Quantum Computing

Trends and Directions

Introducing myself

Francisco Gálvez

BS in Experimental Physics (UV)
Master in Advanced Physics (UV)

IBM

Cloud and Integrated Systems Expert

fjgramirez@es.ibm.com
@fjgramirez
Francisco J. Galvez Ramirez

Agenda

- IBM Quantum Computer
- Basic Concepts in Quantum Computing
- Quantum Architecture
- Quantum Computing Applications
- The IBM Quantum Experience

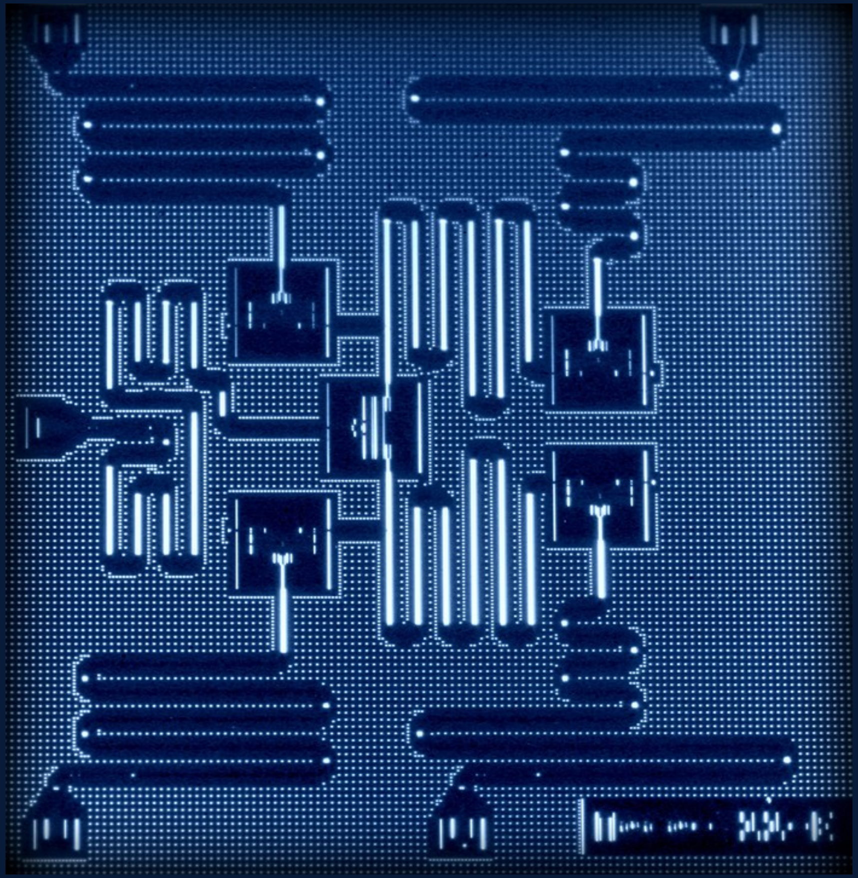
IBM Quantum Computers

March 2016

Quantum Computing in the Cloud

- IBM scientists have built a quantum processor that any user can access through the first quantum computing platform available in the cloud.

- IBM Quantum Experience, allows users to execute algorithms and experiments on a real quantum processor



March 2017

IBM announces IBM Q

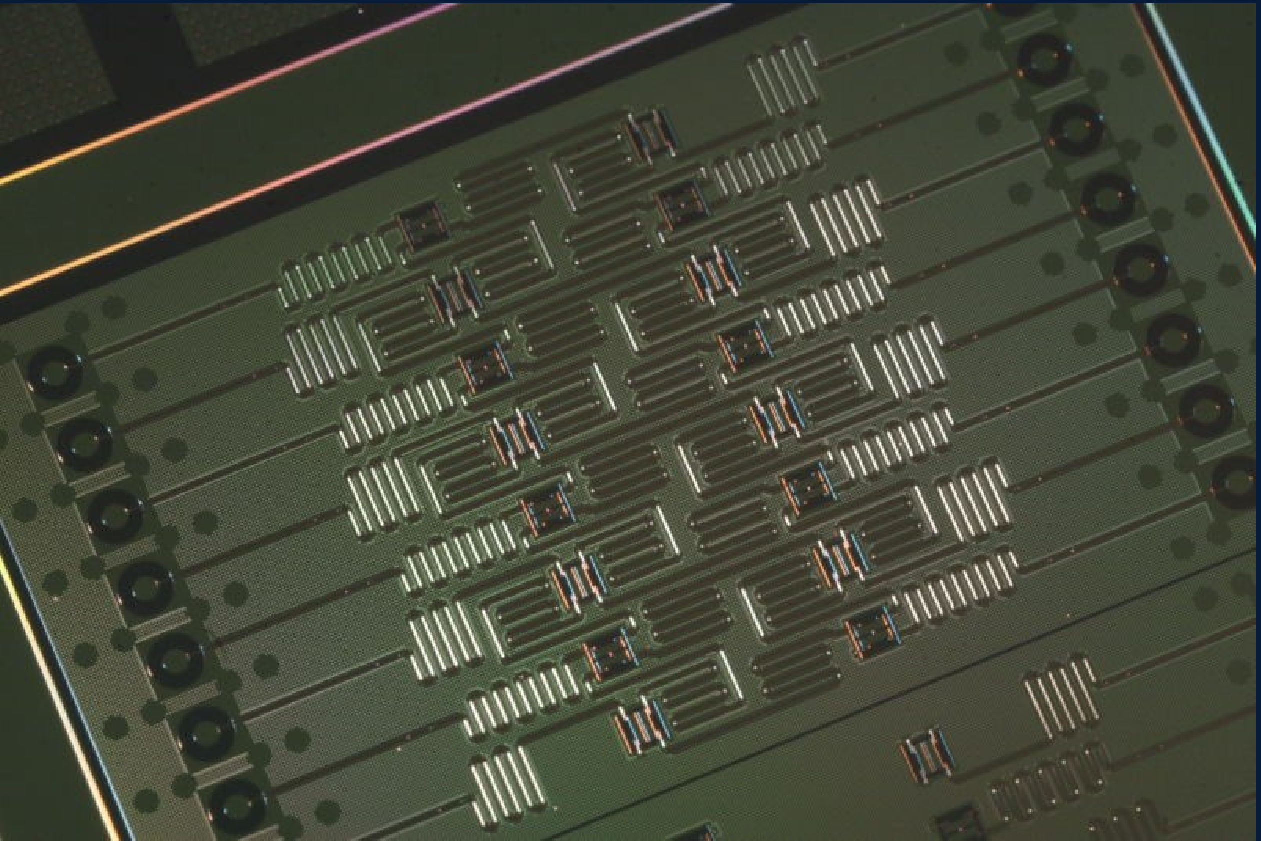
IBM Q is the new line of Quantum Computers

IBM announces the building of a quantum computer of 50 qubits and that will offer services of quantum computation in the cloud

May 2017

First Commercial Quantum Computer

16 and 17 qubits universal quantum computers



IBM says they are testing a new 17 qubits commercial quantum computing

IBM has discovered how to scale quantum architecture

In three years it is planned to reach 50 qubits

Basic Concepts in Quantum Computing

Basic Concepts in Quantum Mechanics

Uncertinty Principle

Measurement on a system means Disturbing the system

State Decoherence

Coherent states behaves like a single statesystem

State Superposition

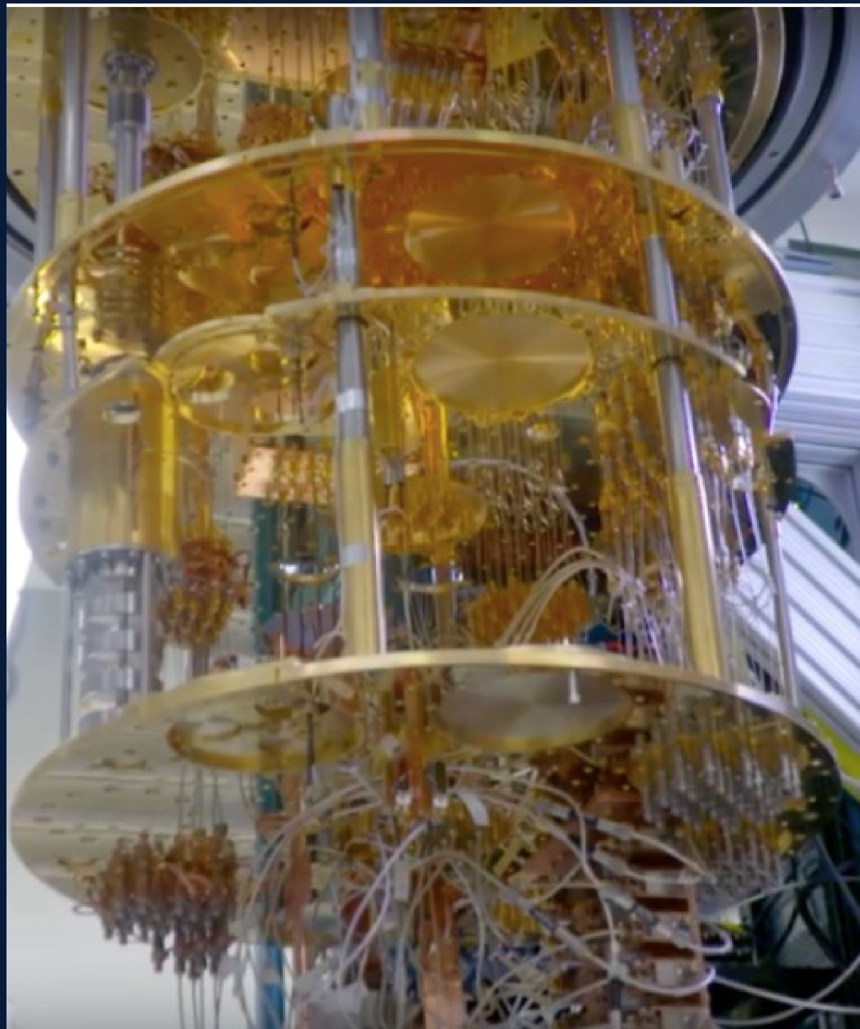
Basis states + Every posible Combination of states.

Quantum Entanglement

EPR Paradox – There's a relationship among the features of entangled particles.

Features of a Quantum Computer

1. Works with Quantum Parallelism
2. Entanglement
3. Keeps the Coherence
4. It has Quantum Bits a.k.a. Qubits



What are the Qubits ?

A qubit is the quantum concept of a bit.

- It’s not any element or device. It’s a logical concept that can be implemented on a wide range of different systems with quantum behaviour

- As a bit, a single qubit can represent two states 0 and 1

But additional a qubit is able to manage all possible combinations amont base states 0 and 1

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$$

Quantum Operations

Quantum Gates

- A basic quantum circuit working on one or more qubits
- It’s equivalent to digital circuits logical gates lógicas

$$H = \frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$$

Hadamard Gate

1. Quantum Gates are reversible
2. Mathematically thery are represented by unitary matrixes
3. Los qubits on which they act must retain their quantum identity

$$CNOT = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

Controlled-NOT gate

Universal Quantum Computing

- Universal Quantum Computing requires entanglement for every qubit included in the system

- **Use Cases** → Secure Computing, Machine Learning, Criptography, Quantum Chemistry, Material Science, Optimization Problems, Sampling Quantum Dynamics, Searching.
- **Scope** → Wider scope
- **Computing Power** → Very High

The Universal Computing is the great challenge in quantum computing. It has the potential to be exponentially faster than traditional computers for a number of applications in the world of science and also in the world of business.

Adiabatic Quantum Computing

- Adiabatic Quantum Computation is based on the Adiabatic Theorem and requires at least a big set of qubist (but not all) to be entangled during process time.

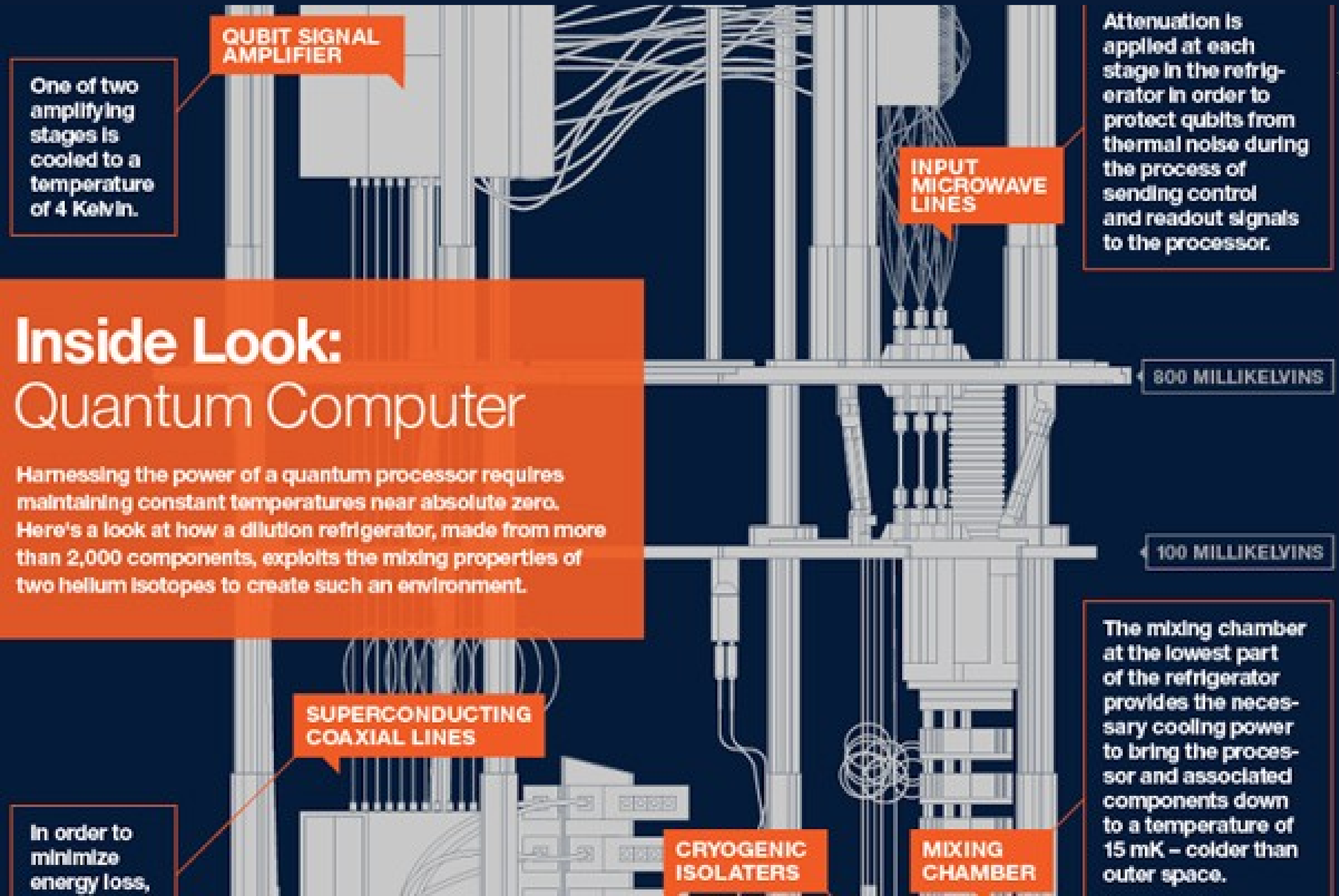
- A very specific algorithm is implemented: “The Quantum Annealer”

- **Use Cases →** Optimization Problems
- **Scope →** Restricted
- **Computing Power →** Similar to current classical computers

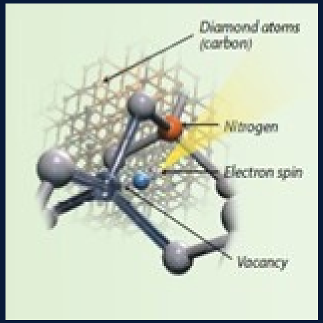
Quantum Architecture

Inside Look:
Quantum Computer

Harnessing the power of a quantum processor requires maintaining constant temperatures near absolute zero. Here's a look at how a dilution refrigerator, made from more than 2,000 components, exploits the mixing properties of two helium isotopes to create such an environment.

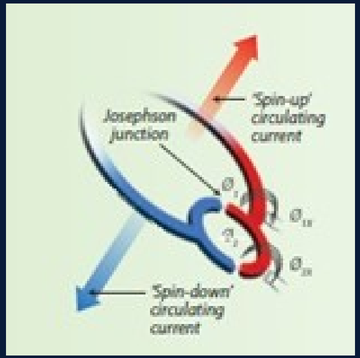


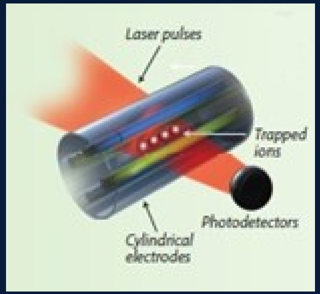
Types of Quantum Processors



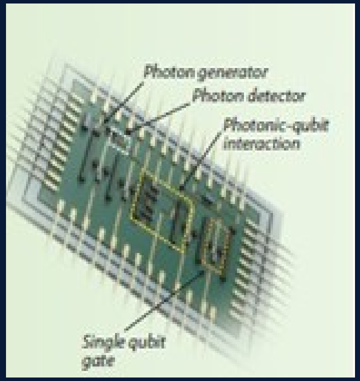
Spin Qubits – Electron or nuclear spins on a solid Substract.

Superconducting Circuits – currents superposition around a superconductor.





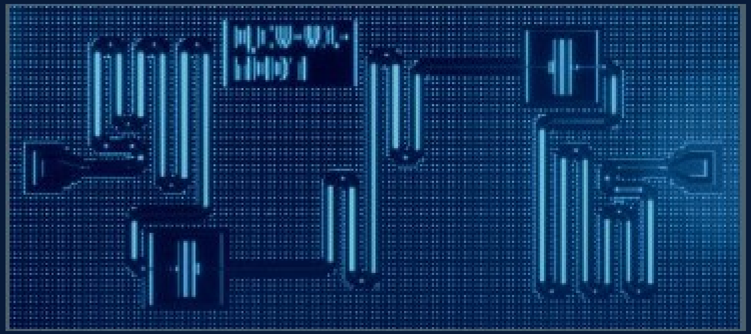
Ion's Traps– Trap ions in electric fields

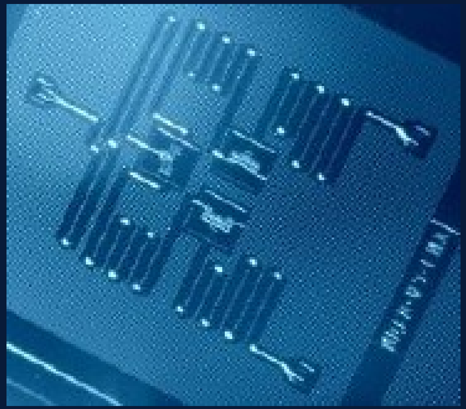


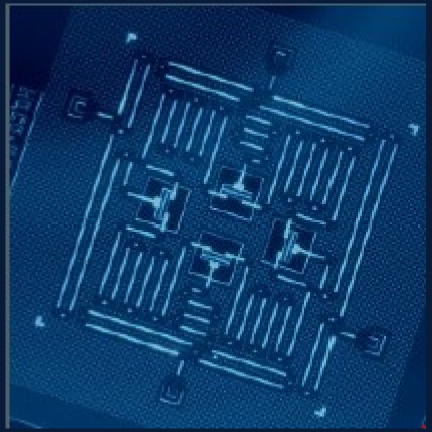
Photonic Circuits – The qubits are photons driven in in silicon circuits.

Superconducting Qubits

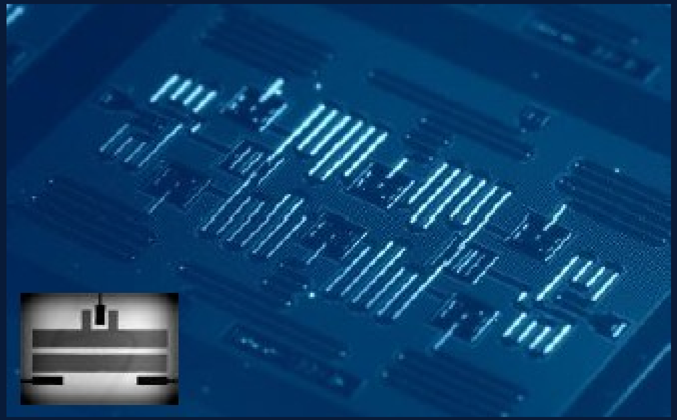
Circuit QED: A superconducting qubit is strongly interacted with a single photon in a microwave cavity.



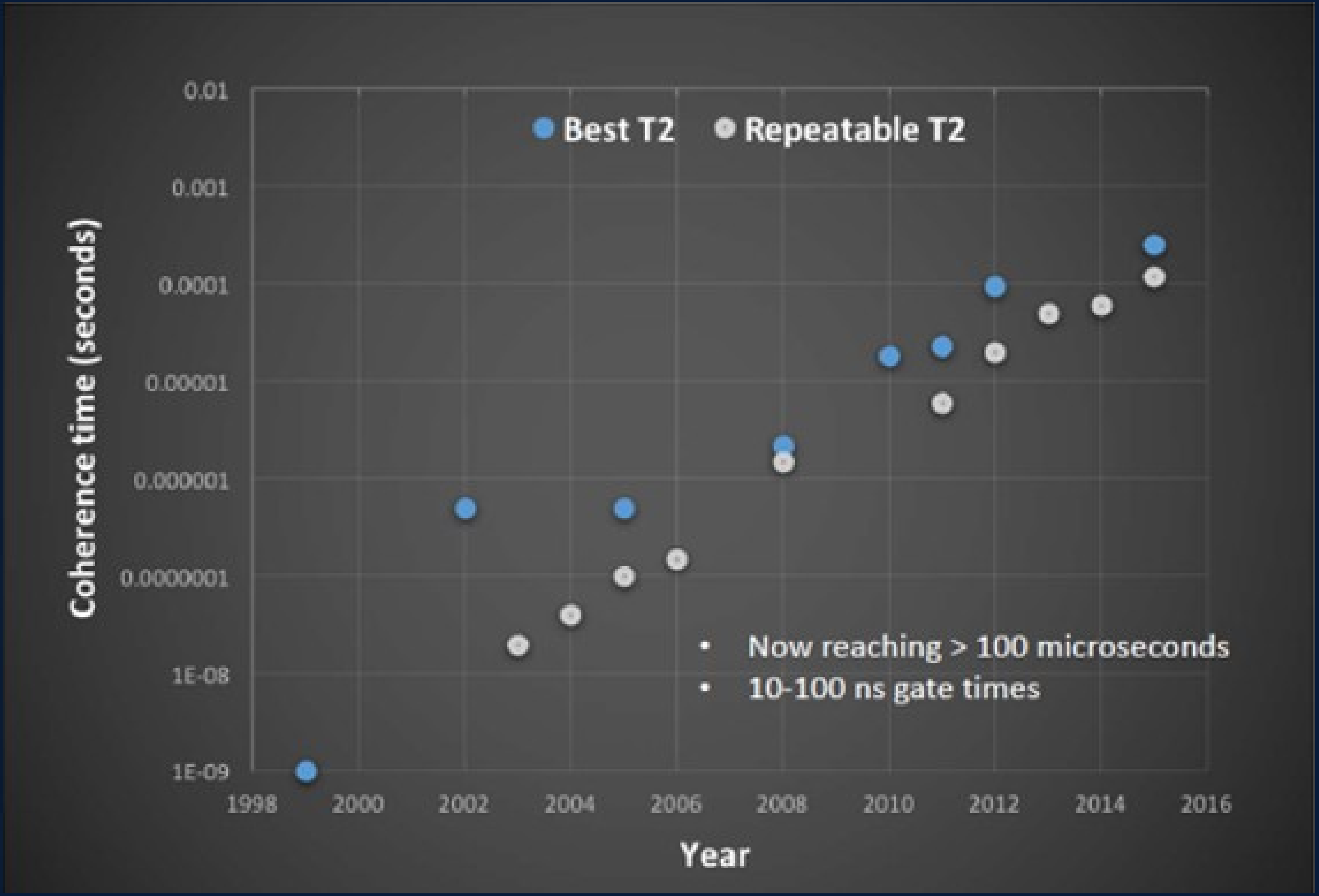




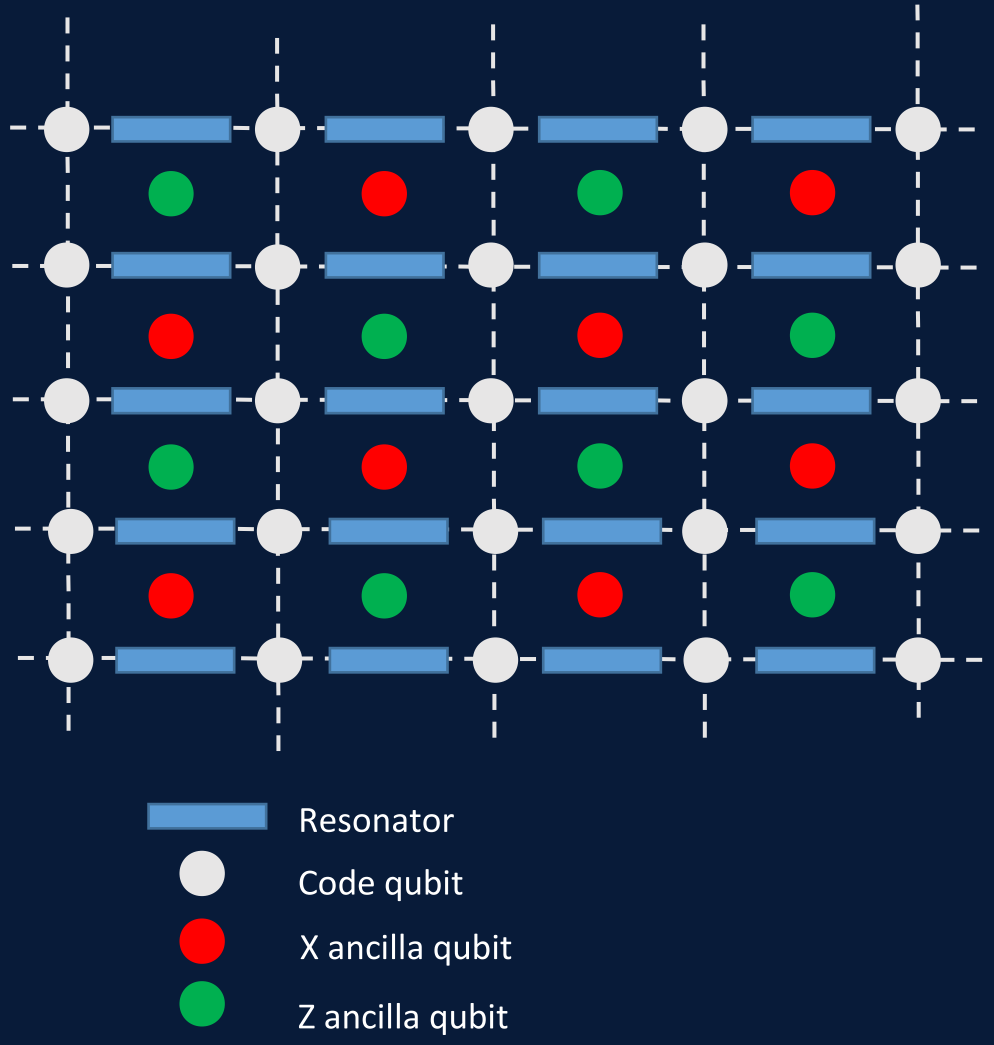
The circuit QED coupling scheme has become the standard for coupling and reading superconducting qubits as systems continue to scale.

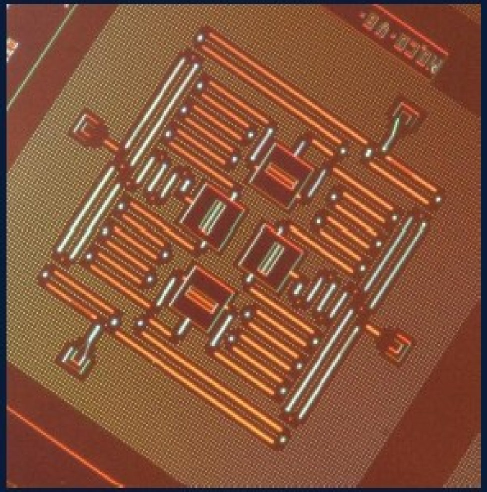


Coherence Time in Superconducting Qubits

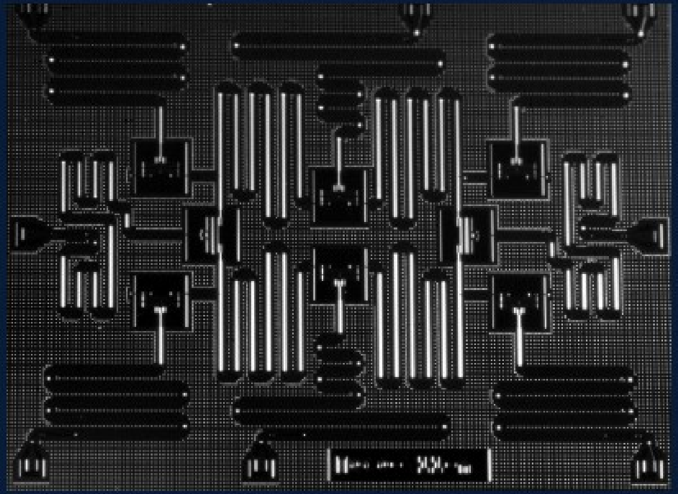


IBM Superconducting Qubits Architecture

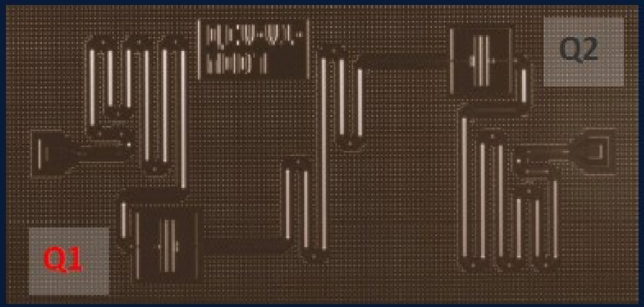




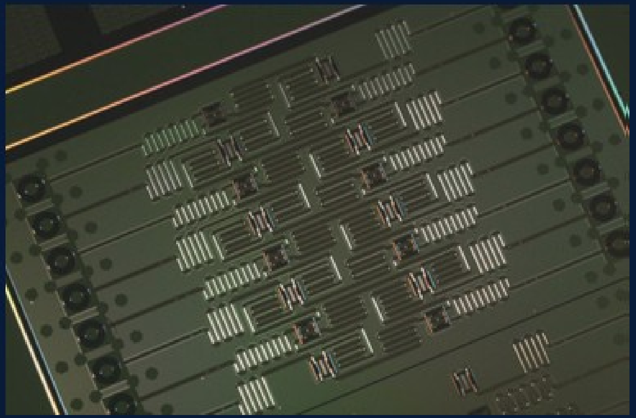
4 qubits/4 bus/4 readouts



8 qubits/4 bus/8 readouts



2 qubits/1 bus/2 readouts

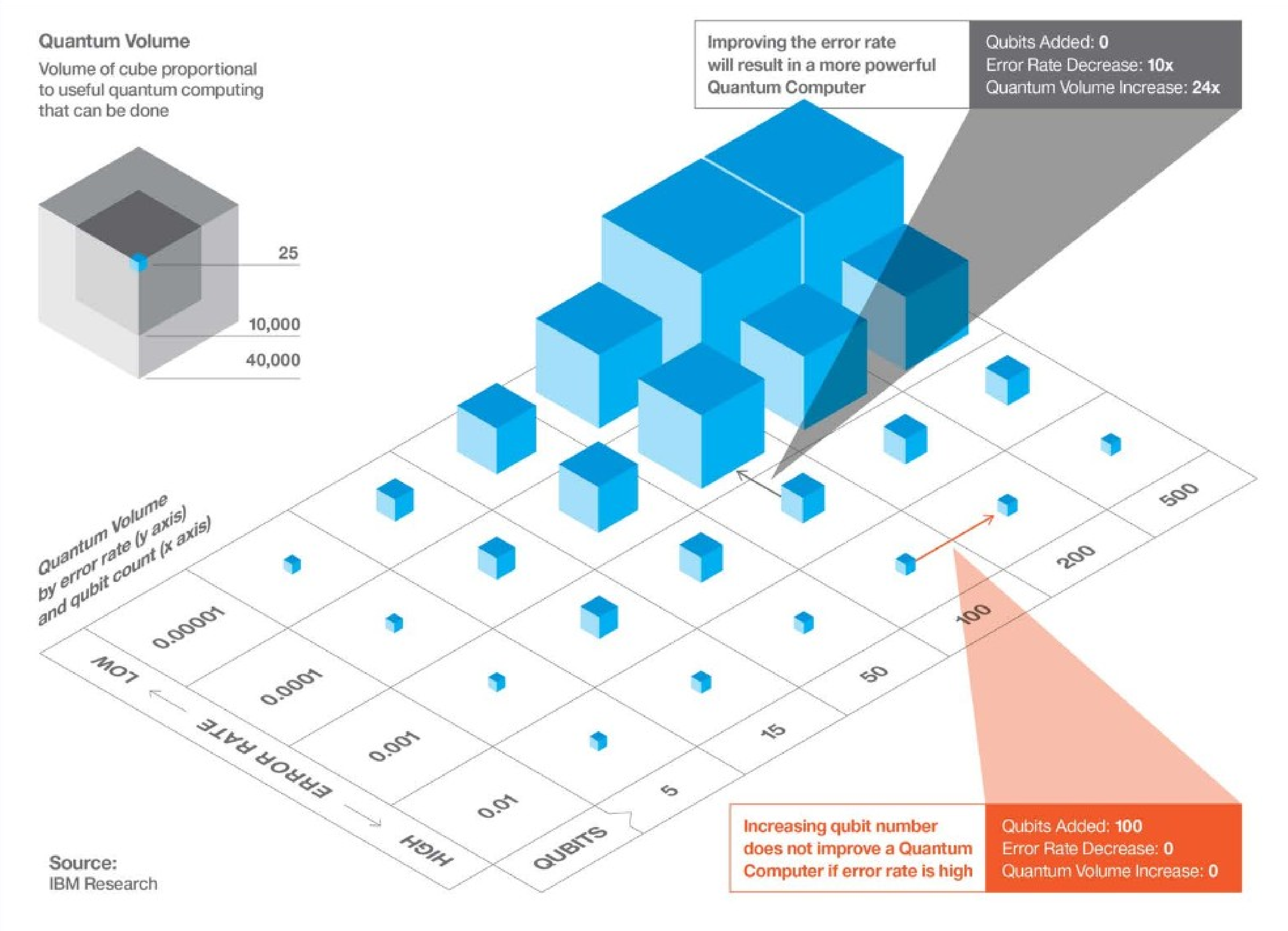


IBM's new 17-qubit quantum computer

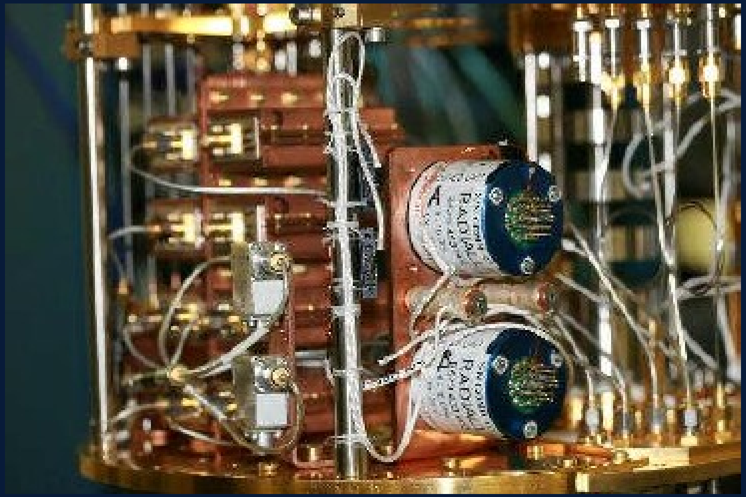
The Quantum Volume

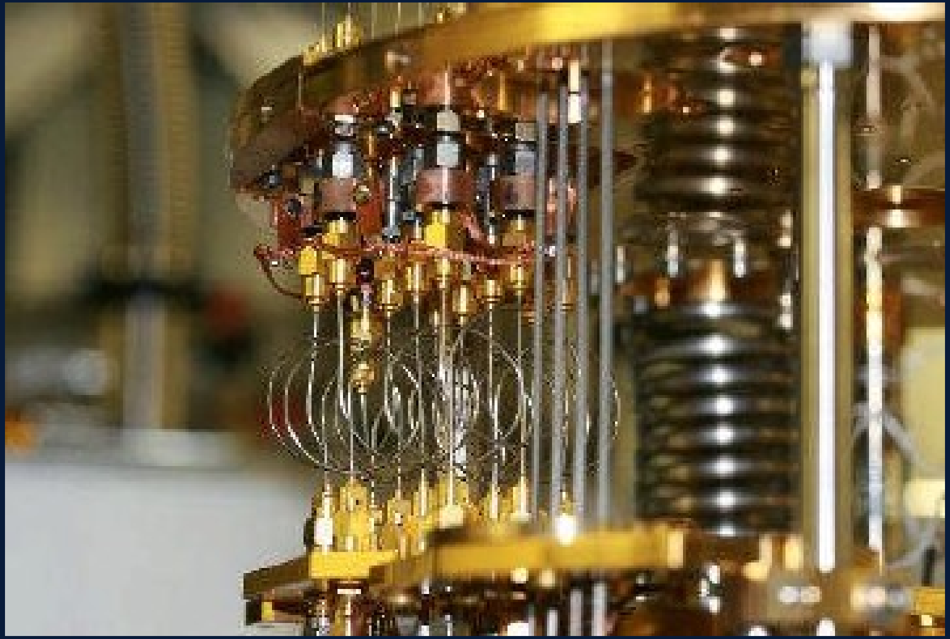
A Quantum Computer's power depends on more than just adding qubits

If we want to use quantum computers to solve real problems, they will need to explore a large space of quantum states. The number of qubits is important, but so is the error rate. In practical devices, the effective error rate depends on the accuracy of each operation, but also on how many operations it takes to solve a particular problem as well as how the processor performs these operations. Here we introduce a quantity called **Quantum Volume** which accounts for all of these things. Think of it as a representation of the problem space these machines can explore.



The Dilution Refrigerator



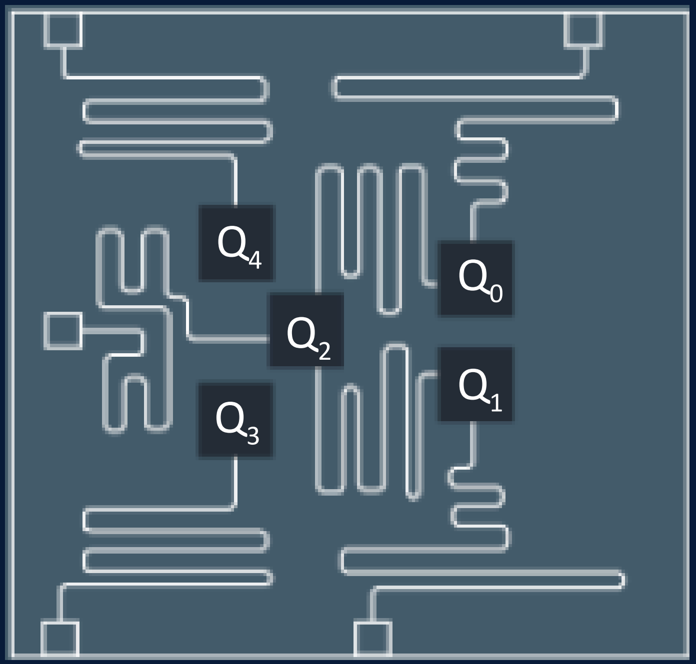


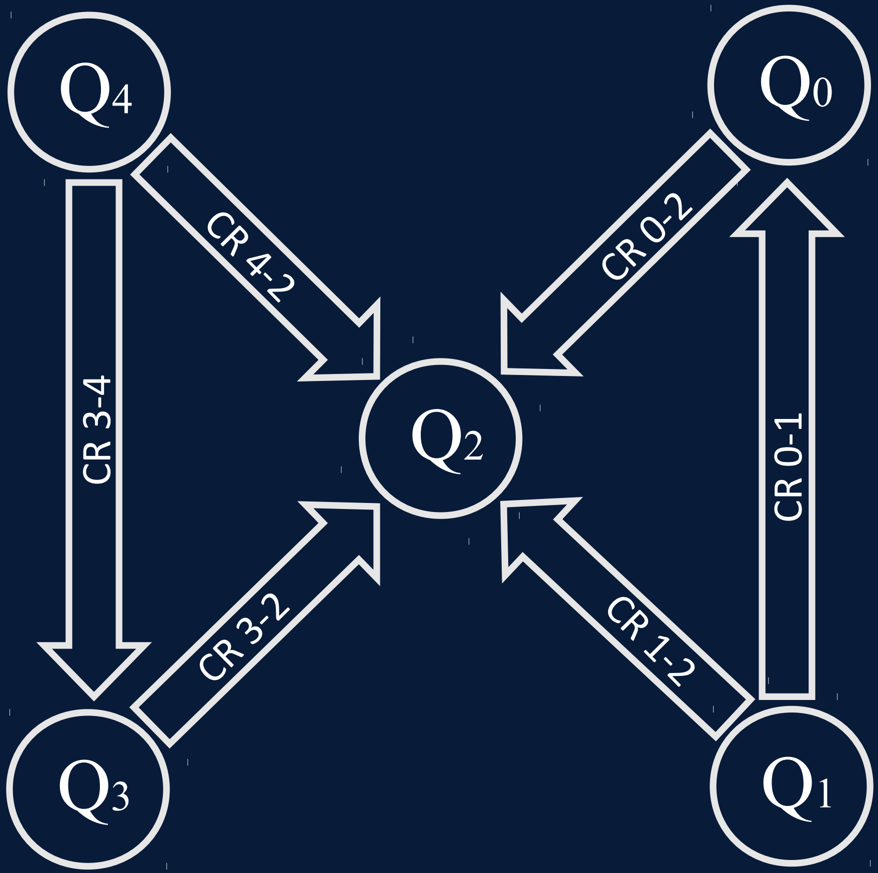
Working Temperature 15 mK

Dilution Refrigerator

$^3He + {}^4He$

IBM Quantum Processor Architecture





- qubits 0, 1, 3 and 4 are coupled to qubit 2.
- Two qubit gates need to involve qubit 2
- Qubit 2 is the target qubit in CNOT gate

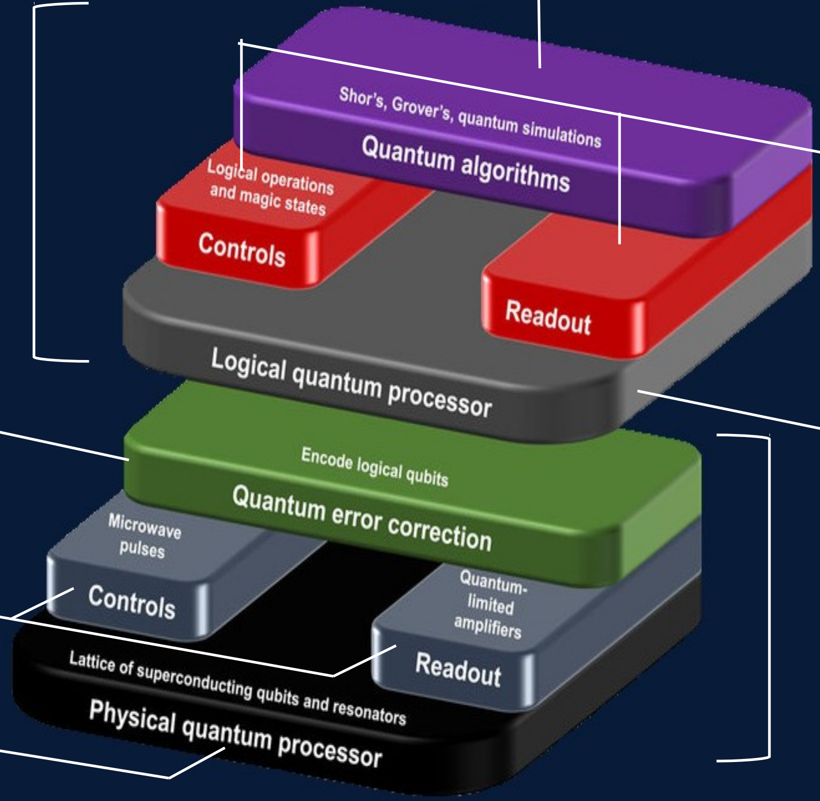
IBM Quantum Processor Architecture

Layered architecture

Logical Layer

Algortihms
Execution

Logical
Input/Output



Error Correction

Logical Qubits

Input/Output
FGPAs

Phisical Layer

Physical qubits

Quantum Algorithms

Quantum Algorithms

- **Deusch Algorithm** – Determines whether a funcion is balanced or unbalanced
- **Shor Algorithm** – Large numbers factorization
- **Grover Algoritm** – Search in unstructured spaces

Shor Algorithm

- Number of steps that a classic computer needs to run in order to find the prime factors of a number N of x digits

It grows exponencially with x

937 x 947 = N (easy)

887339 = p x q (hard)

hardness of factoring is basis of RSA public key crypto:

In 2001, IBM and Stanford University, executed for the first time the Shor algorithm in the first quantum computer of 7 qubits developed in Los Álamos.

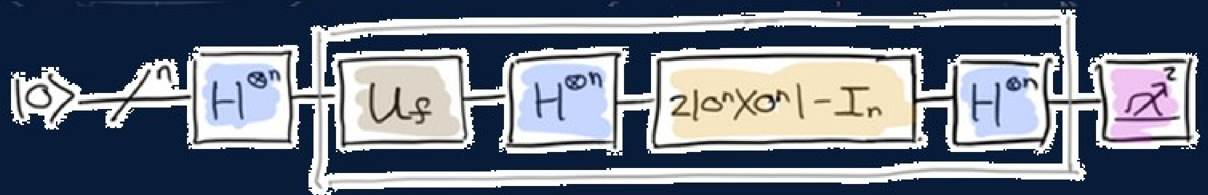
https://www-03.ibm.com/press/us/en/pressrelease/965.wss

Grover Algorithm

How many attempts need a data search in an unordered N-element database to locate a particular element??

An average of N/2 attemps are needed)

A quantum computing executing the Grover algorithm would run $\sqrt{N}$ attemps



http://www.dma.eui.upm.es/MatDis/Seminario4/AlgoritmoGrover.pdf

Applications for Quantum Computers

Fields of Application

Cryptography

- Quantum computers have the potential to keep private data safe from snoops and hackers, no matter where it is stored or processed.

Medicine & Materials

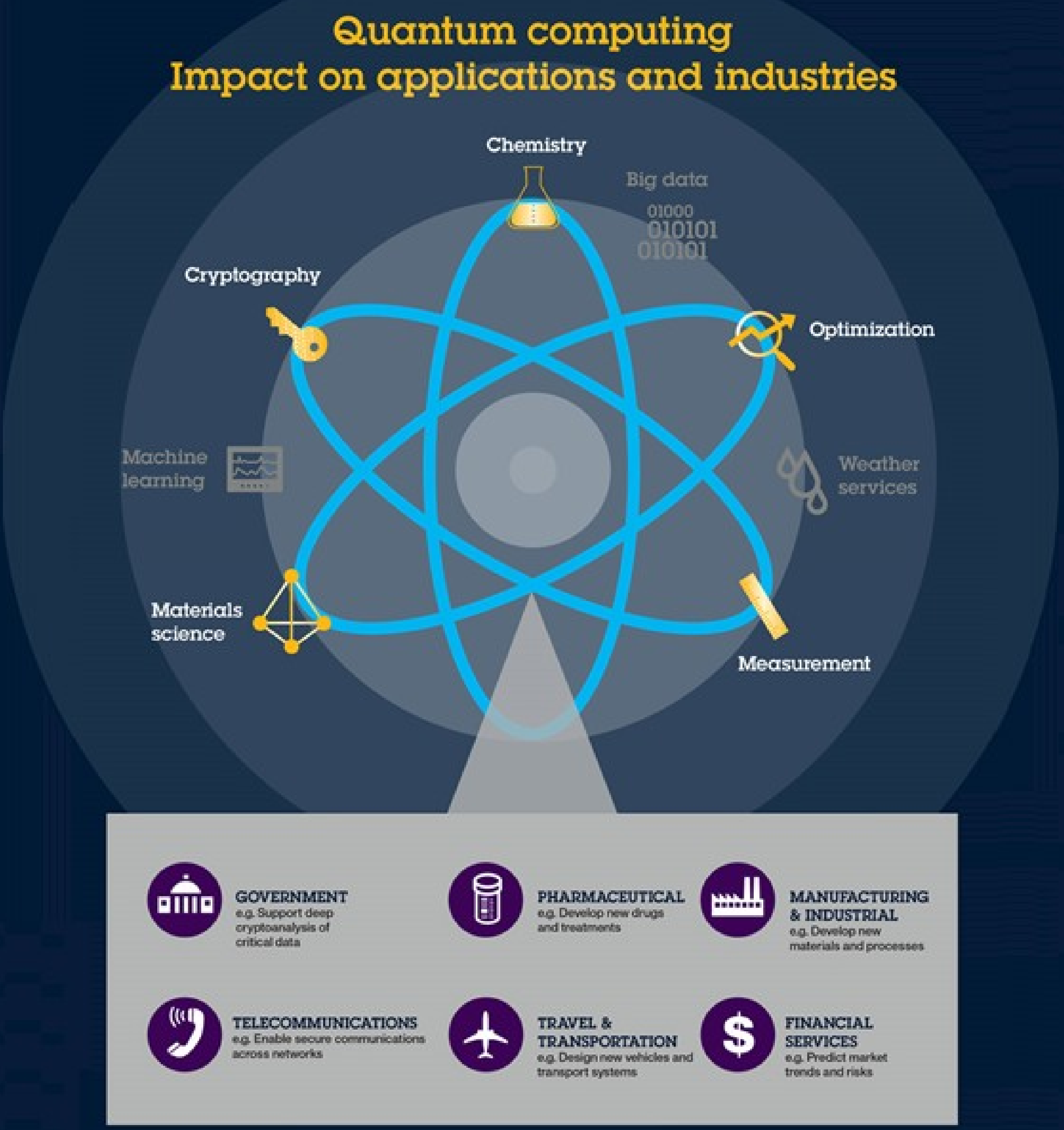
- A quantum computer mimics the computing style of nature, allowing it to simulate, understand and improve upon natural things—like molecules, and their interactions.

Machine Learning

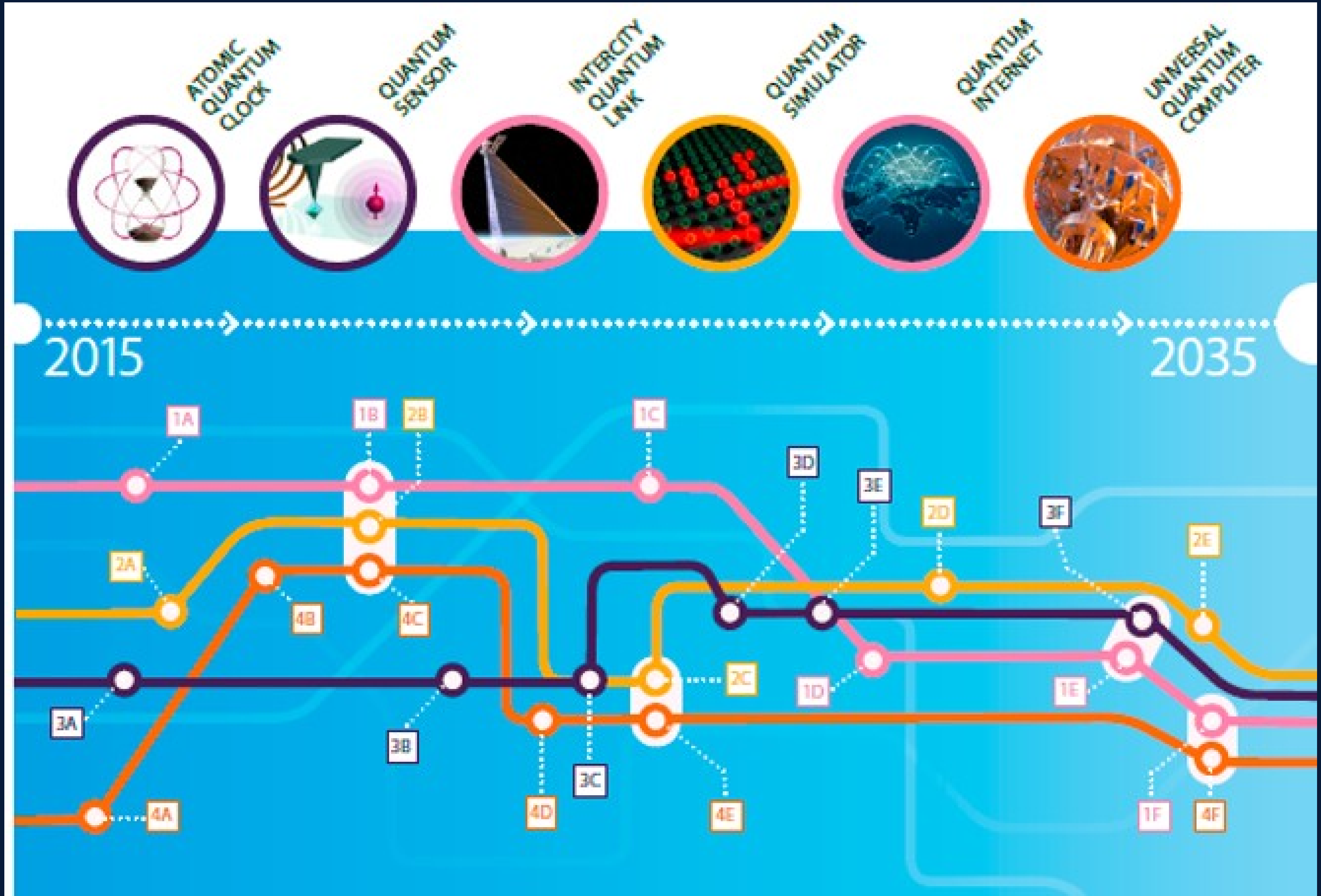
- Research indicates that quantum computing could significantly accelerate machine learning and data analysis tasks.

Searching Big Data

- Quantum computing can search the ever-growing amount of data being created, and locate connections within it, significantly faster than classical computers, that will have tremendous impact across many industries.


Quantum computing
Impact on applications and industries
Chemistry
Big data
01000
010101
010101
Cryptography
Optimization
Machine learning
Weather services
Materials science
Measurement
GOVERNMENT
e.g. Support deep cryptoanalysis of critical data
PHARMACEUTICAL
e.g. Develop new drugs and treatments
MANUFACTURING & INDUSTRIAL
e.g. Develop new materials and processes
TELECOMMUNICATIONS
e.g. Enable secure communications across networks
TRAVEL & TRANSPORTATION
e.g. Design new vehicles and transport systems
FINANCIAL SERVICES
e.g. Predict market trends and risks

Quantum Technologies Timeline

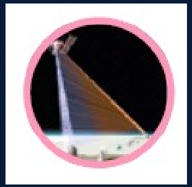


Quantum Technology

- Atomic Quantum Clocks

- Quantum Sensors

- Intercity Quantum Link



- Quantum Simulators

- Quantum-Safe Communication Network

- Universal Quantum Computers

IBM Quantum Experience

What is IBM Quantum Experience?

- A set of tutorials which is guide to understand all the quantum experiments.
- The ***quantum Composer,*** is a graphical interface where a quantum circuit can be designed.
- **A simulator** used to execute the quantum circuits designed in the composer.
- **Access to a real Quantum Processor** which is physcally located and working at Quantum Computing IBM Lab
- Under construction: **A Quantum Community**

The Quantum Operations Library

Id

Yellow Blocks. Are empty operation on a qubit for a unit of time which equals the duration of a gate for one qubit.

X

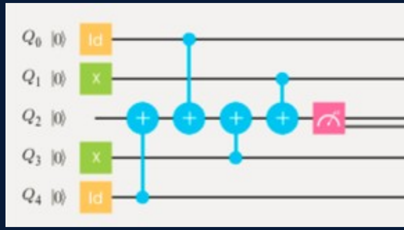
Green Blocks. These are the Operators the the Pauli Group (X, Y, Z).

H

Blue Blocks. *Clifford Operators*. These gates are H, S and S†
and they are used to generate quantum superposition

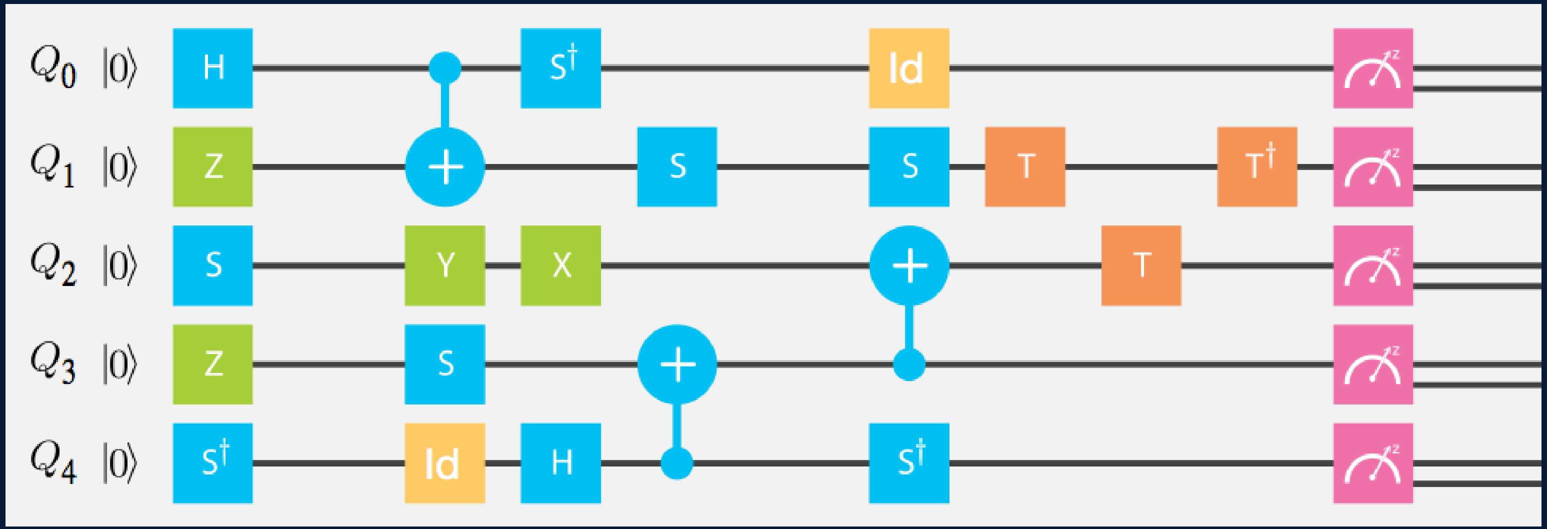
T

Orange Blocks. These are the gates necessary for universal computation (Non-Cliford gates).



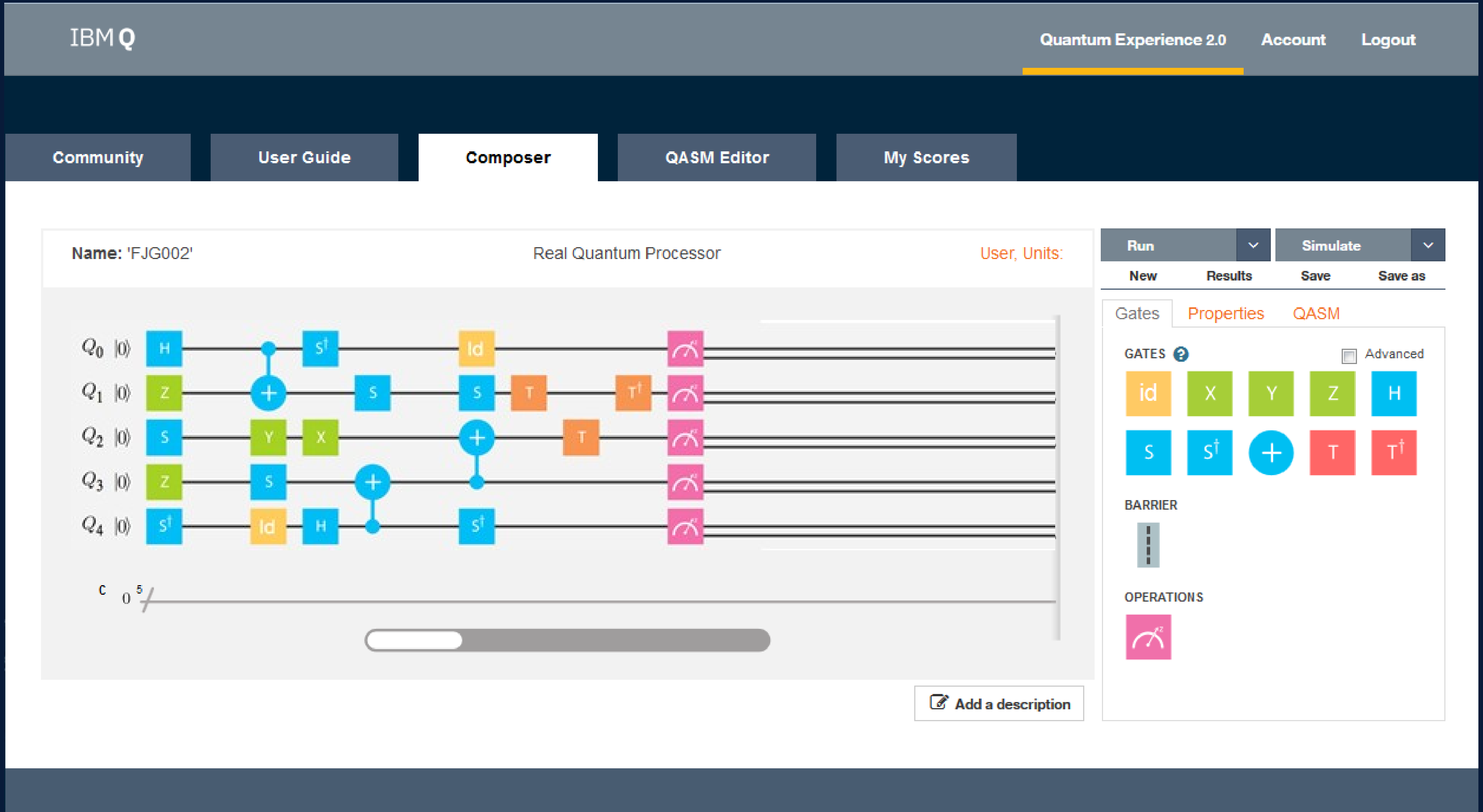
The Quantum Composer

- Graphical Interface used to create programs for the quantum processor
- It allows to create quantum circuits using a logical gates library and well defined points of measurement

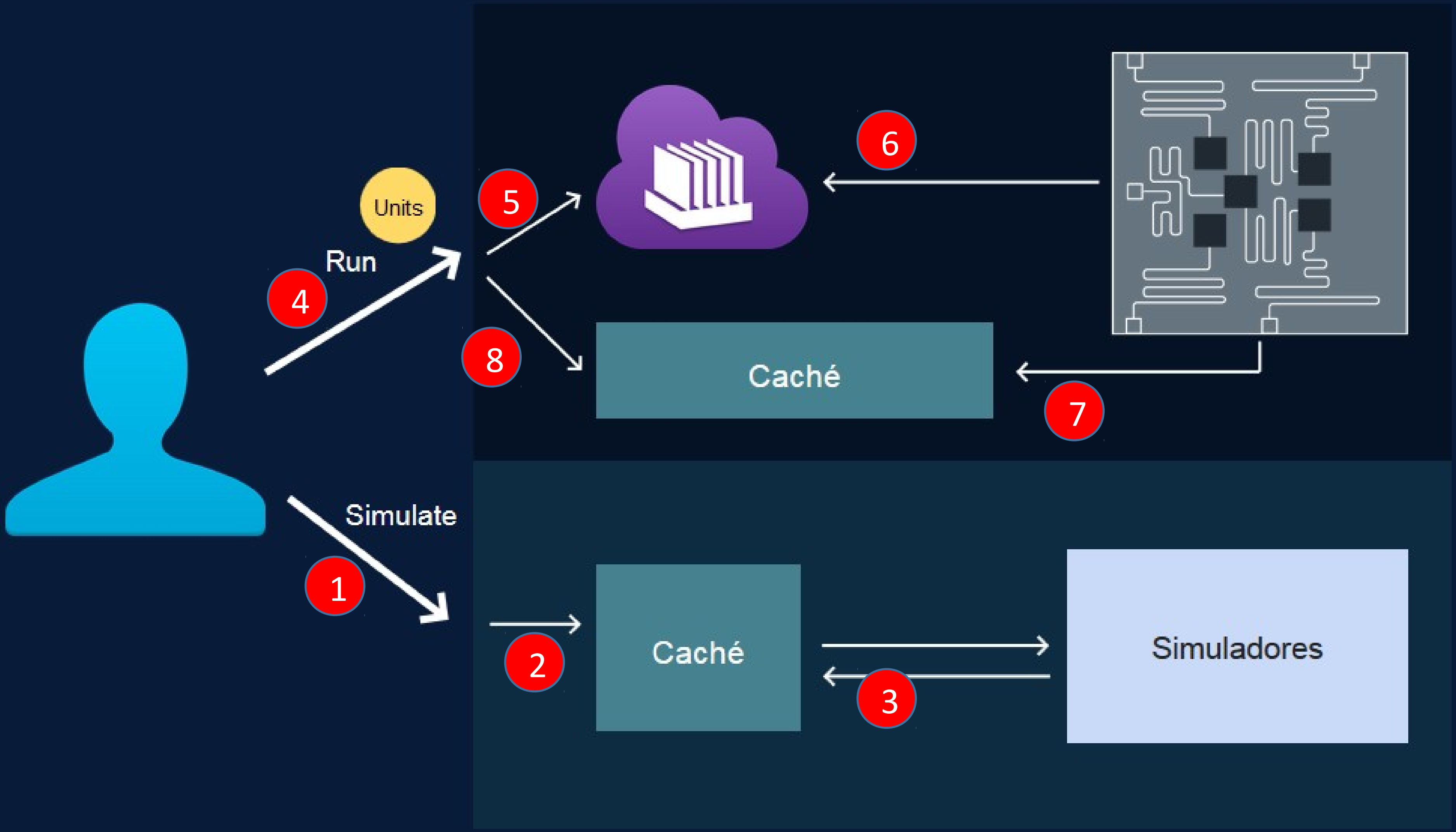


Working with the Composer

Graphical interface to build quantum circuits by simply drag and drop.

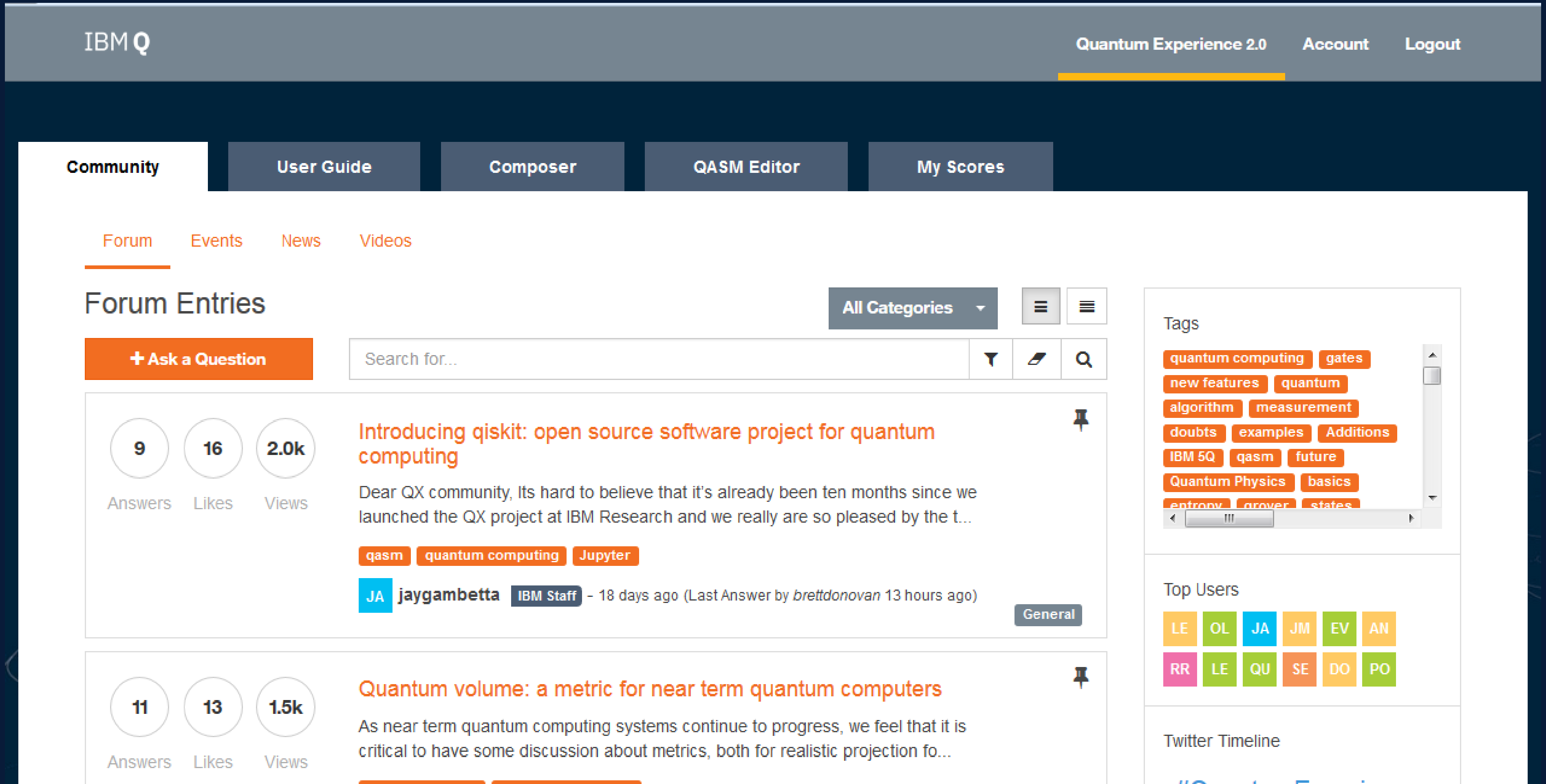


The Quantum Experience, How it works?



The Quantum Experience Blog

A blog which goal is to build a **Quantum Community** of users



Thank You