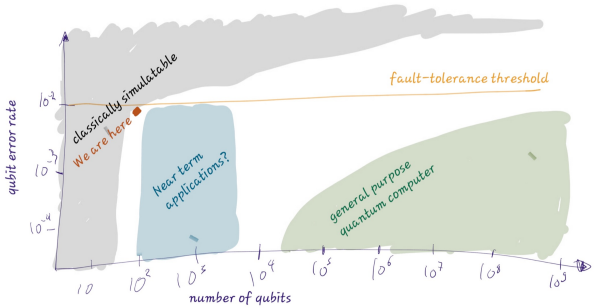
Quantum computing opportunities for the two infinities – and the QC2I project

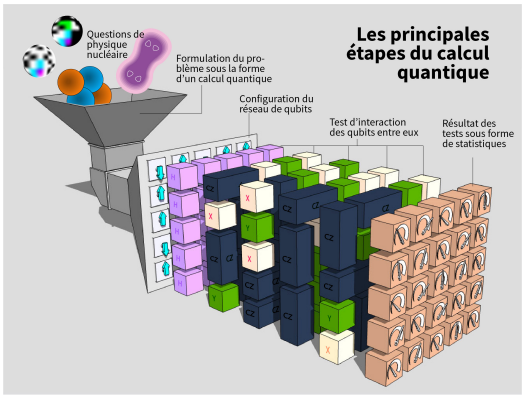
Denis Lacroix (IJCLab-IN2P3)

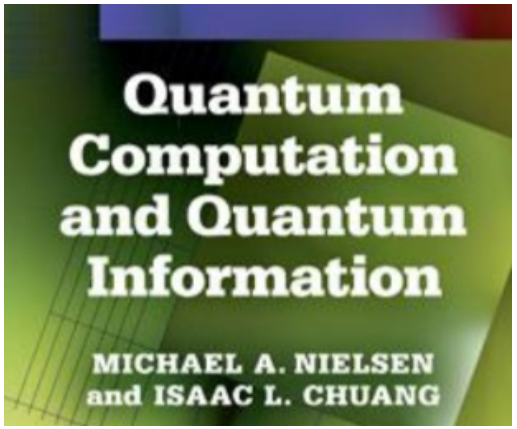
QC2I project

Current status and opportunities



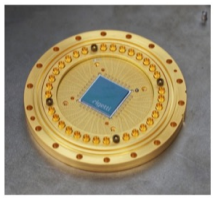
Discussion on ongoing projects

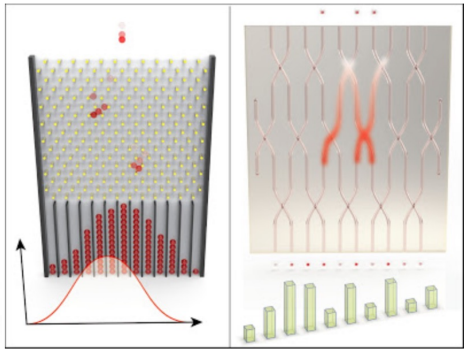




Quantum computational advantage using photons, Science 370 (2020)

RIGETTI superconducting
19 Qubit



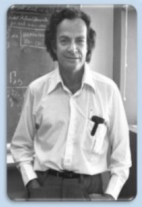


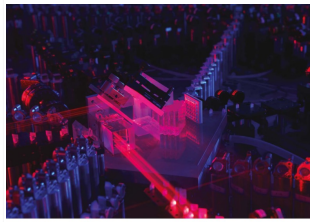
IBM QX5 (16 qubits)

→ IBM Q Experience

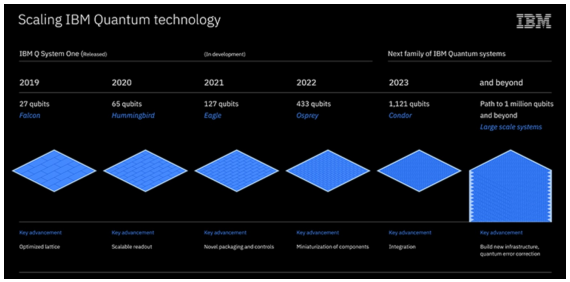
Simulating physics with computers-1982
Richard P. Feynman (Nobel Prize in Physics 1965)

"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."





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



(2020) (2021)

?

IonQ Gemini desk computer

Quantum supremacy using a programmable superconducting processor

Nature | Vol 574 | 24 OCTOBER 2019 | 505

IBM Cloud

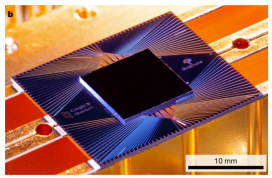
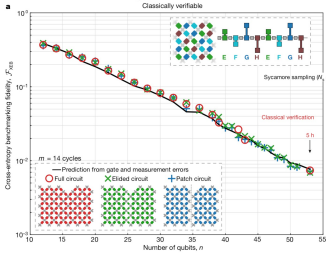
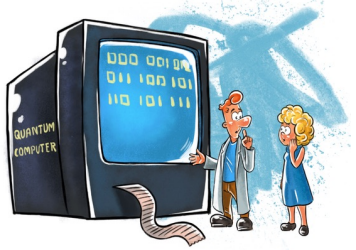


Fig. 1 | The Sycamore processor. a, Layout of processor, showing a rectangular array of 54 qubits (grey), each connected to its four nearest neighbours with couplers (blue). The inoperable qubit is outlined. b, Photograph of the Sycamore chip.

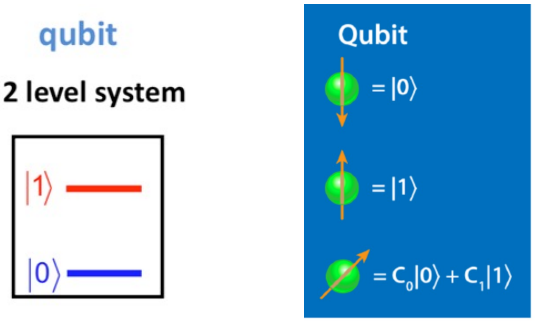


Quantum computing today is firstly an experimental challenge

Classical computers
Works with bits



Bits are only 0 or 1

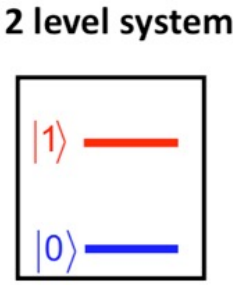


Advantages: dimensionality 2^n, entanglement, teleportation, tunneling, quantum secret, …

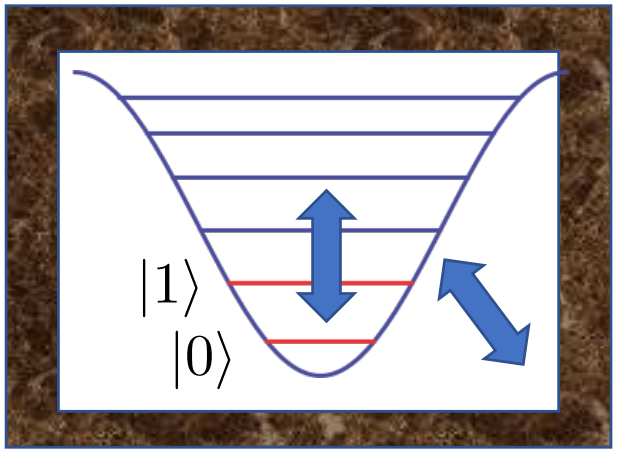
REALITY

Everything around want to destroy the ideal picture and the quantum coherence.

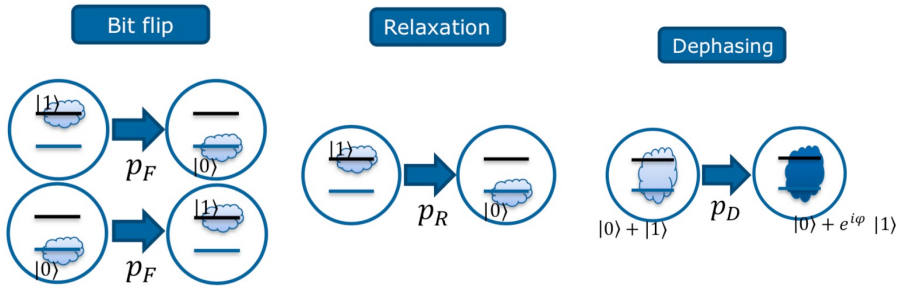
Ideal Qubits



External Exp. Setup



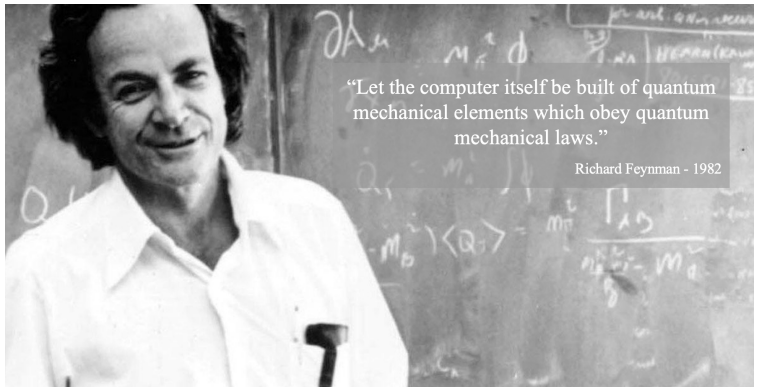
Leads to loss of information
And decoherence



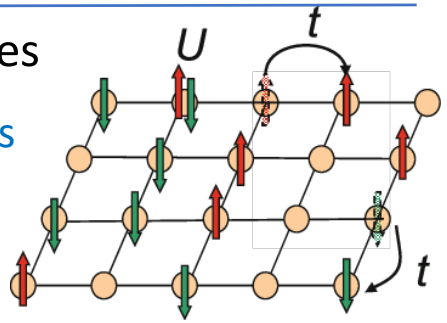
Working with quantum computers now means working in a noisy environment short programs

What are the anticipated applications ?

Simulation of Quantum complex systems



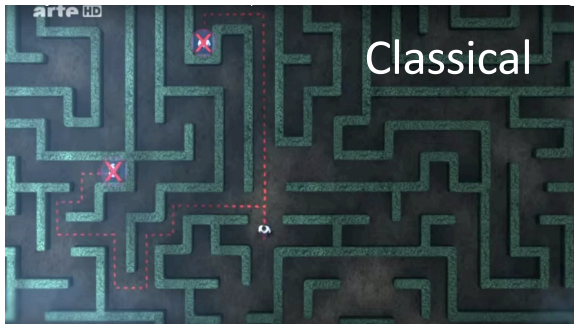
Ex: systems on lattices



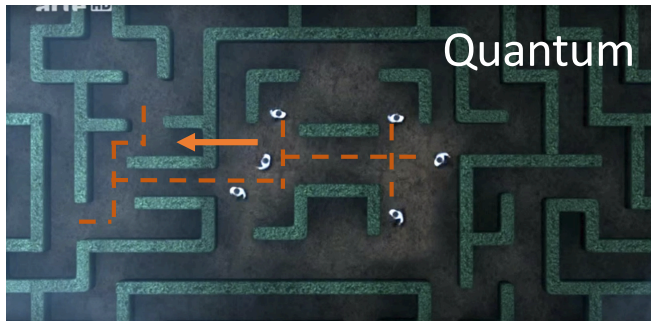
On classical computers
Can be solved exactly
For max 20 particles.

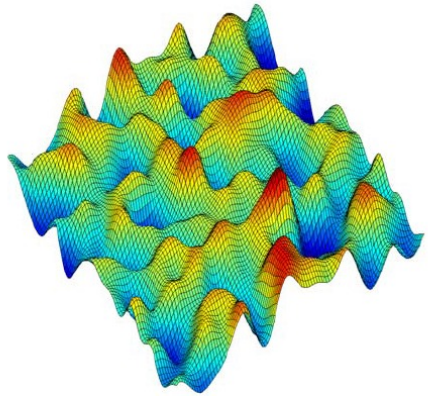
On quantum computers:
N sites means only N qubits

Quantum versus classical search



VS

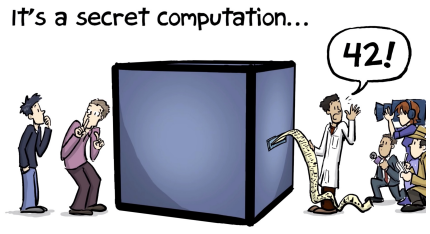


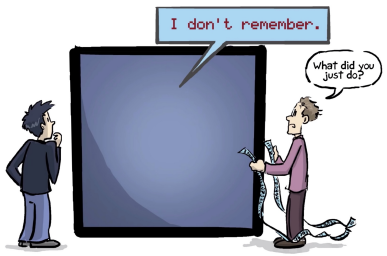


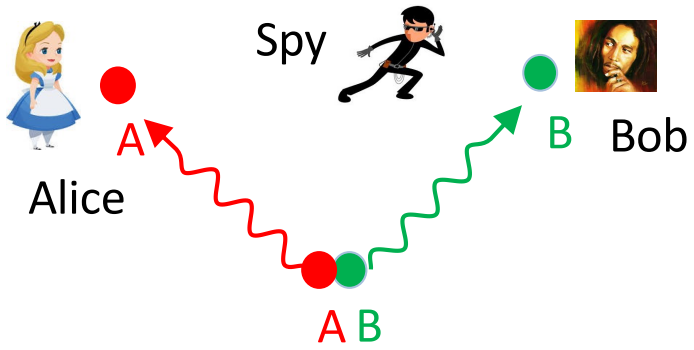
Credit: The Fabric of The Cosmos: Quantum Leap

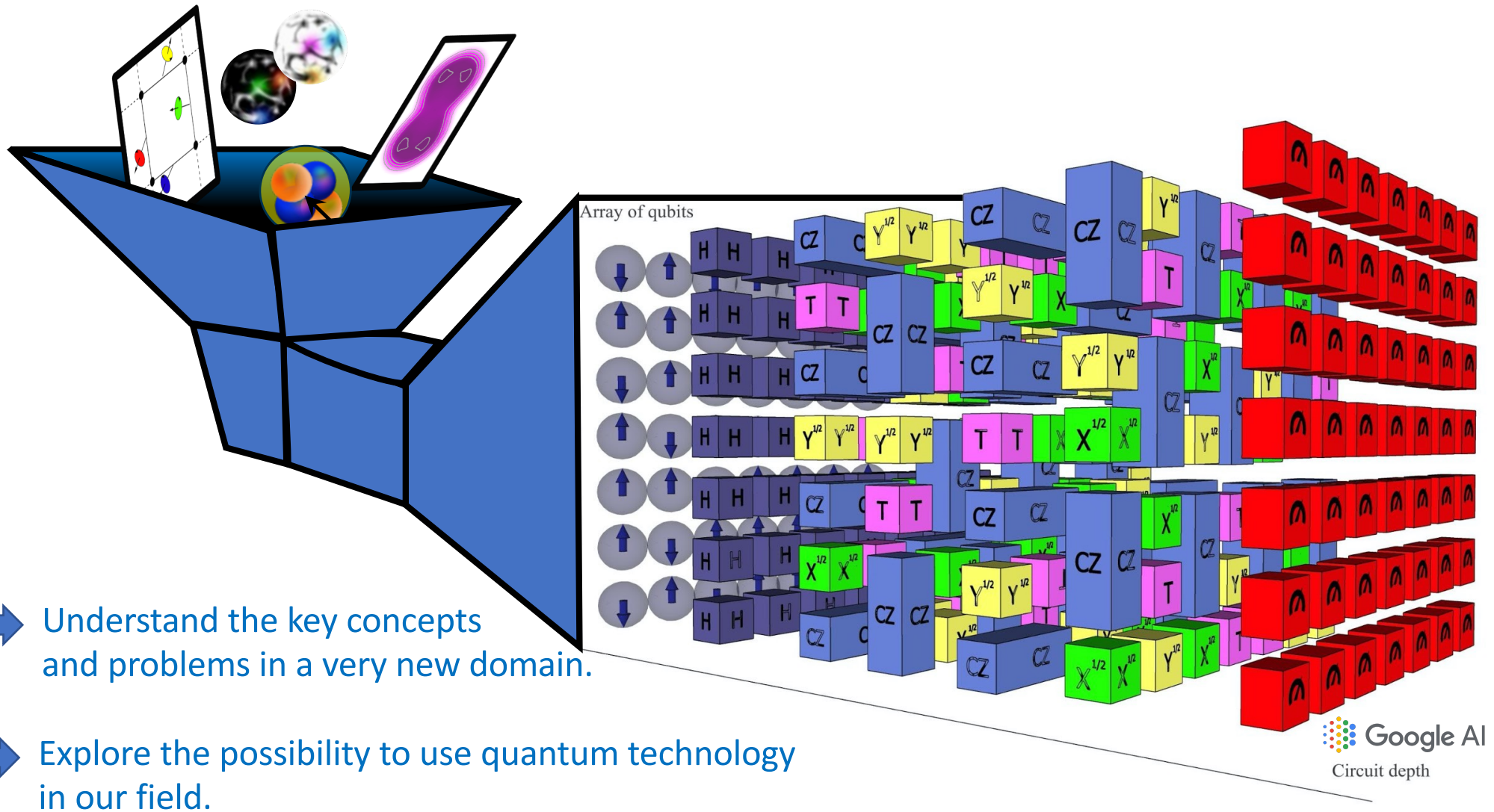
Exploring complex landscape:
molecules,
customers preferences (amazon), …

Quantum secrets (cryptography, quantum key, …)









- Understand the key concepts and problems in a very new domain.
- Explore the possibility to use quantum technology in our field.
- Prepare the arrival of a new disruptive technology that might give a significant boost in our domain.
- Try to contribute to this enthusiastic adventure.

The QC2I project in more details

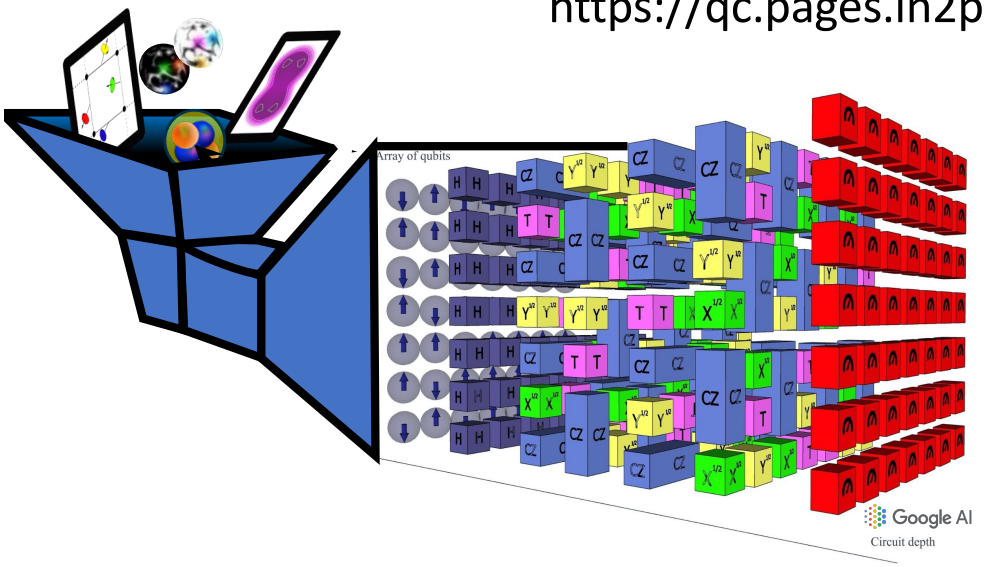
IJCLab Irène Joliot-Curie Laboratoire de Physique des 2 Infinis

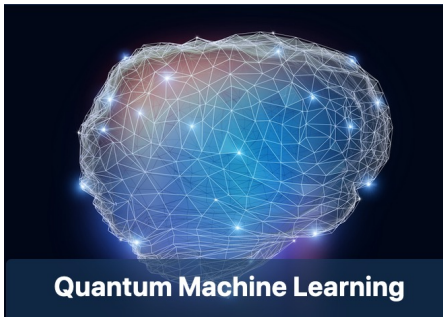
cnrs

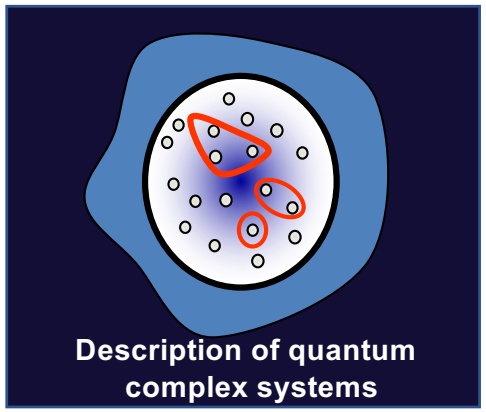
université PARIS-SACLAY

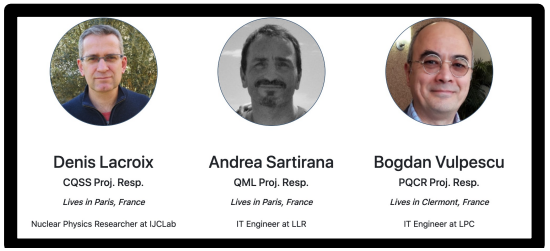
Université de Paris

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







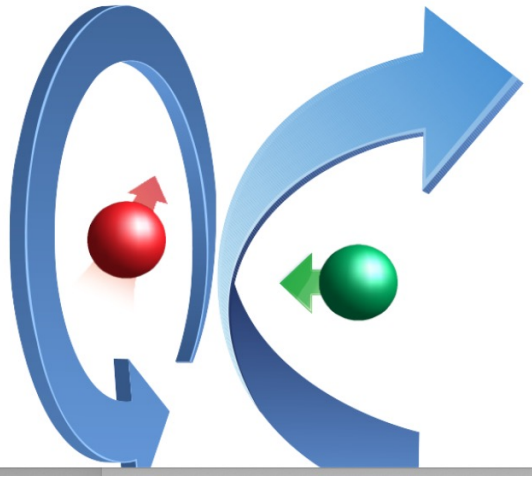


Few highlights on ongoing actions/work: preparing the quantum transition

QC2I About Members Meetings Talks Collab-Tools QC-Usefull

QC-Events
QC-Basics
QC-Tools
QC-Hardware
QC-Web
QC-Q&A

QC2I:
Quantum Computing for the two Infinites

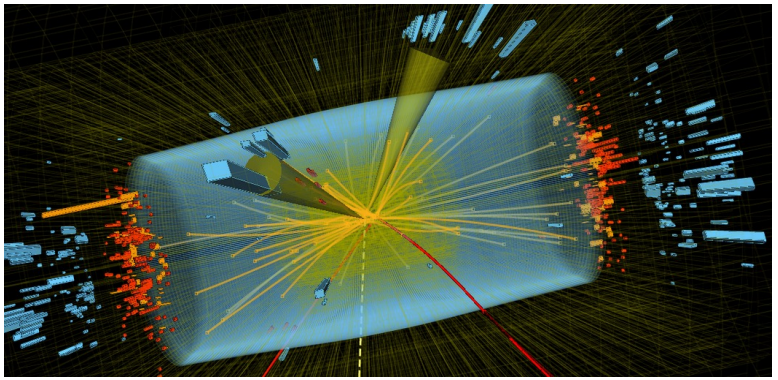


QC2I is a computing project supported by IN2P3, the French national nuclear and particle physics institute. Its goal is to explore the possible applications of the emerging quantum computing technologies to particles and nuclear physics problems as well as astrophysics. The main tasks are:

- to identify, within IN2P3, scientists/engineers/technicians who are interested in using quantum technologies,
- to facilitate the access and training on quantum computers,
- to identify milestones applications for nuclear/particle physics and astrophysics,
- to design dedicated algorithms and proof of principle applications.

The project action has three main directions: **Prepare the Quantum Computing Revolution** (PQCR), **Quantum Machine Learning** (QML), **Complex Quantum Systems Simulation**

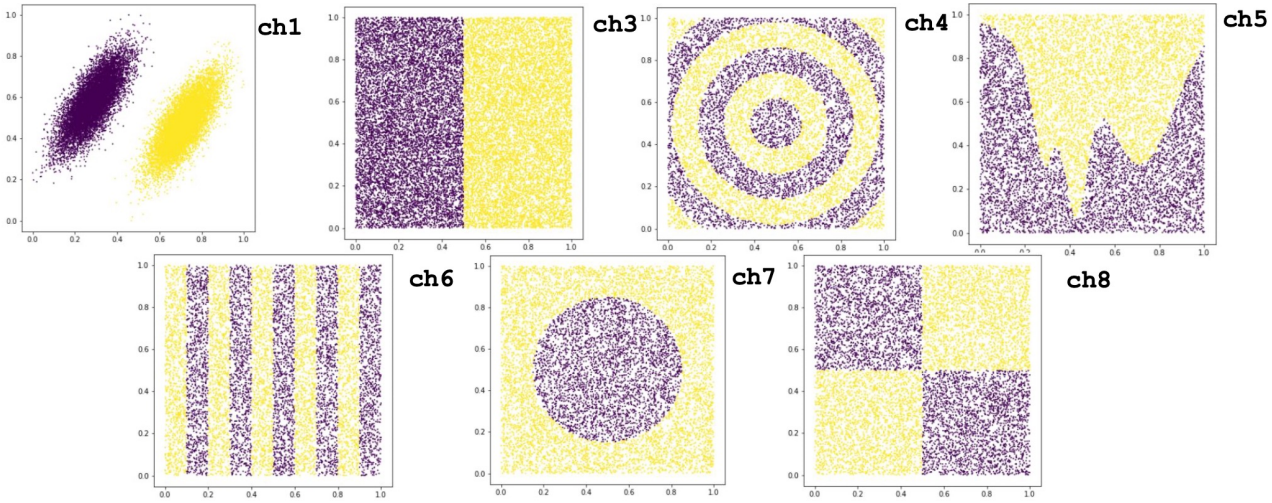
Machine learning vs Quantum Machine Learning for event classification



Project status

- Testing existing tools
- Defining milestones and intermediate steps

Example: 2D classification

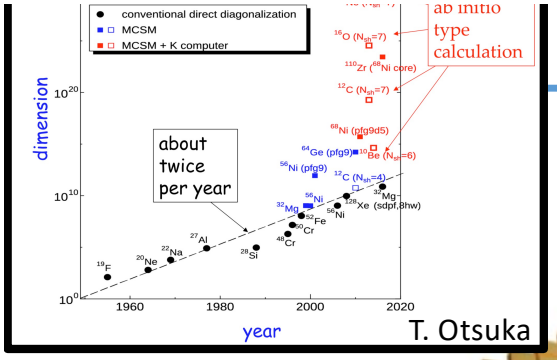


A. Sartirana (LLR), F. Magniette (LLR), et al

Test with QMLSimple software (A. Sartirana)

	Ch	Depth	Epochs	Succes Rate
0	ch1	1	15	100.0%
1	ch3	1	15	99.985%
2	ch4	13	105	95.59%
3	ch5	13	45	96.69%
4	ch6	13	45	98.03%
5	ch7	13	75	98.53%
6	ch8	13	45	98.91%

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

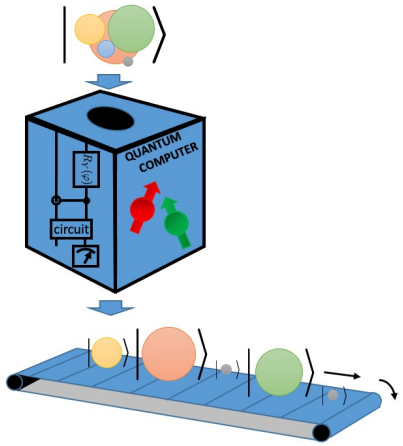


Some evident sources of complexity in nuclei

-There are many nuclei (>3000). Nuclear phenomena evolve along the nuclear chart. A unified description of all facets would be desirable.

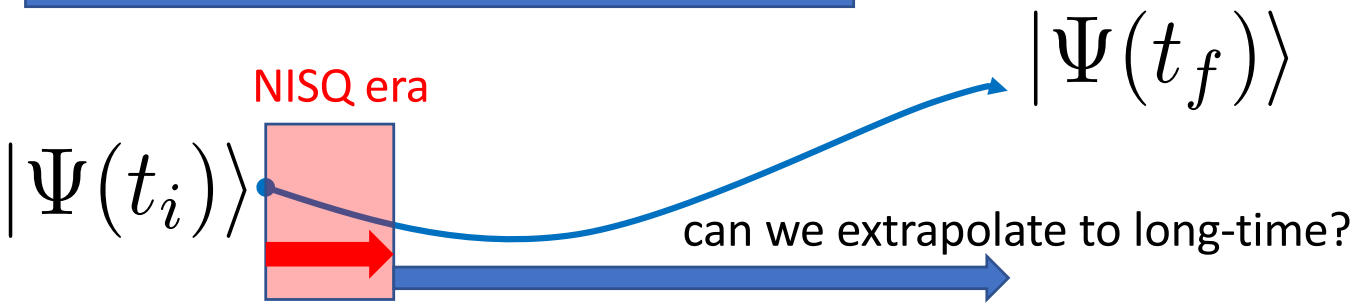
-Ideally, one should get all phenomena from the bare interaction BUT nuclei are mesoscopic systems (A~1-500) with bad numerical scaling.

Initial entangled state preparation for many-body physics



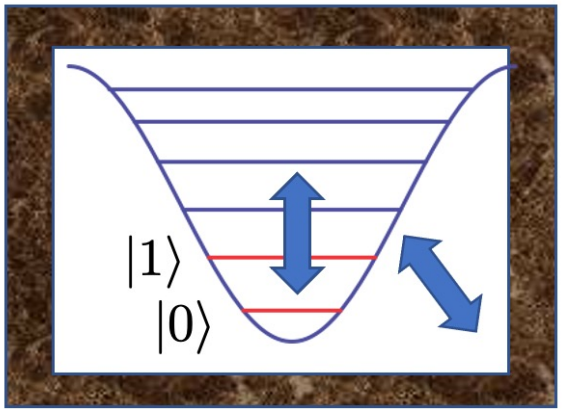
DL, PRL 125, 230502 (2020).

Predicting long time evolution from short-time propagation



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

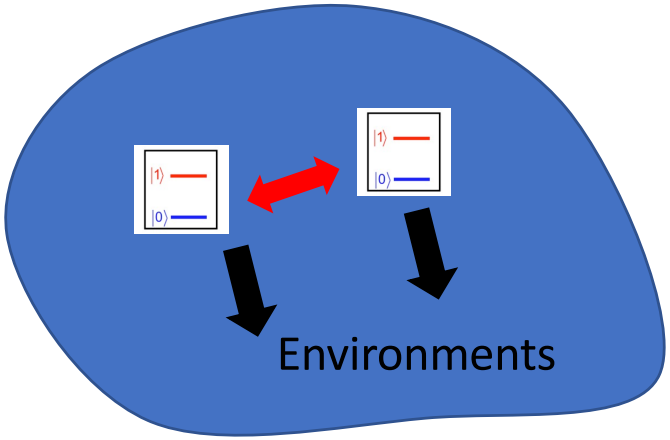
Qubits coupled to environments



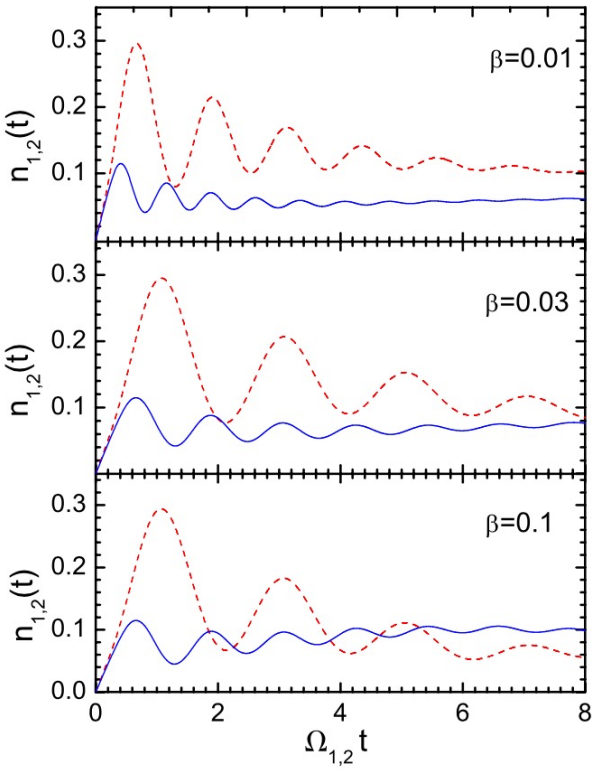
Sargsyan et al, PRE 103, (2021) [Editor suggestions]
DL et al, PRE (2020)
and many mores.
Ongoing JINR-IN2P3 collaboration


G.G.Adamian


N.V.Antonenko



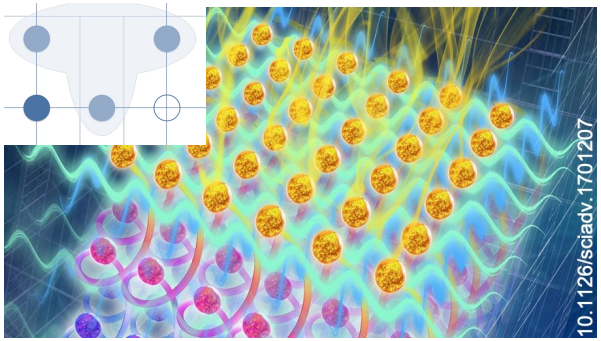
Treating Fermi/Bose systems coupled to one or several baths



Sargsyan et al, submitted to Phys. Lett. A (2021)

Few initiated applications in the world related to the infinities

Lattice gauge theories



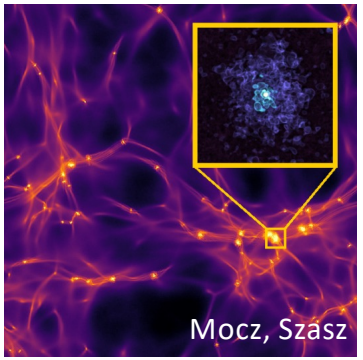
Zohar, Klco, Savage, …

N-body problem

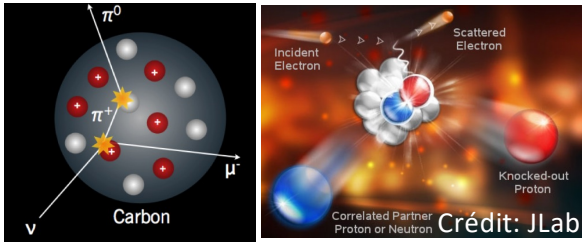
N-body nuclear systems

Dumitrescu, Hagen, Carlson, Papenbrock…

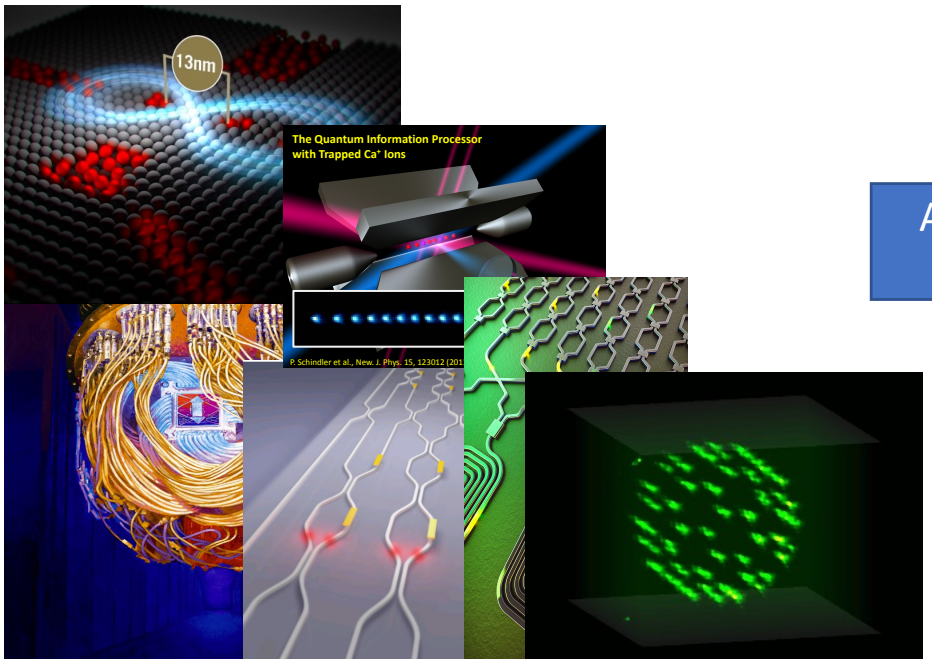
Dark matter



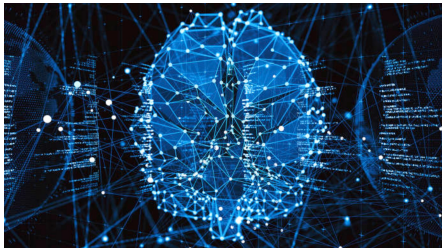
Dynamics: e, ν scattering



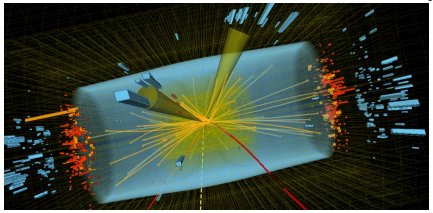
Roggero, Carlson, …



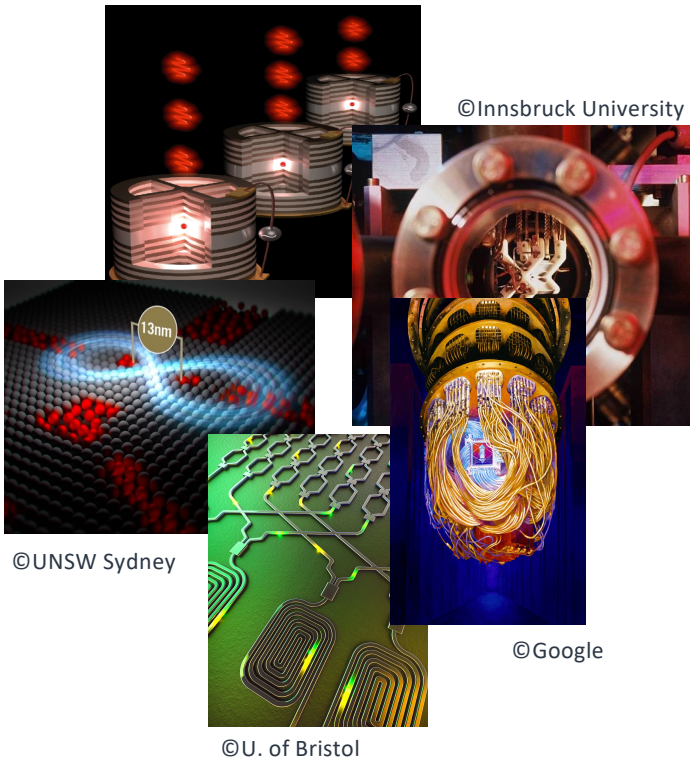
Applications to data mining (event classification)



CMS-detector (with LLR)



Summary



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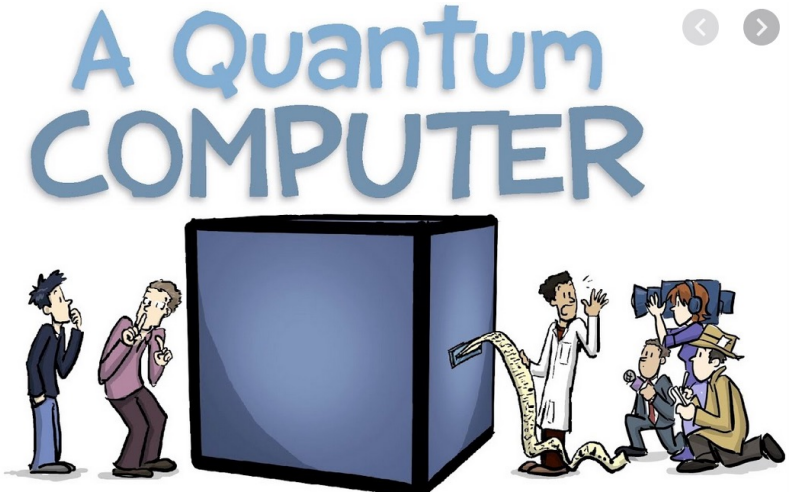
- Quantum computing is an interdisciplinary field
- There are many “new” opportunities
  - In quantum computing itself
  - In quantum technologies
  - In quantum information



Thank you !