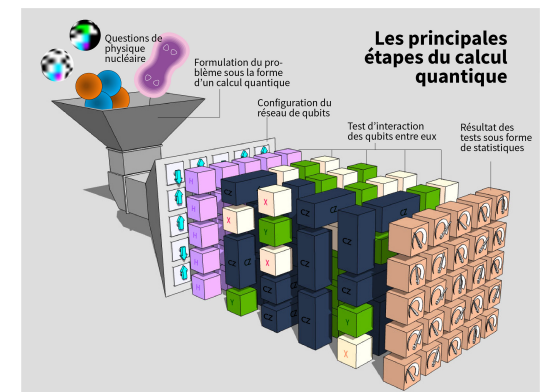
D. Regnier (CEA-DAM)
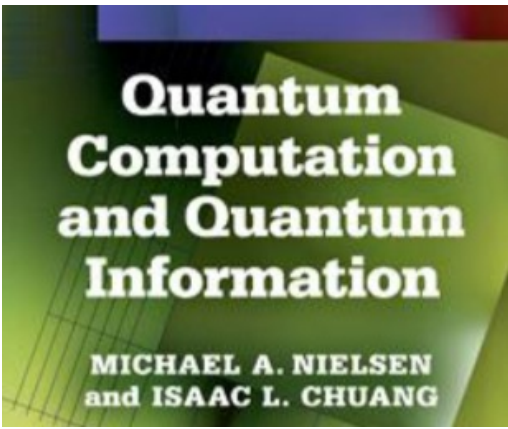
QC2I project

Current status
and opportunities

Discussion on
ongoing projects

Quantum Computation and Quantum Information

MICHAEL A. NIELSEN and ISAAC L. CHUANG

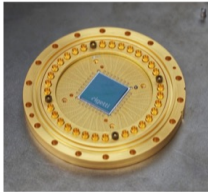**Quantum computational advantage using photons, Science 370 (2020)**

RIGETTI superconducting 19 Qubit
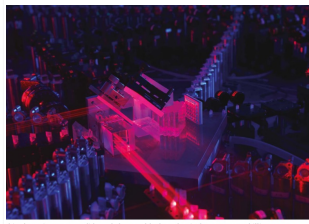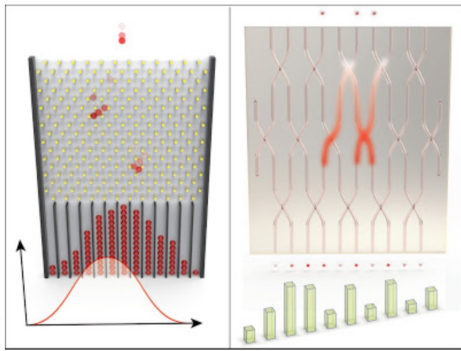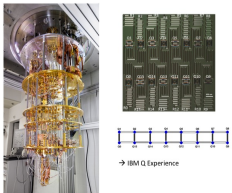
IBM QX5 (16 qubits)

→ IBM Q Experience

Simulating physics with computers-1982

Richard P. Feynman (Nobel Prize in Physics 1965)

"Nature isn't classical, dammit, and if you want to make a simulation of nature, you'd better make it quantum mechanical, and by golly it's a wonderful problem, because it doesn't look so easy."
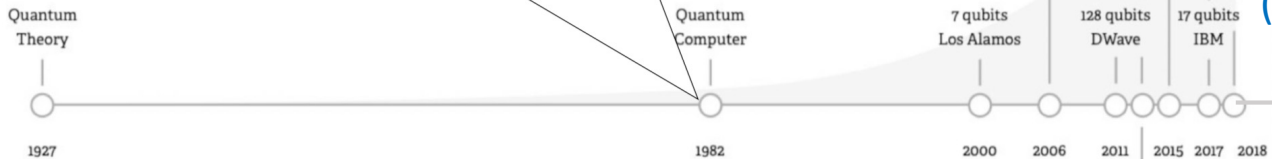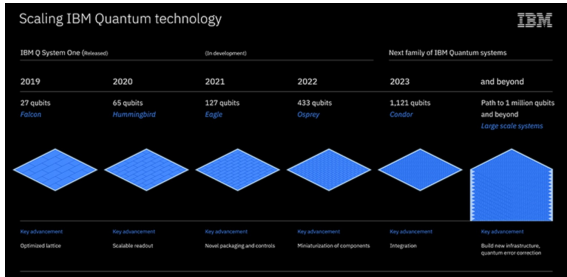
Quantum Theory

1927

Quantum Computer

1982

Quantum supremacy using a programmable superconducting processor

Scaling IBM Quantum technology

	IBM Q System One (Released)		(In development)		Next family of IBM Quantum systems	
	2019	2020	2021	2022	2023	and beyond
	27 qubits	65 qubits	127 qubits	433 qubits	1,121 qubits	Path to 1 million qubits and beyond
	Falcon	Hummingbird	Eagle	Osprey	Condor	Large scale systems

128 qubits Rigetti

72 qubits Google

1152 qubits DWave

2048 qubits DWave

512 qubits DWave

50 qubits IBM

12 qubits MIT

7 qubits Los Alamos

128 qubits DWave

17 qubits IBM

This photonic computer did a task that would take a classical computer 2.5 billion years.

(2020) (2021)

IonQ Gemini desk computer

2000 2006 2011 2015 2017 2018

2013

55 YEARS   **18 YEARS**   **6 YEARS**   **1 YEAR**

?

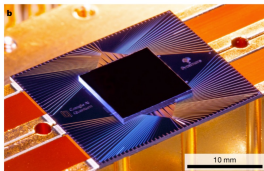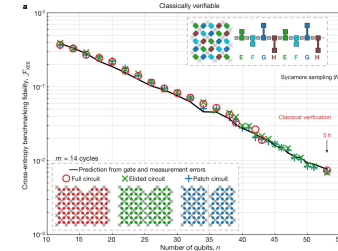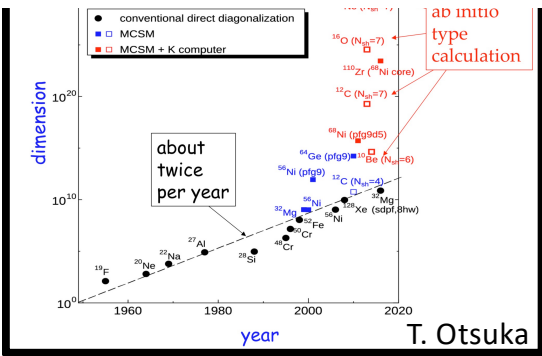IBM Cloud

Nature | Vol 574 | 24 OCTOBER 2019 | **505**

Fig. 1 | The Sycamore processor. a, Layout of processor, showing a rectangular array of 54 qubits (grey), each connected to its four nearest neighbours with couplers (blue). The inoperable qubit is outlined. b, Photograph of the Sycamore chip.

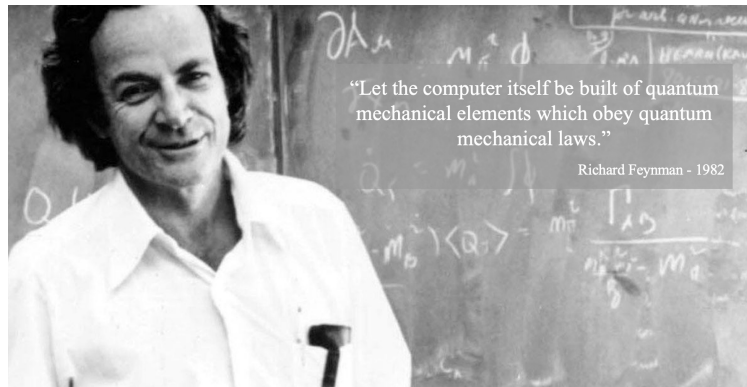Few highlights on ongoing actions/work: treating complex quantum problems

Some evident sources of complexity in nuclei
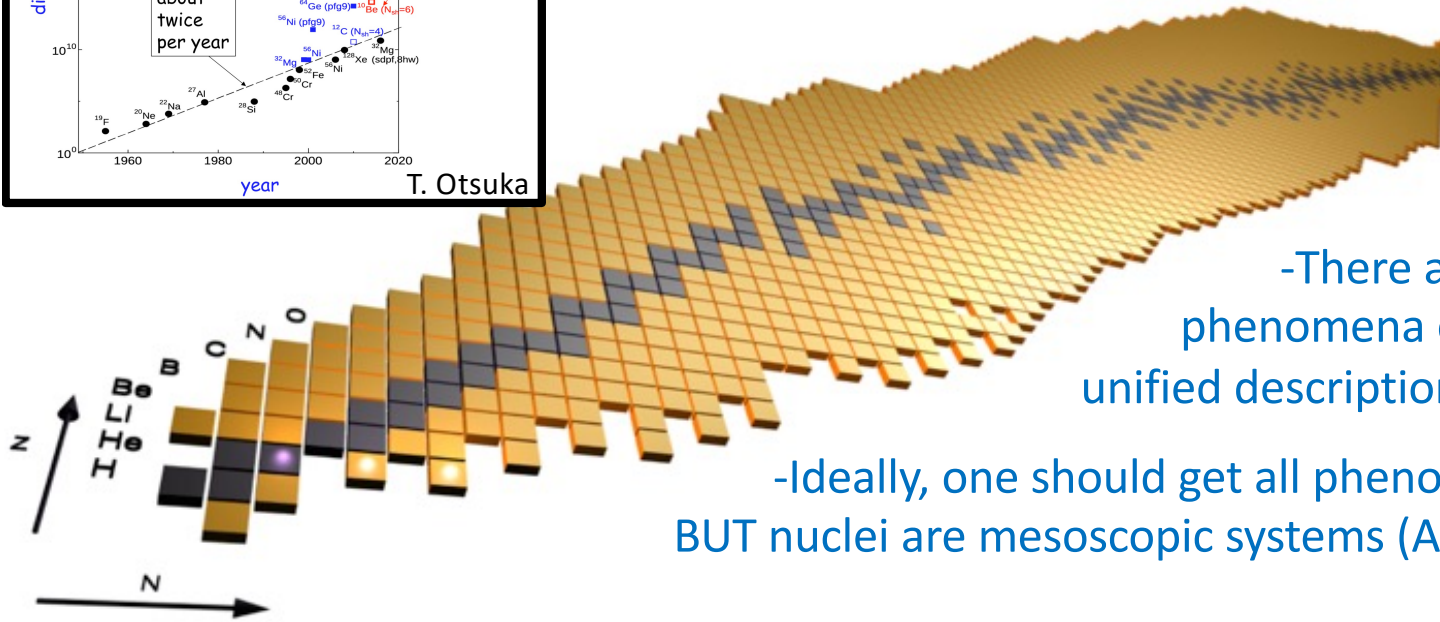
-There are many nuclei (>3000). Nuclear phenomena evolve along the nuclear chart. A unified description of all facets would be desirable.
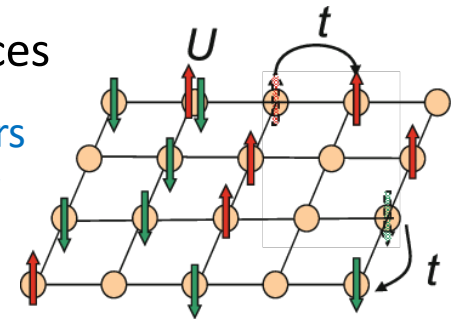
-Ideally, one should get all phenomena from the bare interaction BUT nuclei are mesoscopic systems (A~1-500) with bad numerical scaling.

Simulation of Quantum complex systems

"Let the computer itself be built of quantum mechanical elements which obey quantum mechanical laws."
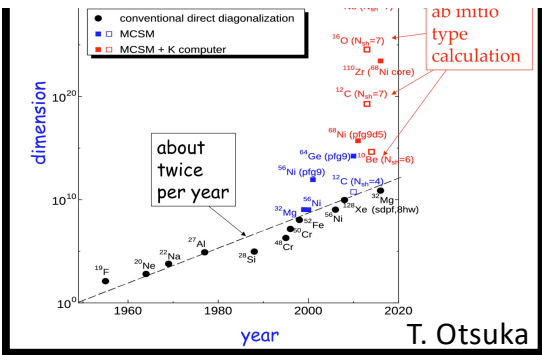
Richard Feynman - 1982

Ex: systems on lattices

On classical computers
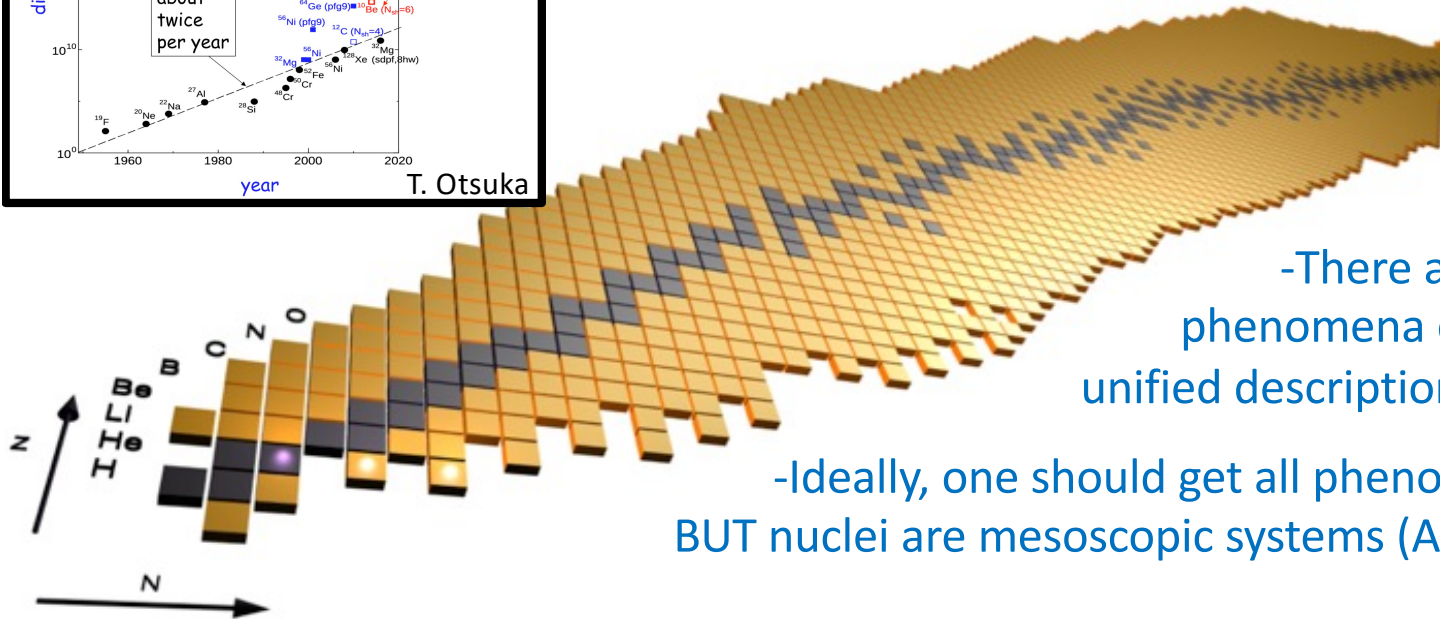Can be solved exactly
For max 20 particles.

On quantum computers:
N sites means only N qubits

Few highlights on ongoing actions/work: treating complex quantum problems

Some evident sources of complexity in nuclei

-There are many nuclei (>3000). Nuclear phenomena evolve along the nuclear chart. A unified description of all facets would be desirable.
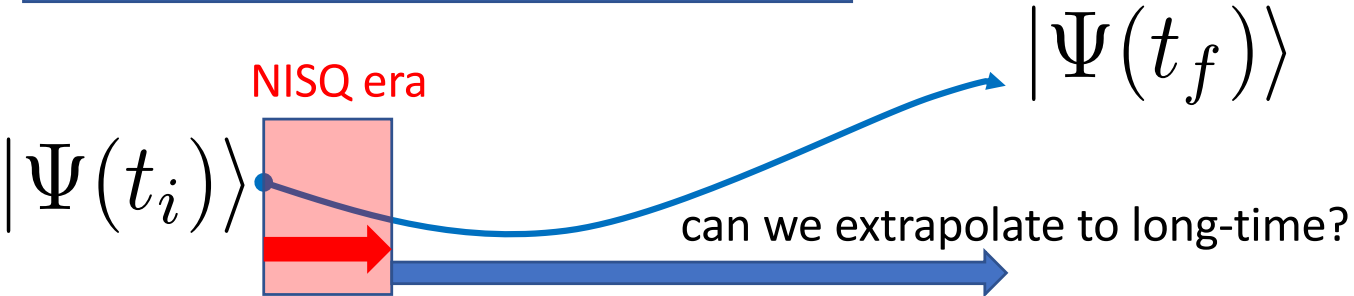
-Ideally, one should get all phenomena from the bare interaction BUT nuclei are mesoscopic systems (A~1-500) with bad numerical scaling.

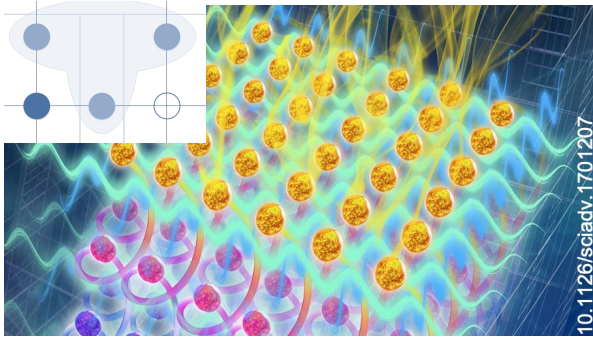Initial entangled state preparation for many-body physics
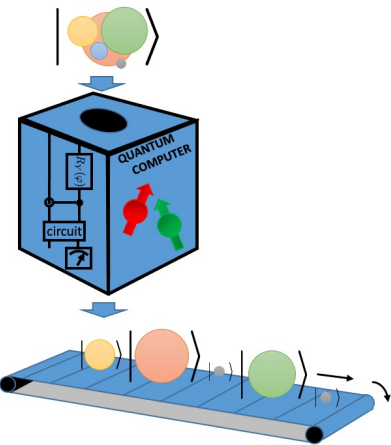
DL, PRL 125, 230502 (2020).

Predicting long time evolution from short-time propagation

$|\Psi(t_f)\rangle$

NISQ era

$|\Psi(t_i)\rangle$

can we extrapolate to long-time?

Ruiz-Guzman and DL, arxiv:2104.08181 (2021)

Few initiated applications in the world related to the infinities
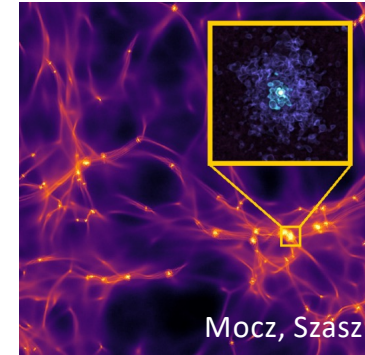
Lattice gauge theories

Zohar, Klco, Savage, …

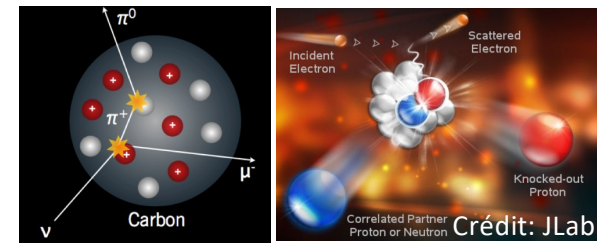## N-body problem

N-body nuclear systems
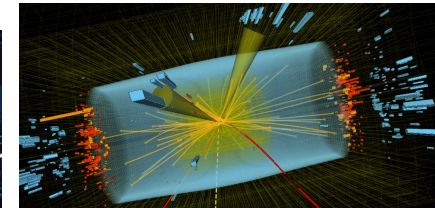
Dumitrescu, Hagen, Carlson, Papenbrock…

Dark matter

Mocz, Szasz

Dynamics: e, ν scattering

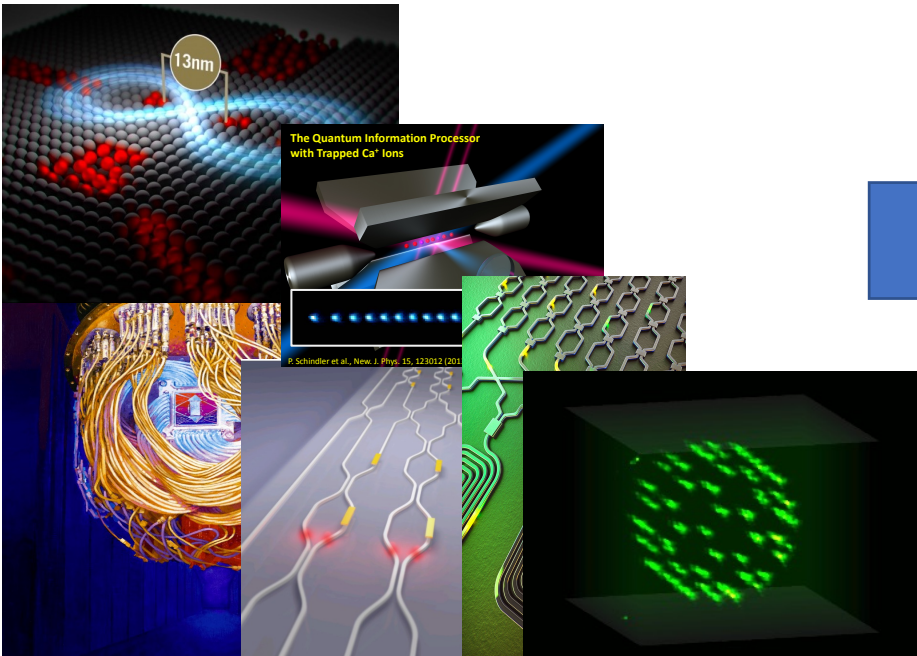π^0
π^+
μ^-
ν
Carbon

Incident Electron
Scattered Electron
Knocked-out Proton
Correlated Partner Proton or Neutron
Crédit: JLab

Roggero, Carlson, …

The Quantum Information Processor with Trapped Ca⁺ Ions

P. Schindler et al., New. J. Phys. 15, 123012 (201...

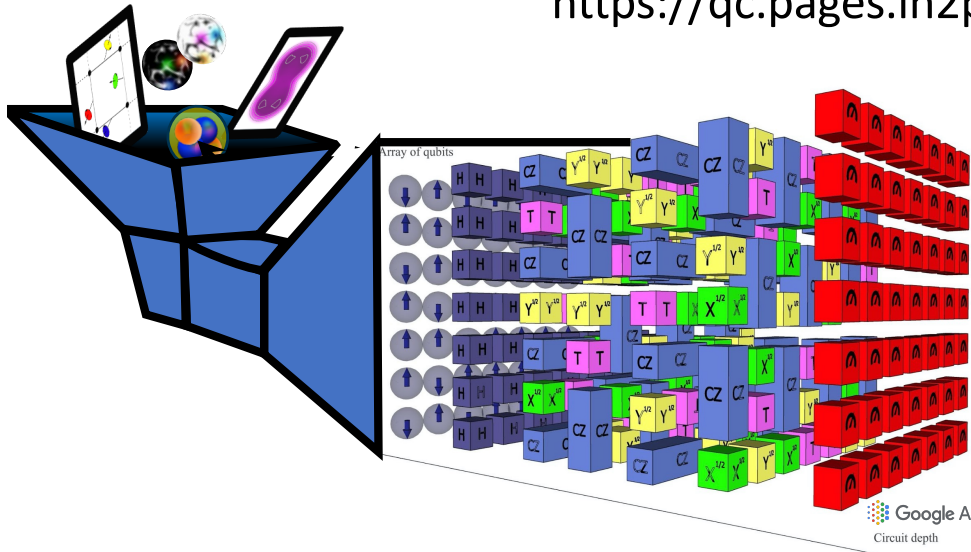## Applications to data mining (event classification)

CMS-detector (with LLR)
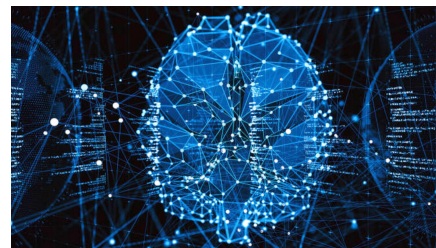
QC2I:
Quantum Computing for the Physics of the Infinites

https://qc.pages.in2p3.fr/web/

Array of qubits

Google AI

Circuit depth

Prepare the Quantum Computing Revolution

Quantum Machine Learning

Description of quantum complex systems

Denis Lacroix
CQSS Proj. Resp.
Lives in Paris, France
Nuclear Physics Researcher at IJCLab

Andrea Sartirana
QML Proj. Resp.
Lives in Paris, France
IT Engineer at LLR

Bogdan Vulpescu
PQCR Proj. Resp.
Lives in Clermont, France
IT Engineer at LPC

Thank you !