Quantum Computation 1 – Introduction

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Pasqal
January – March 2023

Lecturers

- Gabriel CHÊNEVERT - Module coordinator

  Crypto , Quantum Computing
  @gchenevert
- Isabelle LEFEBVRE - In charge of

  Theoretical electronic structure : crystals, surfaces, nano …(CNRS)
  @ilefebvre_iemn
- Samuel DELEPLANQUE

  Algorithmic & Optimization problems
  @DeleplanqueSam2
- PASQAL
- (Jean-François ROBILLARD

  Thermoelectricity (heat propagation in nanostructured materials)
  @jeffrobil

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WHY THIS MODULE?

Why should you learn this?

- An engineer at the beginning of the 21st century can't be unaware.

- Knowledge directly useful for a profession by combining the qualities of computer scientist, engineer and quantum physicist.

- A great need for engineers , informaticians knowing a bit of quantum physics

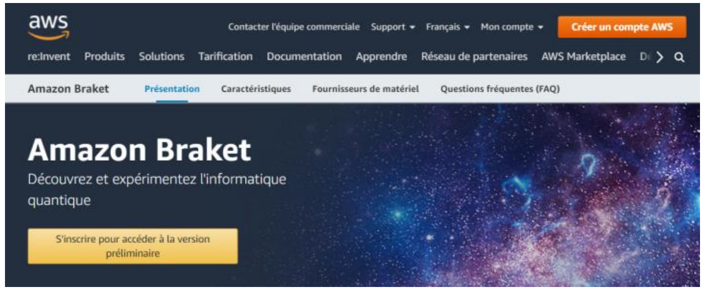
- Knowledge of the possibilities presented by quantum computers can be used very quickly, whatever the profession.

What you should understand

- A Quantum computer IS NOT a very big Classical computer
- Which kind of problem are addressed
- What kind of results can be expected
- What are the technical constraints due to quantum aspect
- Be able to follow current events and give an informed opinion (more than bit/qubit)
- Understand programs and realize some simple computations

Not too early

Already accessible for all



Overview

Syllabus

Séance 1 6 Janvier :
Séance 2 13 Janvier
Séance 3 20 Janvier
Séance 4 27 Janvier
Séance 5 03 Février
Séance 6 10 Février
Séance 7 24 Février
Séance 8 3 Mars

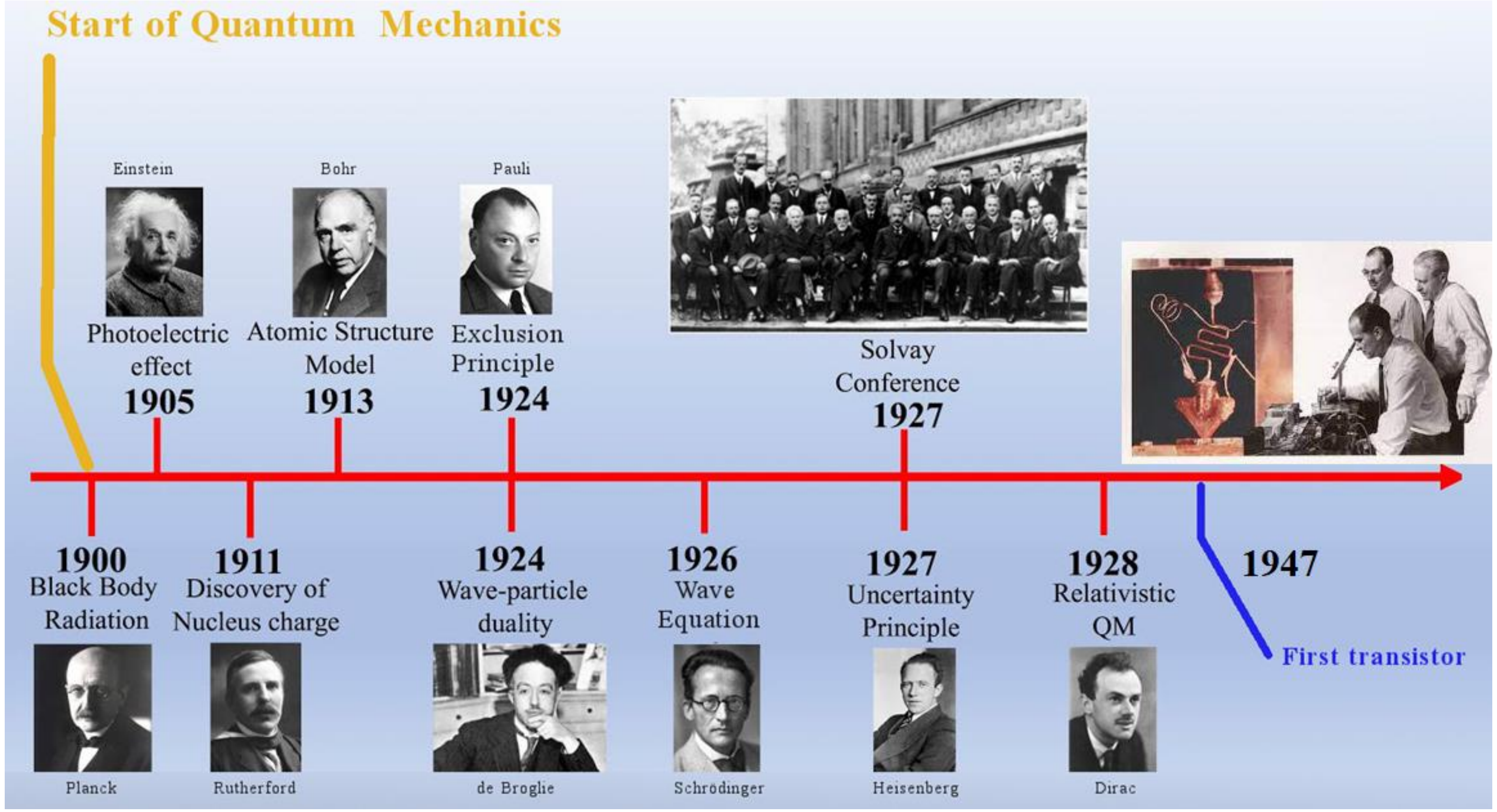
Assessment methods

1) 20 % exercices on circuits
2) 20 % TP Grover
3) 20 % TP D-Wave
4) 40 % final exam 10 mars.

A quantum computer from where to what

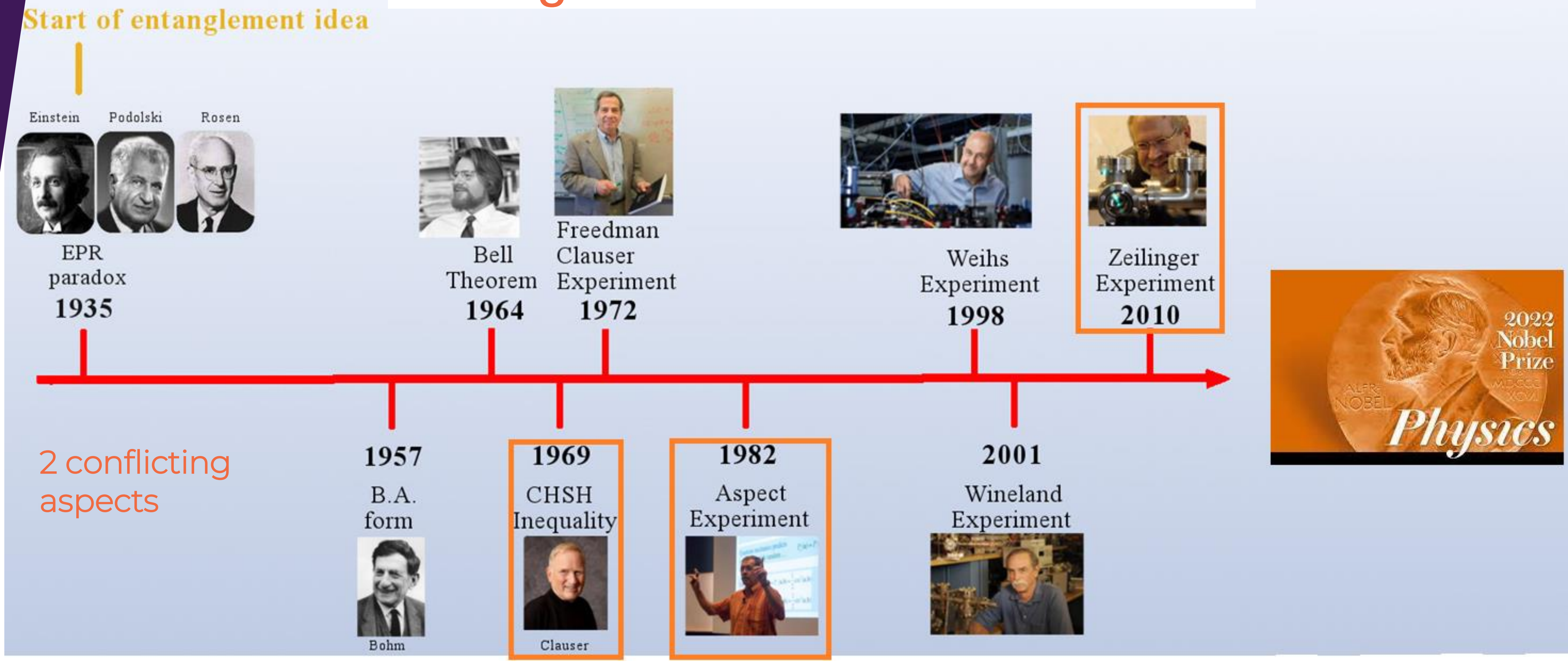
Construction – First revolution

Discovery of concepts



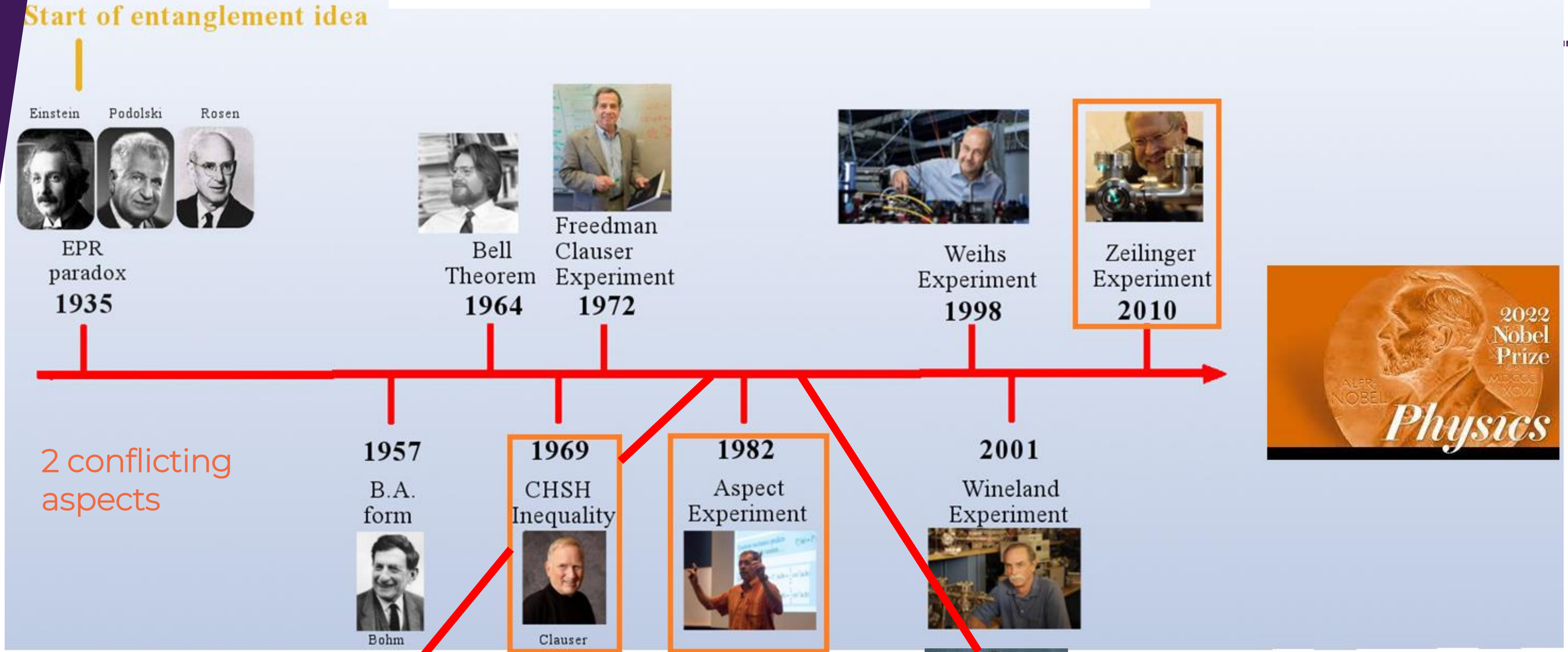
Control of particle groups

Entanglement – Second revolution



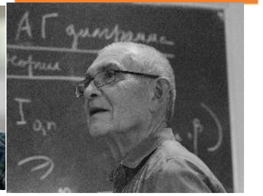
2 conflicting aspects

Intrication – Second revolution



2 conflicting aspects

1980 Yuri Manin - Paul Benioff
Quantum computer ideas/theory



1985 David Deutsch
Develops a Türing machine
Demonstrates universality

1981 Feynmann à Endicott - Physics of Computation

Computer types

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Gate based

Universal

QEC FTQC

NISQ

IBM Google rigetti IONQ Honeywell NTT intel Alibaba

Annealing

Emulator

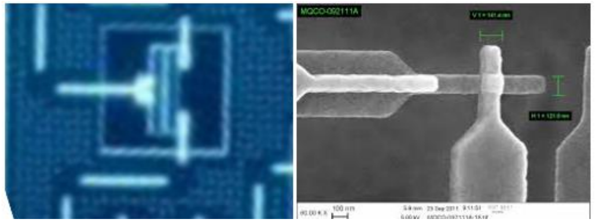
Atos IBM FUJITSU Google Microsoft aws Alibaba HUAWEI

Simulator

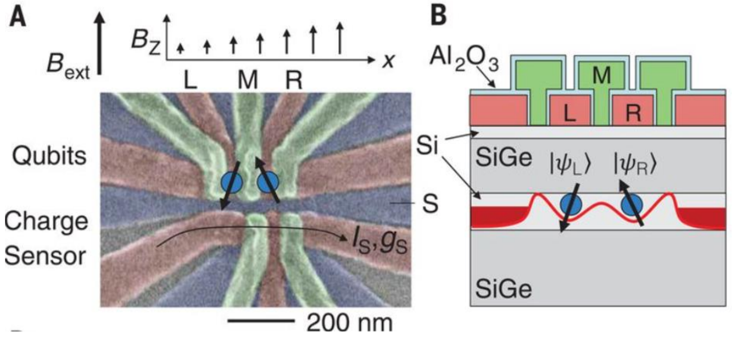
PASQAL PASQuanS Qombs SQUARE PhoQuS

Programmable simulator

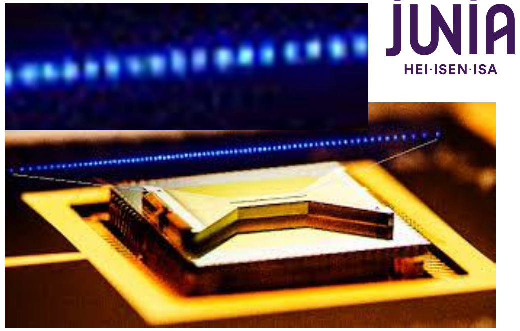
Various technologies



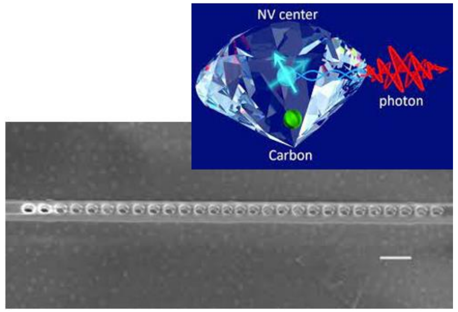
Supraconductors Alice&Bob



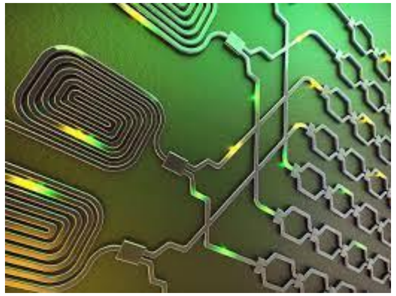
Semiconductors Siquance



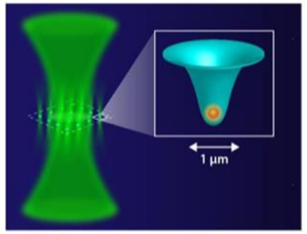
Trapped ions



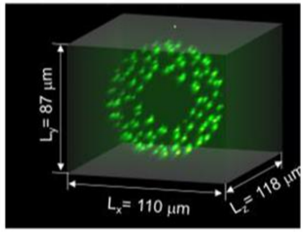
Colored centers



Photons Quandela

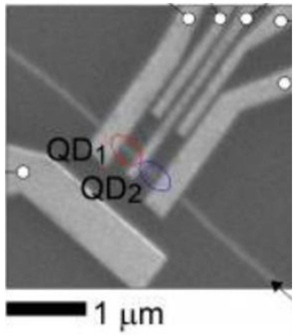


Single atoms are trapped in an energy potential pattern created by lasers

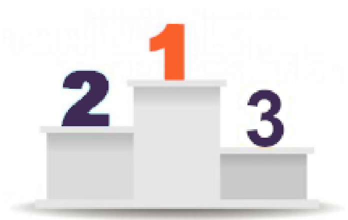


Each green dot is a Rubidium atom arranged within a torus

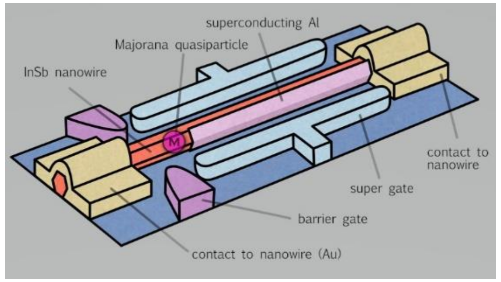
Cold atoms Pasqal



Nanotubes C12



No winner yet!

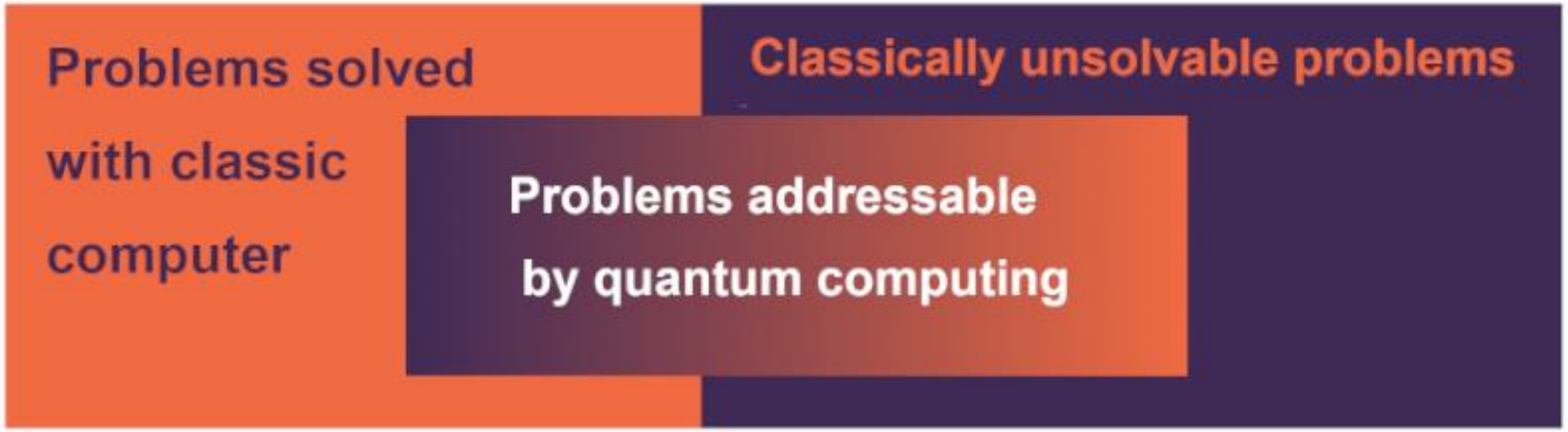


Topologics
Microsoft

Hybrid computations (HPC-Q)

04/01/22

Computer ++ ?



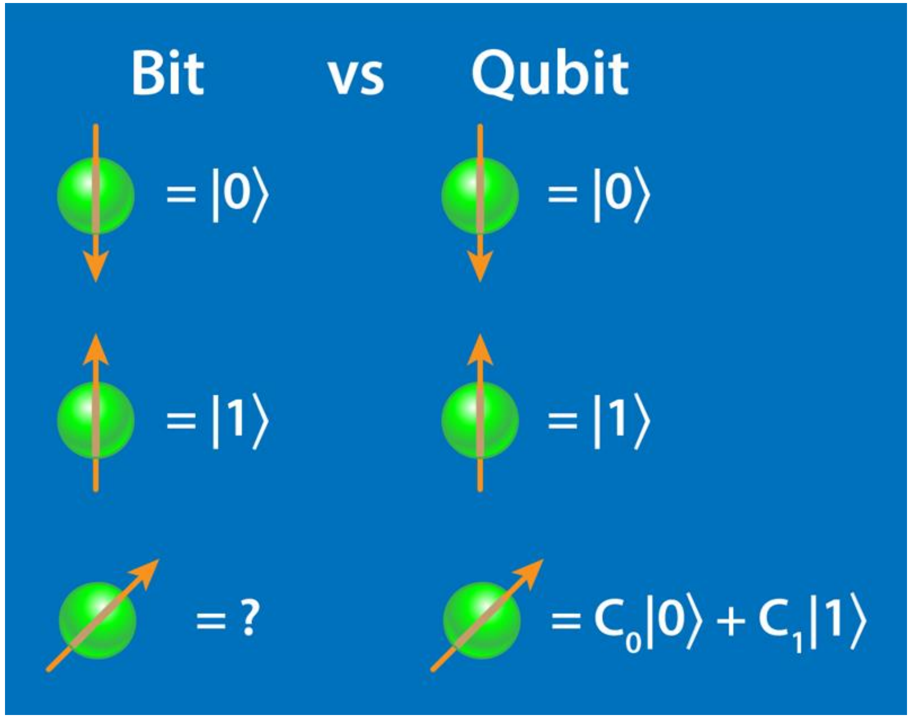
faster

more power

Thinking with quantum concepts

New paradigm

A Qubit in brief



Quantum system – 2 levels
Superposition
Q. Measurement (probability)
Extremely sensitive to very weak disturbance

Superposition
Entanglement

Di Vincenzo criteria

director of the Institute of Theoretical Nanoelectronics at the Peter Grünberg Institute in Jülich and Professor at the Institute for Quantum Information at RWTH Aachen University

In 1996, during his research at IBM

REQUIREMENTS FOR THE PHYSICAL IMPLEMENTATION OF QUANTUM COMPUTATION	
D1: Scalable qubits	Scalable physical system of well-defined, characterized qubits
D2: Initialization	Prepare a simple, fiducial input state
D3: Measurement	Measure the qubit state
D4: Universal gate set	Perform a universal set of gate operations with high fidelity
D5: Coherence	Robustly represent quantum information (long coherence times)
REQUIREMENTS FOR ROUTING QUANTUM INFORMATION	
D6: Interconversion	Ability to interconvert stationary and flying qubits
D7: Communication	Ability to transmit flying qubits faithfully between two locations

DiVincenzo, David (16 December 1996). "TOPICS IN QUANTUM COMPUTERS". Mesoscopic Electron Transport. arXiv:cond-mat/9612126

The reality of machinery

Qubit

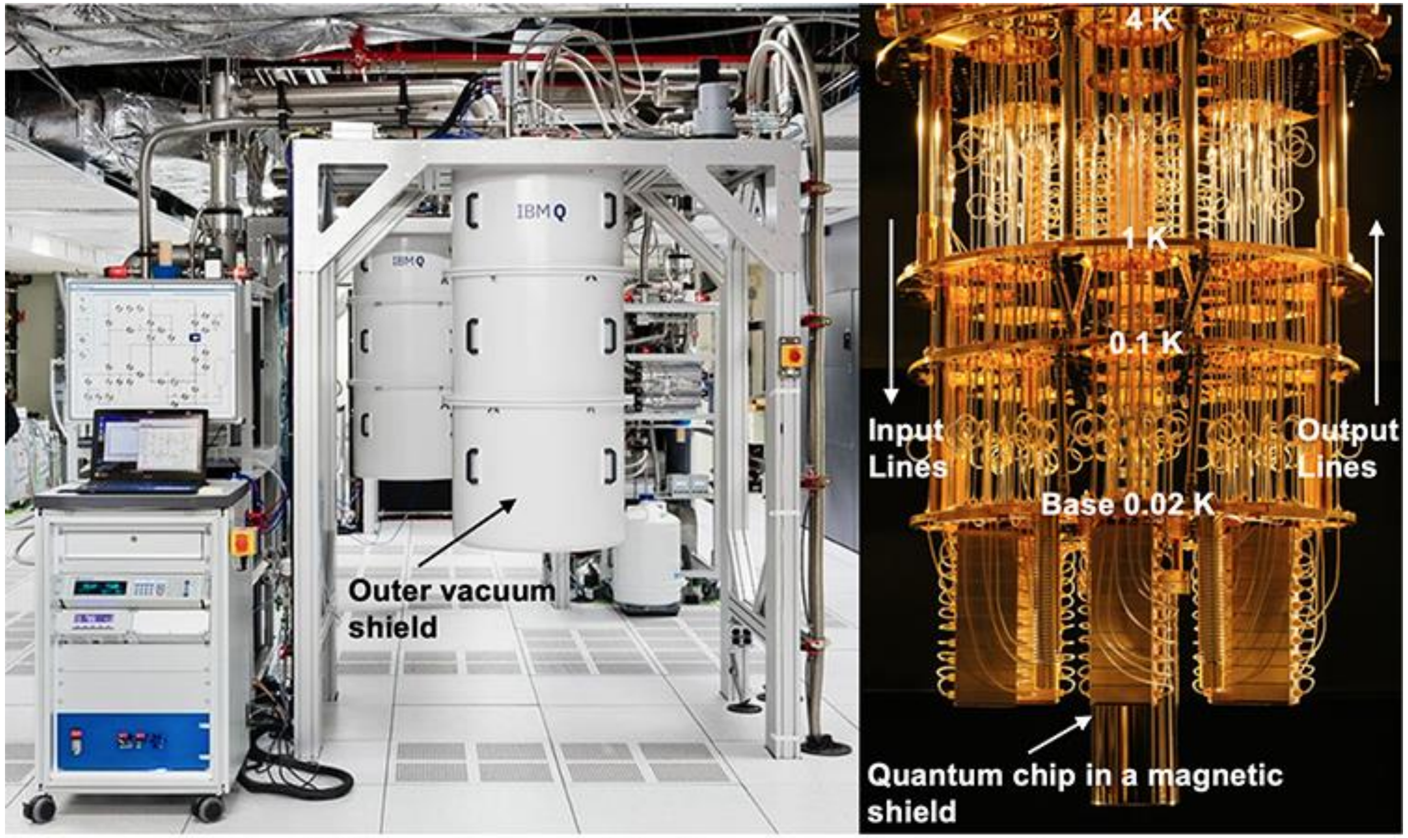
Measurement

Superposition

Extremely sensitive to small disturbances

heat,
électromagnétic radiations,
croos-talk
and so on…

problem of scaling up

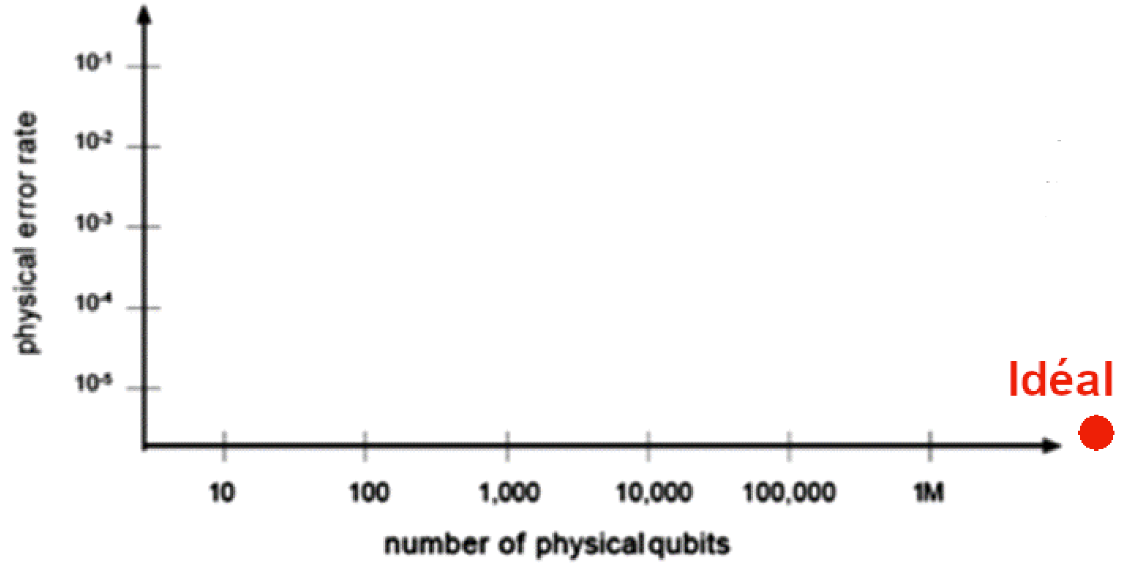


Dilution fridge setup: outside view **Dilution fridge setup:** inside view

0,02K = -273,13°C (T cosmic radiation = -272°C)

Universal quantum computer (quality, number) does not exist yet, but

fidelity

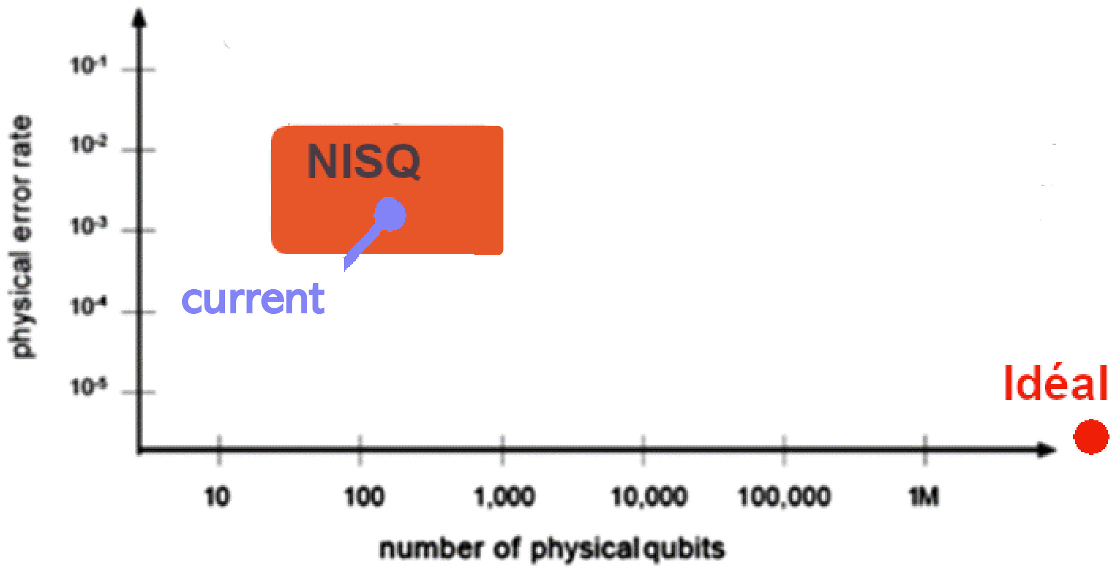


quantity

Universal quantum computer (quality, number) does not exist yet, but

Improving quality and
"dealing with" defects

NISQ
(Neay Intermediate Scale Quantum)



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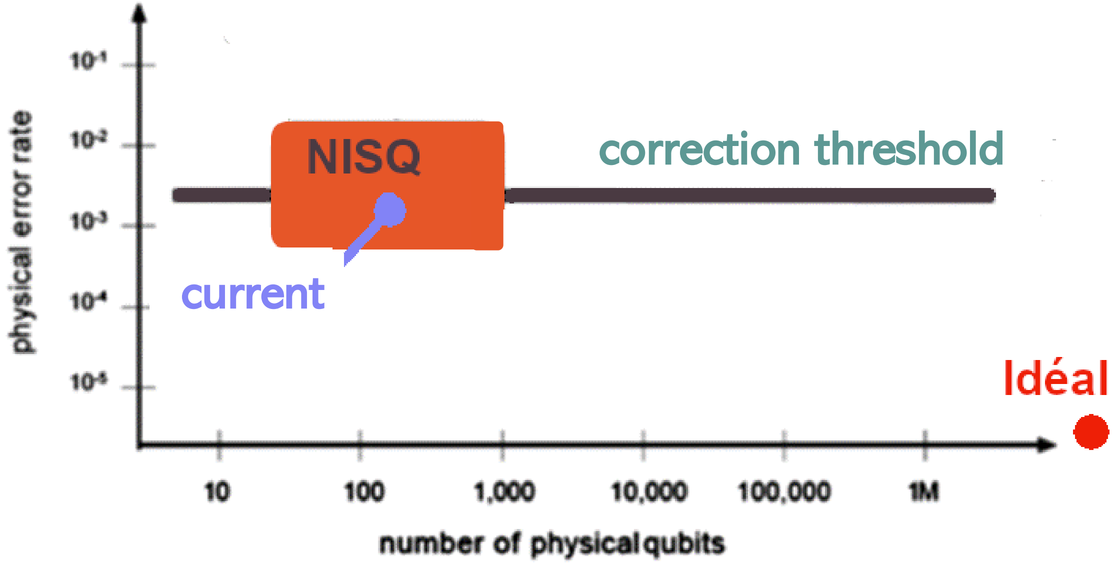

Error correction (cf classic)
Increase quality (correct errors by making the same errors…)
Threshold crossed

Universal quantum computer (quality, number) does not exist yet, but

Improving quality and
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NISQ
(Nearly Intermediate Scale Quantum)
Error correction (cf classic)
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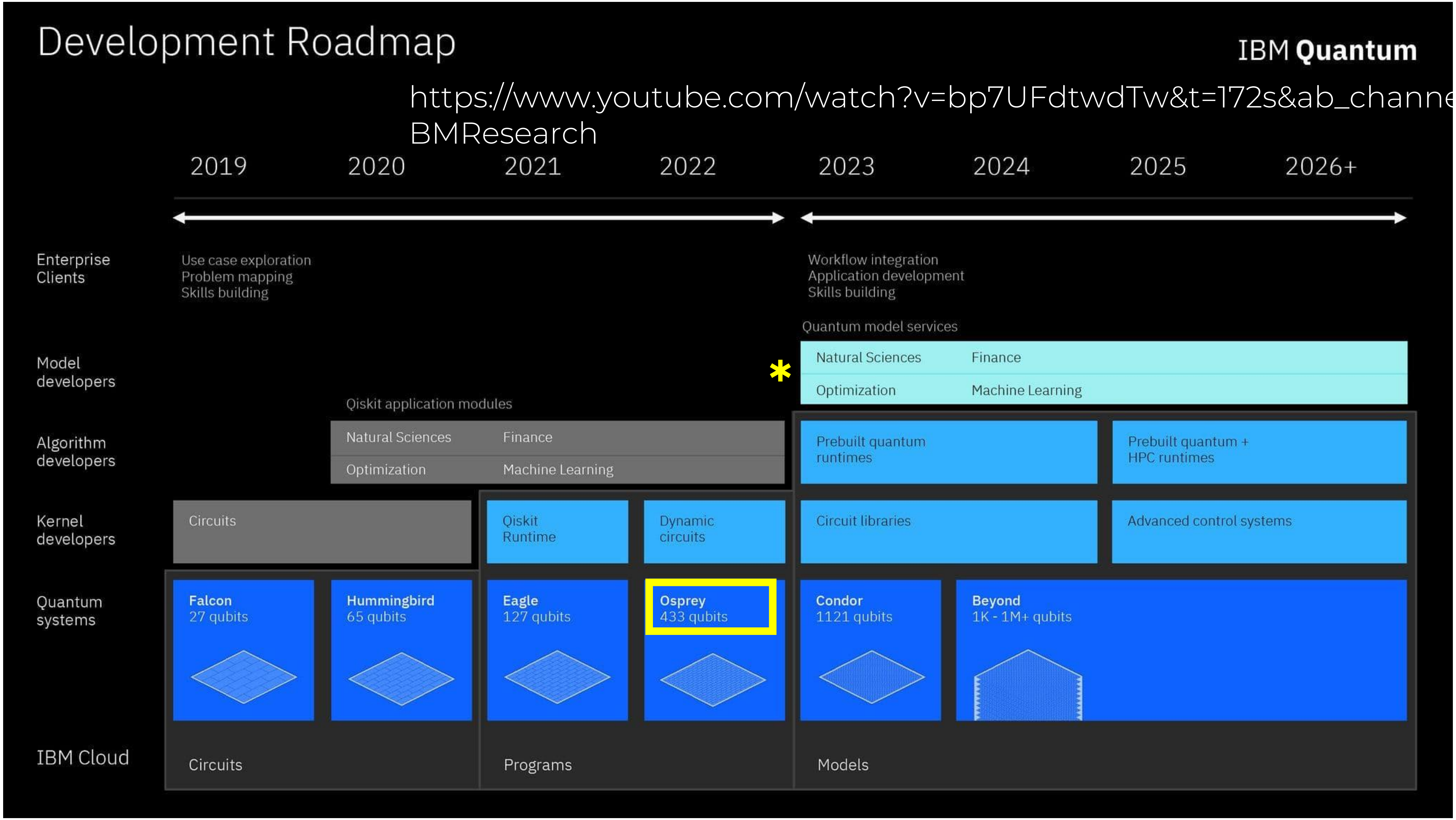
FTQC Fault Tolerant Quantum Computer



Development Roadmap
IBM Quantum
https://www.youtube.com/watch?v=bp7UFdtwdTw&t=172s&ab_channe
BMResearch
2019
2020
2021
2022
2023
2024
2025
2026+
Enterprise Clients
Use case exploration
Problem mapping
Skills building
Workflow integration
Application development
Skills building
Model developers
Quantum model services
Natural Sciences
Finance
Optimization
Machine Learning
*
Qiskit application modules
Algorithm developers
Natural Sciences
Finance
Optimization
Machine Learning
Prebuilt quantum runtimes
Prebuilt quantum + HPC runtimes
Kernel developers
Circuits
Qiskit Runtime
Dynamic circuits
Circuit libraries
Advanced control systems
Quantum systems
Falcon
27 qubits
Hummingbird
65 qubits
Eagle
127 qubits
Osprey
433 qubits
Condor
1121 qubits
Beyond
1K - 1M+ qubits
IBM Cloud
Circuits
Programs
Models

QUANTUM APPLICATIONS

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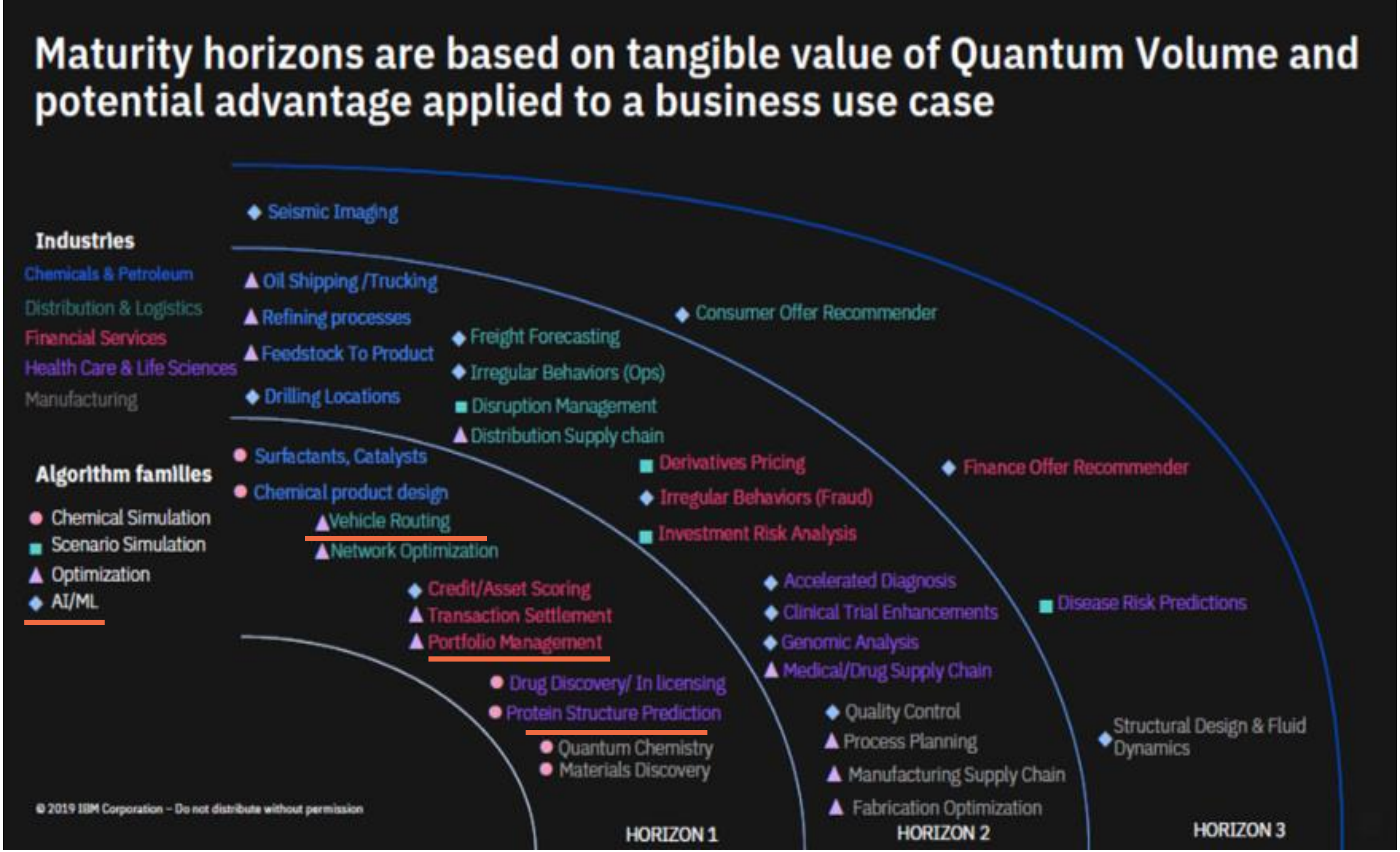

THANKS FOR YOUR ATTENTION

ANY QUESTION?

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