Quantum Computing in Finance

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European Investment Bank

European Investment Bank (EIB)

European Investment Bank (EIB)

"The EU bank“

Its mission is to fund infrastructure projects in Europe

Located in Luxembourg

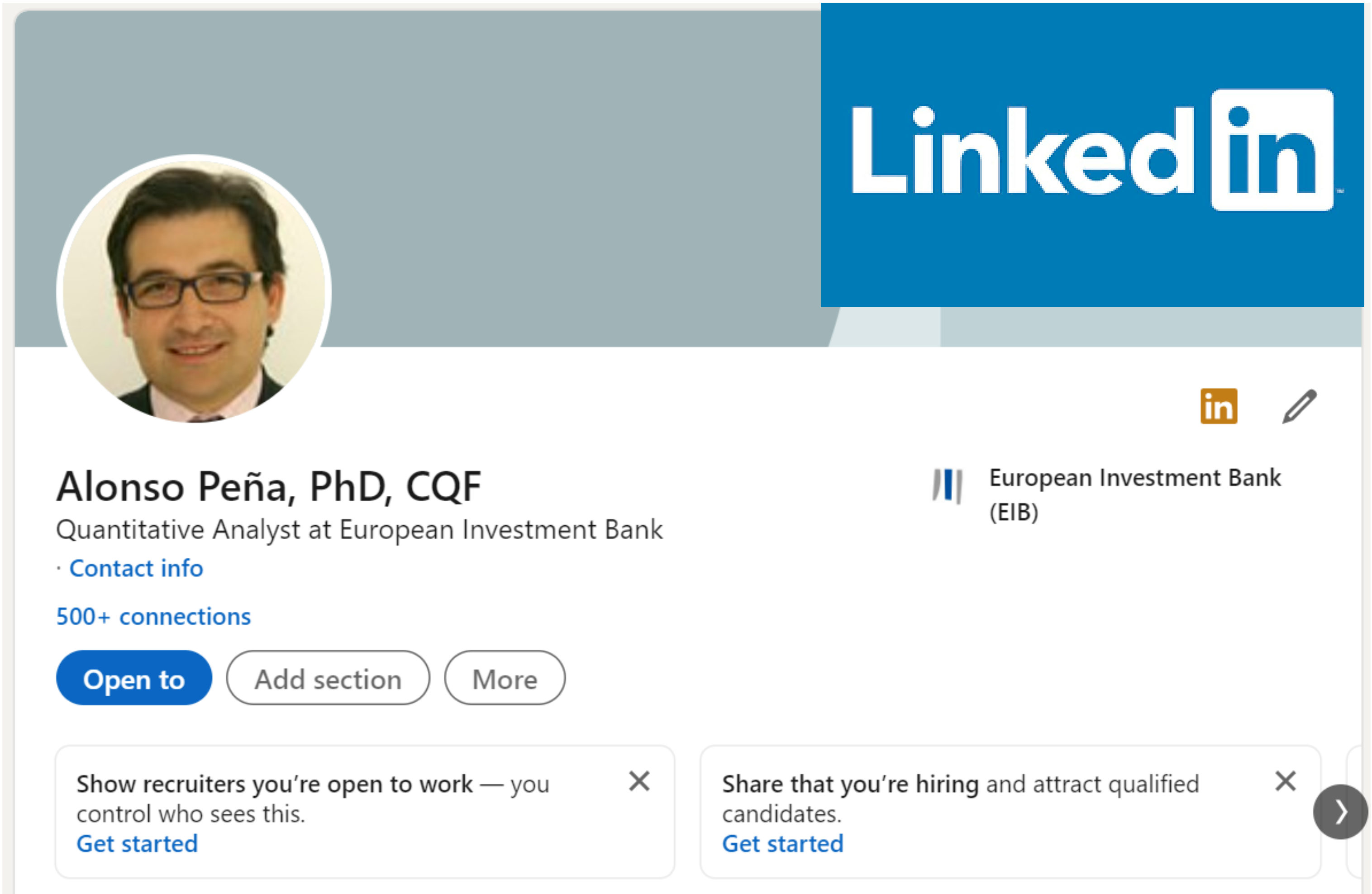
Shareholders are the EU member states

Established in 1958 under the Treaty of Rome

The world's largest international public lending institution

Disclaimer

I confirm that I act in a private capacity and not as a representative of the EIB and that the opinions expressed are personal and may not necessarily reflect the EIB position.

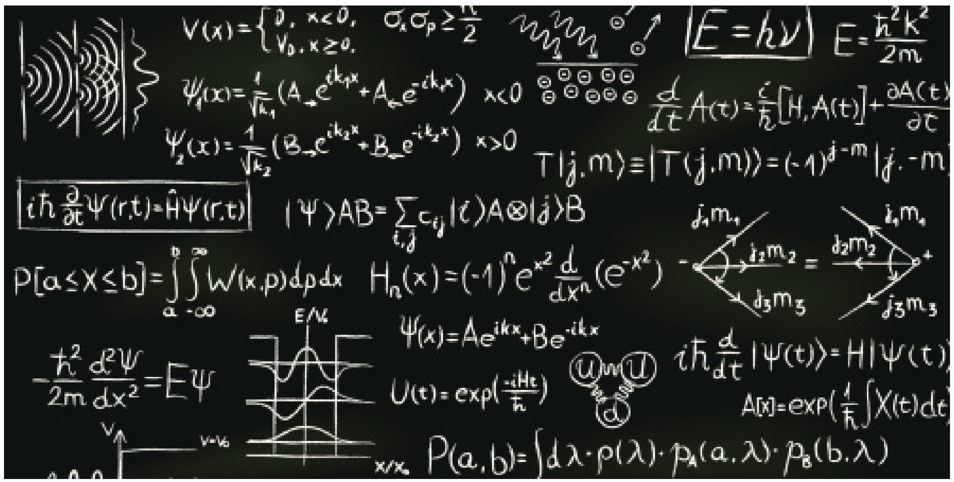


https://www.linkedin.com/in/alonso-pe%C3%B1a-phd-cqf-80bb97a/

Quantum Computing

Quantum

Computing



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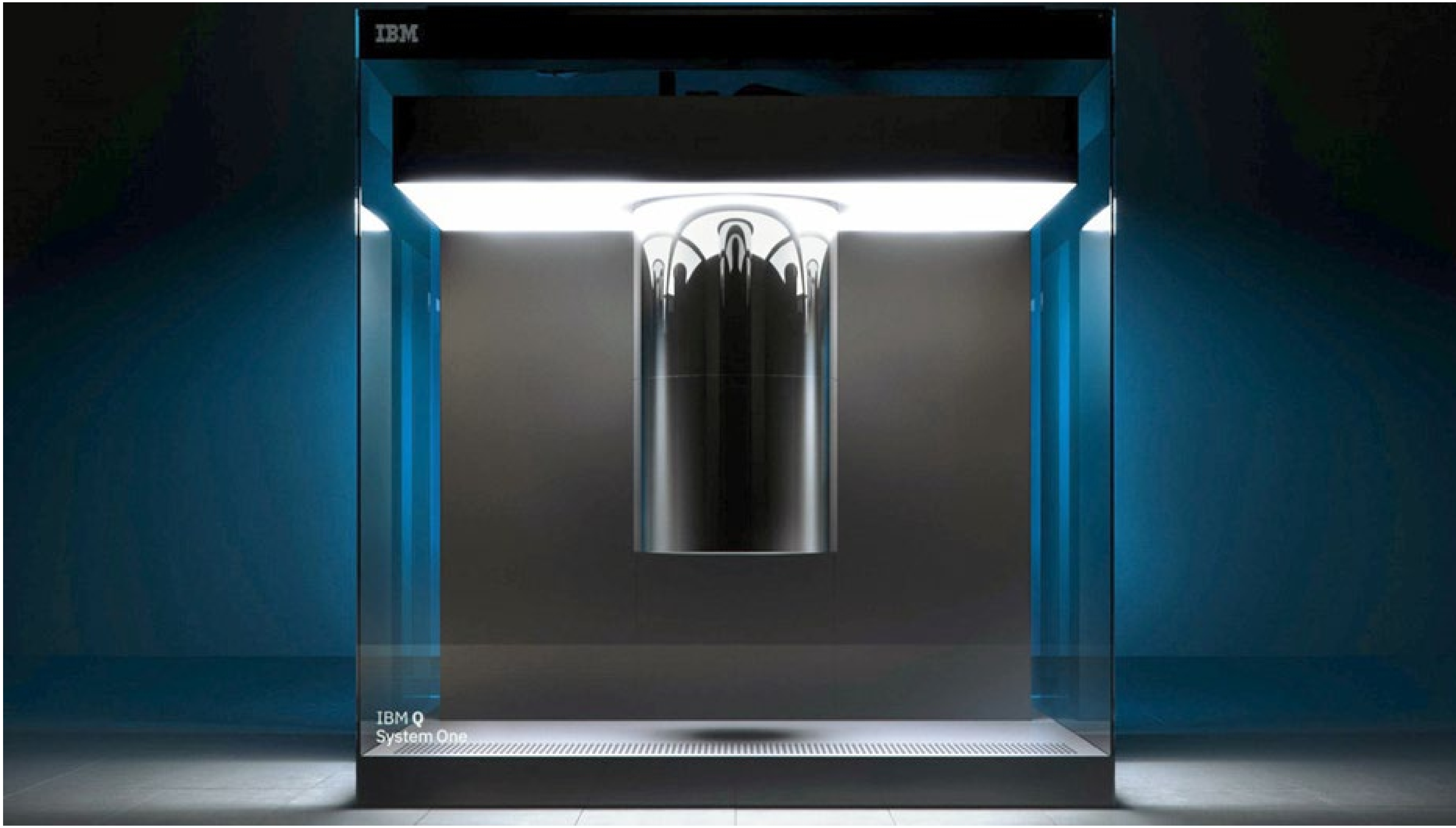


IBM System One: the first commercial quantum computer, 2019

Lecture:

A Crash Introduction
to Quamtum Computing

In this lecture we will:

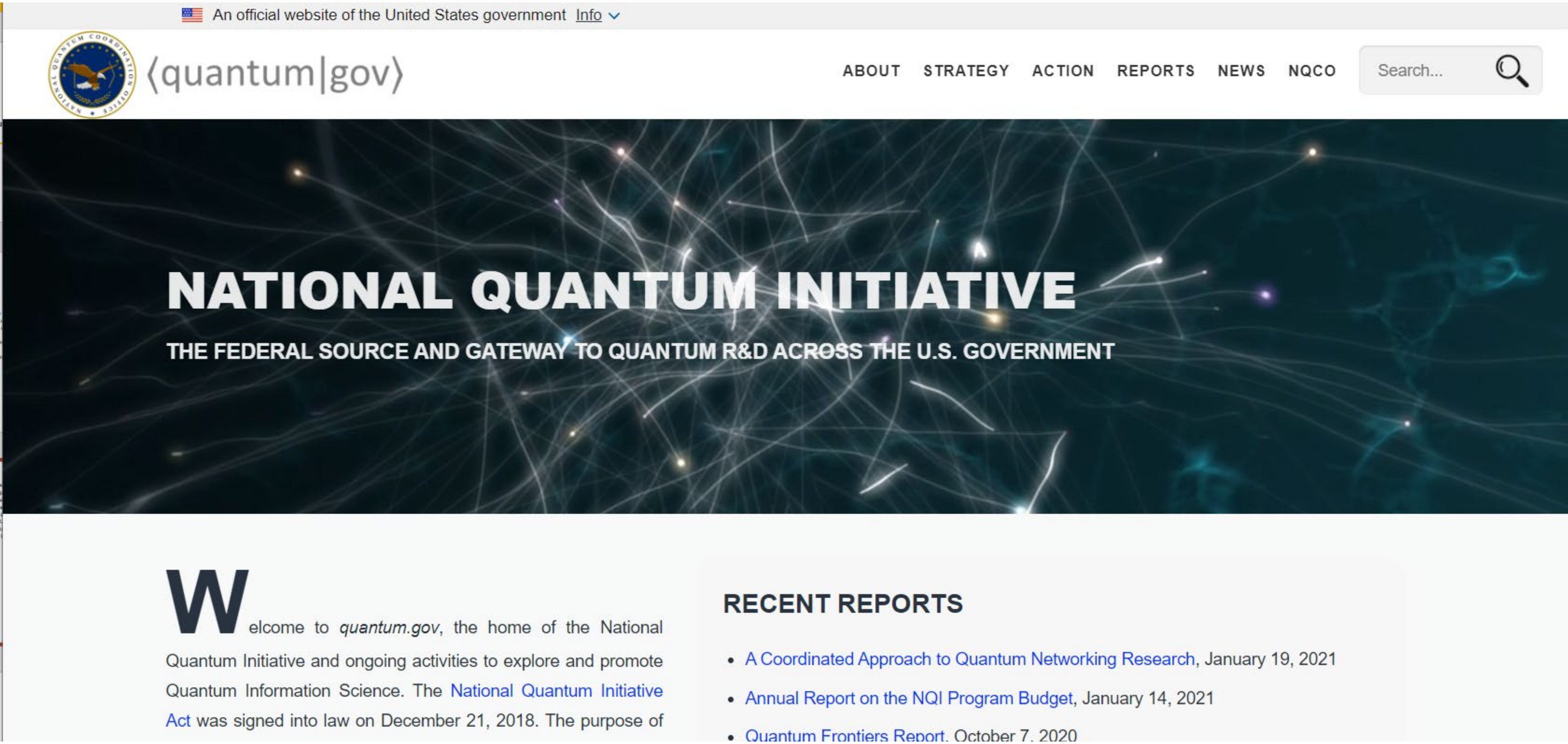
- **review** the fundamentals of quantum computing, and its three key ingredients: qubits, quantum gates and quantum circuits
- **enumerate** some of the applications of quantum computing in various fields
- **construct** a simple quantum circuit online using the IBM Quantum Experience
- write your **first quantum program** using the Python module Qiskit

The quantum computing revolution is here!

*We hear every day that quantum computers are becoming a reality, offering **high-speed solutions to problems in cryptography, medicine, logistics, meteorology, drug design…***

*Public and private institutions around the world announce **new initiatives** to fund research and development in this field. Books and articles are published. Courses are taught…*

President Trump poses with the signed National Quantum Initiative Act. Behind him are, from left, White House Deputy Chief of Staff for Policy Coordination Christopher Liddell, Deputy U.S. Chief Technology Officer Michael Kratsios, and the president’s daughter and adviser Ivanka Trump, who has been involved with STEM education policy issues.



https://www.quantum.gov/

AGENCIES

https://www.quantum.gov/

From Academia to Industry

The story of quantum computing starts in a precise place and a precise date...

1981

May 6, 1981. Boston, Massachusetts, USA. One of the most famous physicist in the world, Professor Richard Feynman from Caltech, is ***about to give a keynote speech in a conference at the Massachusetts Institute of technology (MIT).*** The conference is entitled “Physics of Computation”. During his talk, the Nobel laureate will present a novel idea about building a revolutionary new type computer, a “quantum computer". This idea will change the world.

Physics of Computation Conference Endicott House MIT May 6-8, 1981

1 Freeman Dyson
2 Gregory Chaitin
3 James Crutchfield
4 Norman Packard
5 Panos Ligomenides
6 Jerome Rothstein
7 Carl Hewitt
8 Norman Hardy
9 Edward Fredkin
10 Tom Toffoli
11 Rolf Landauer
12 John Wheeler
13 Frederick Kantor
14 David Leinweber
15 Konrad Zuse
16 Bernard Zeigler
17 Carl Adam Petri
18 Anatol Holt
19 Roland Vollmar
20 Hans Bremerman
21 Donald Greenspan
22 Markus Buettiker
23 Otto Floberth
24 Robert Lewis
25 Robert Suaya
26 Stan Kugell
27 Bill Gosper
28 Lutz Priese
39 Madhu Gupta
30 Paul Benioff
31 Hans Moravec
32 Ian Richards
33 Marian Pour-El
34 Danny Hillis
35 Arthur Burks
36 John Cocke
37 George Michaels
38 Richard Feynman
39 Laurie Lingham
40 Thiagarajan
41 ?
42 Gerard Vichniac
43 Leonid Levin
44 Lev Levitin
45 Peter Gacs
46 Dan Greenberger

Feynman's idea was to move away from the binary representation of information, used in all computers until then.

He argued that the basic building block of information ought to be the individual subatomic particles, such as electrons and photons, where the laws of quantum mechanics apply.

So **not only zeros and ones as binary computers do, but a unit of information infinitely more dense. In fact, the unit of information used by nature**.

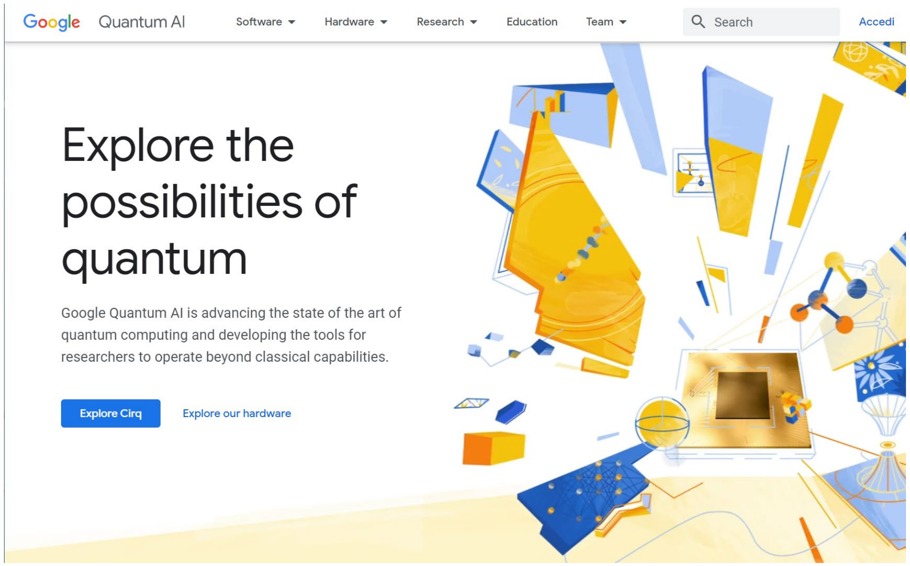
2019

January 8, 2019. Yorktown Heights, New York, USA. The company International Business Machines (IBM) presents ***the first commercial quantum computer in the world.*** A 20-qubit quantum computer. It is a powerful sleek device inside a heavy-duty borosilicate glass enclosure of about 3 meters by 3 meters in size. It looks more like a museum display than a computer. In fact, it has been designed by Goppion, manufacturer of high-end museum display cases with headquarters in Milan.

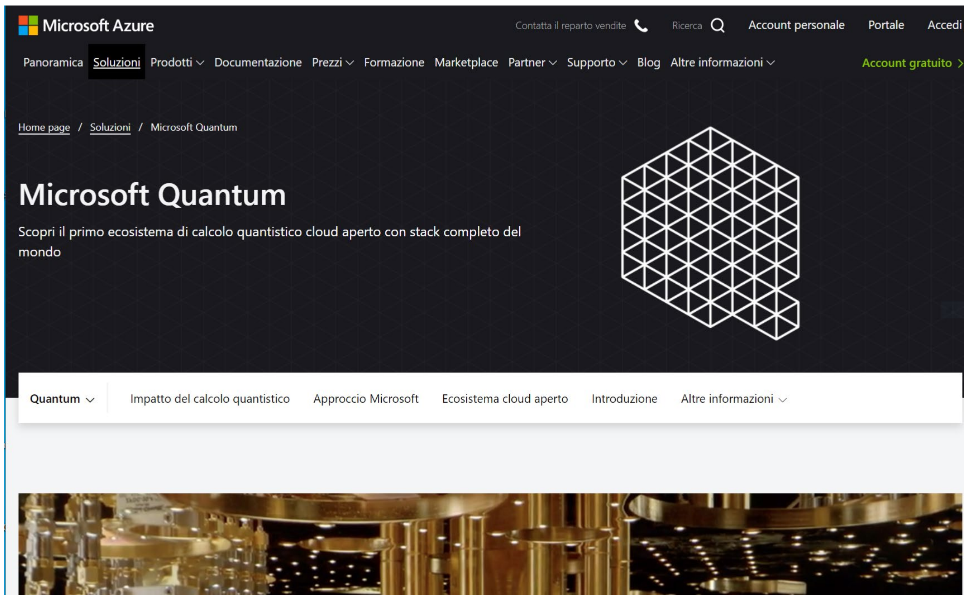
IBM: https://quantum-computing.ibm.com


IBM Q
System One
IBM

It is not only IBM who is making Feynman's quantum computing dream a reality. **Google Research** is making tremendous contributions as well. In a recent paper published in the science journal *Nature,* scientists at its research lab in California managed to have their quantum system perform a mathematical calculation in 200 seconds that today's most powerful supercomputers would need more than 10,000 years to complete. [https://www.nature.com/articles/s41586-019-1666-5]. The company has a particular interest in applying quantum computing to artificial intelligence and machine learning.



Google: https://research.google/teams/applied-science/quantum/

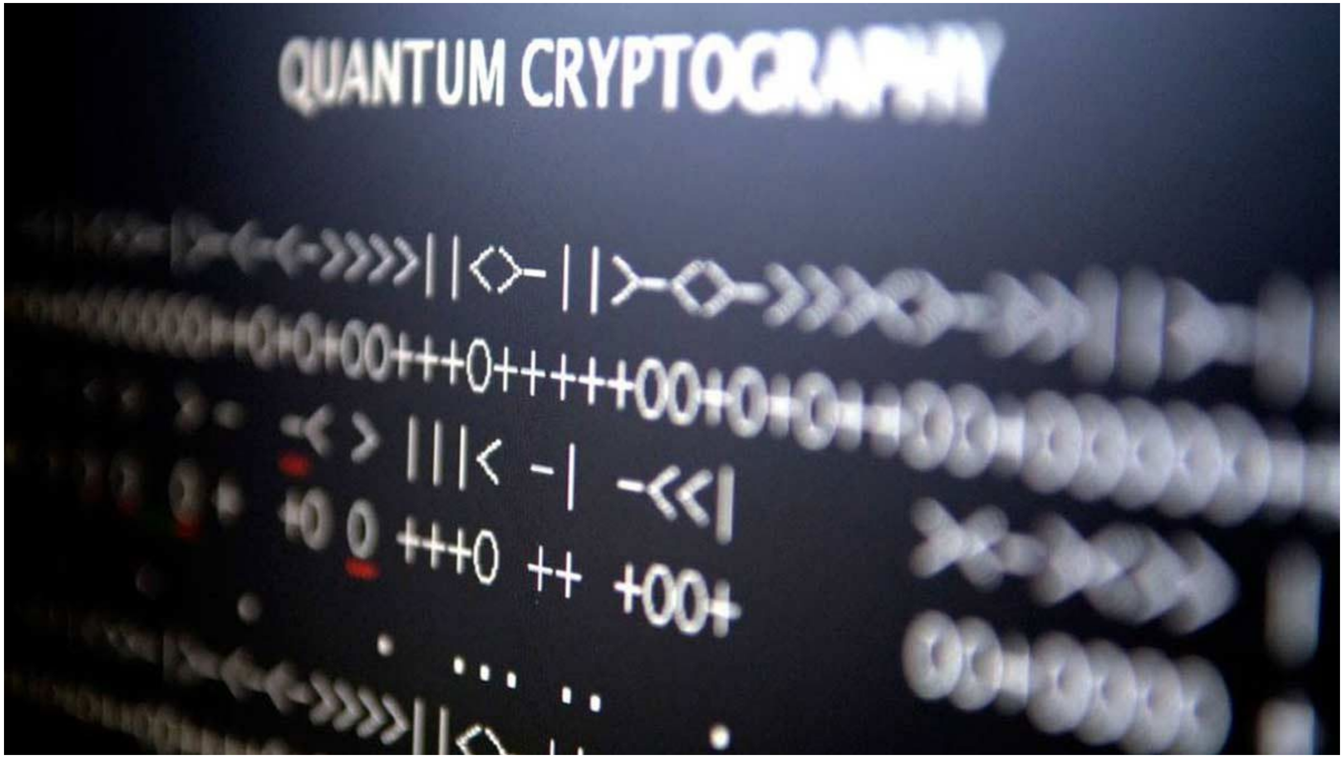


Microsoft Corporation is also very much into the Quantum Computing race. They have created the Microsoft Quantum Network as a community of interested parties collaborating with Microsoft to learn about, research, and launch quantum computing applications. The company has also developed Q# , which is a programming language used for expressing quantum algorithms. It was initially released to the public by Microsoft as part of the Quantum Development Kit.

https://www.microsoft.com/en-us/quantum

Industrial applications

Quantum Computing has been mentioned to have many applications. The most quoted application of quantum computing is **cryptography**. Here, quantum computers would be able to send super secure messages using security protocols that would be unbreakable, making messages incredibly safe for current standards.



An area where quantum computers could also really bring an edge is **in drug design**. To simulate in a computer the behavior of the structure of molecules would be prohibitively slow. The amount of individual atoms and their interactions that would need to be modelled will very quickly overcome classical computers. Current simulations are restricted to toy versions of the molecules required for real drugs. With quantum computers of say 200 qubits could handle the molecules and simulate the behavior of new drugs.

A similar problem is faced by **airplane design**. Current computers cannot handle simulation the behavior of the solid-fluid interactions in large surfaces, such as wings. Instead, a significant effort in terms of time and money is dedicated to physically build components and test them in wind tunnels under a variety of conditions. This is an expensive and complex task. Instead, quantum computers are expected to offer powerful algorithms to conduct full computer simulations in a short time. The company Airbus launched the Airbus Quantum Computing Challenge 2019 to explore this issue.

Another example of how quantum computing might accelerate the leap from the drawing board to commercial applications is in **battery technologies**, such as the lithium-sulfur (Li-S) battery. Mercedes-Benz R&D North America is currently exploring how this complex chemical design could be conducted with the help of quantum computers in alliance with IBM.

Government Initiatives

United States. The US government has recently created the National Quantum Initiative following the National Quantum Initiative Act (signed into law on December 21, 2018 by President Trump). The purpose of this Act is to help in the promotion of quantum information science and its technology applications. This is backed by significant investments in this field.

China. The Chinese government via the Chinese Academy of Science has been are the forefront of efforts in the field of quantum computation. Recently, Chinese scientists have created the world's first light-based quantum computer, called Jiuzhang, that can reliably demonstrate "quantum computational advantage”.

European Union. The EU launched a investment program for Quantum Computation in October 2018, called the Quantum Technologies Flagship. Its aim is to support the work of hundreds of quantum researchers in Europe over ten years, with an expected budget of EUR 1 billion. It brings together research institutions, industry and public funders.

USA: www.quantum.gov

China: https://english.cas.cn

European Union: https://qt.eu

Quantum Computing

quantum computing is about the applications of the principles of quantum mechanics to information technology.

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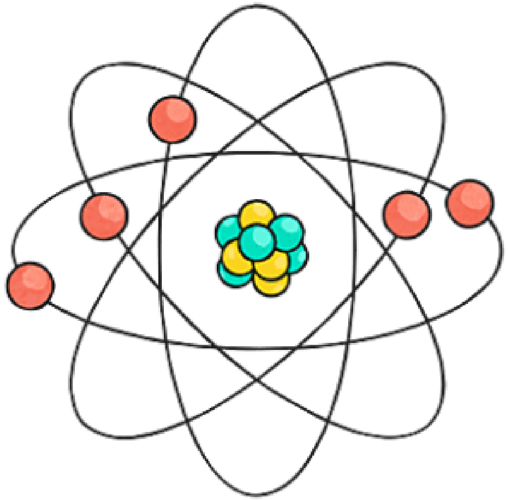
so what !!!

2.8179 × E −15 m

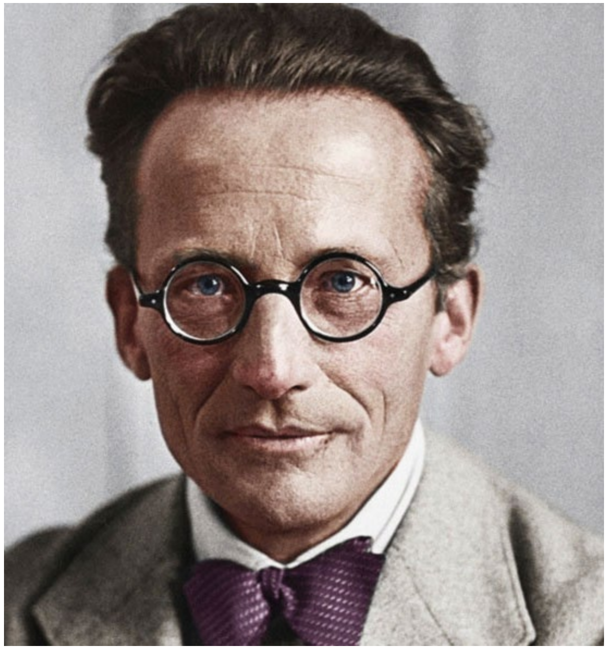


MICROSCOPIC WORLD

6.3781 × E +6 m

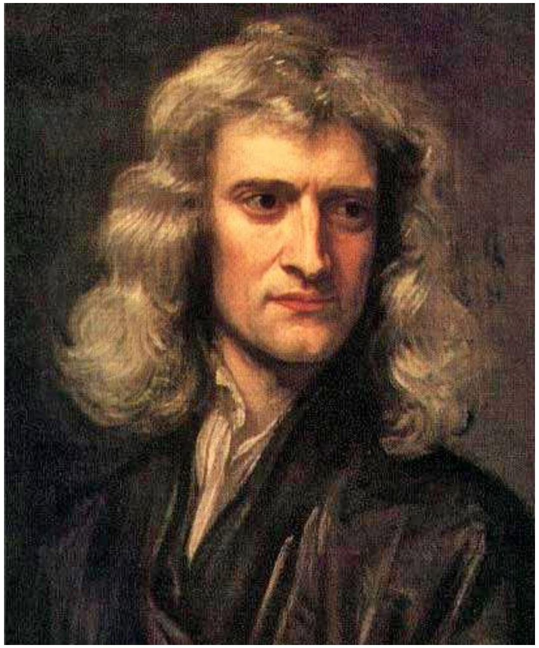
MACROSCOPIC WORLD

Schroedinger



MICROSCOPIC WORLD

Newton



MACROSCOPIC WORLD

Schroedinger

$$i\hbar\frac{\partial}{\partial t}\Psi = \hat{H}\Psi$$

MICROSCOPIC WORLD

Newton

$$F = G\frac{m_1 m_2}{r^2}$$

MACROSCOPIC WORLD

The laws of physics are different depending on the scale (size)

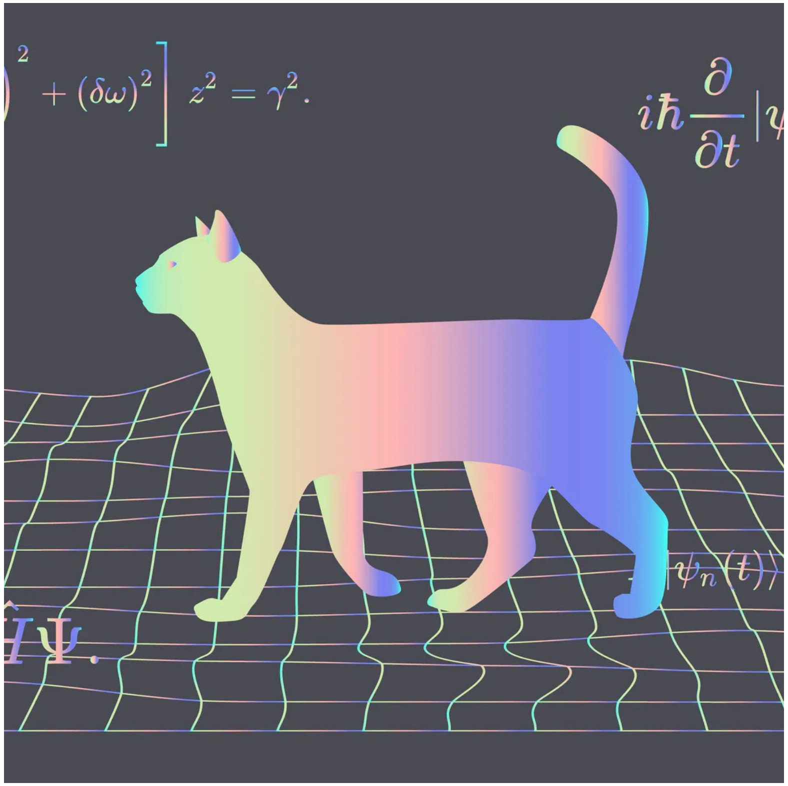
Quantum mechanics ought to be distinguished from classical physics …

One is that while **classical physics applies to the macroscopic world, quantum mechanics applies to the microscopic** world.

Another is that quantum mechanics is based on probabilistic laws rather than deterministic laws.

A crucial difference is that objects in the quantum world behave according to **two principles that are unique to the microscopic world**: **Superposition and Entanglement**.

Quantum computers are going to allow us to use these principles to our advantage, by **manipulating individual atoms (electrons and photons) that behave according to these laws.**



Superposition

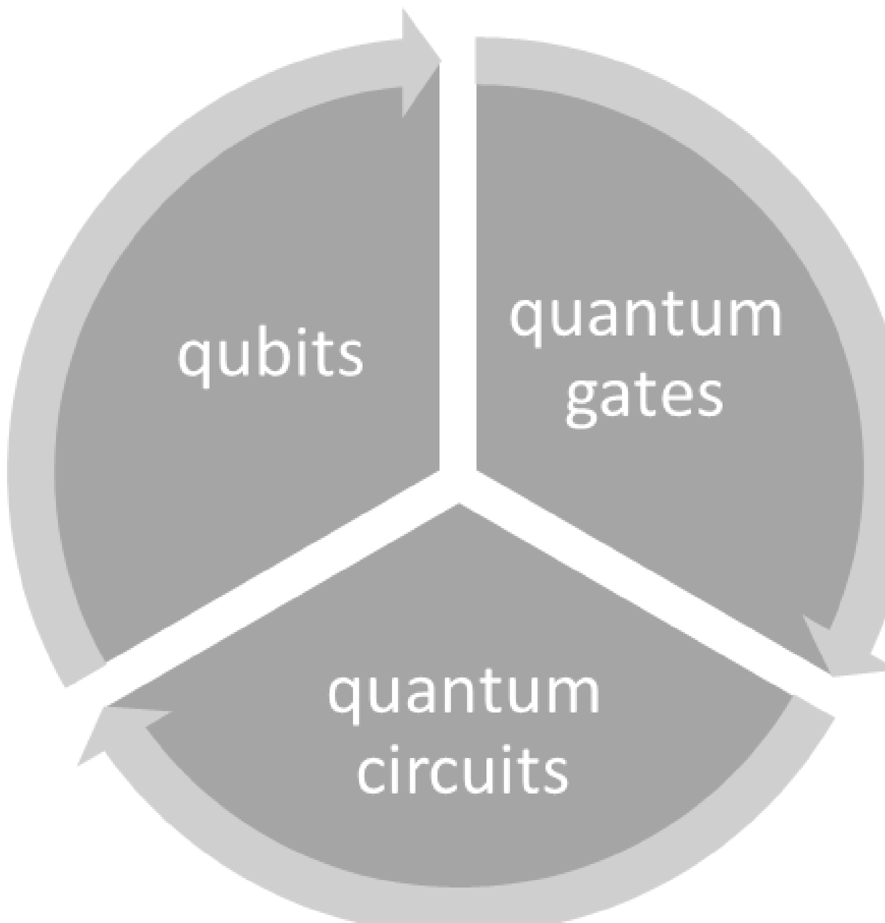
the act of putting something on or above something else

Entanglement

the act of becoming caught or twisted in something; the state of being caught or twisted in something

The Three Ingredients

The Three Ingredients of QC



Ingredient 1: Qubits

qubit = quantum bit

Ingredient 1: Qubits

The first ingredient are qubits. In classical computers, a bit can take only two possible values: either 0 or 1. In quantum computing, the values 0 and 1 are substituted by more general objects, i.e. the vectors $|0\rangle$ and $|1\rangle$. This can be understood as a transformation from scalars into vectors.

This special notation is called the **Dirac notation** and is commonly used in quantum mechanics. In contrast to classical bits, a quantum denoted $|\psi\rangle$ can also be a linear combination of vectors $|0\rangle$ and $|1\rangle$, therefore we can write it as:

$$|\psi\rangle = a|0\rangle + b|1\rangle$$

Imagine the following. If computers were ***photographs*** made up of dots (pixels). Classical computers use pixels than can be only black or white. Quantum computers allow each pixel to have any color in the spectrum. Imagine what images!

bits = black/white

qubits = color

bits = black/white

qubits = color

$$|\psi\rangle = a|0\rangle + b|1\rangle$$

where a and b are complex numbers. The vector is said to be a superposition of the vectors $|0\rangle$ and $|1\rangle$, with probabilities (or amplitudes) a and b. Therefore $|\psi\rangle$ can be regarded as a vector in a two dimensional complex vector space, where $|0\rangle$and $|1\rangle$forms its orthonormal basis, called the computational basis.

We can also have a matrix representations of the vectors $|0\rangle$and $|1\rangle$ as

$$|0\rangle = \begin{bmatrix} 1 \\ 0 \end{bmatrix} \quad , \quad |1\rangle = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$$

There exists a very important geometrical representation of the qubit using the Bloch sphere (Marquezino et al, 2019). In order to understand this representation, we can write the amplitudes as

$$\boldsymbol{a} = |\boldsymbol{a}|\boldsymbol{e}^{\boldsymbol{i}\boldsymbol{\gamma}}$$
$$\boldsymbol{b} = |\boldsymbol{b}|\boldsymbol{e}^{\boldsymbol{i}(\boldsymbol{\gamma}+\boldsymbol{\varphi})}$$

and if we define

$$cos\left(\frac{\theta}{2}\right) = |a|$$

$$sin\left(\frac{\theta}{2}\right) = |b|$$

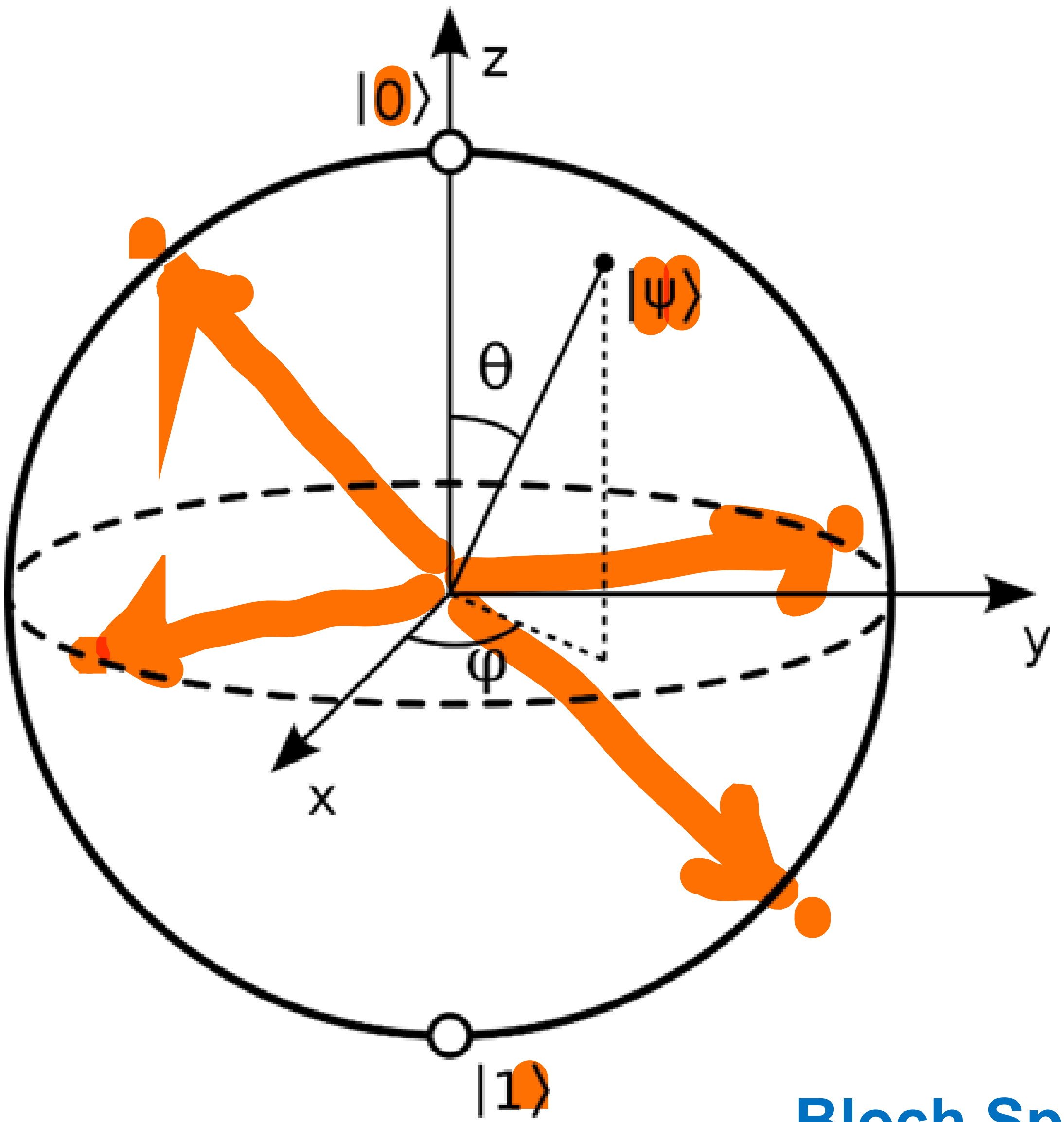
then it is possible to prove that we can write the qubit as:

$$|\psi\rangle = e^{i\gamma}\left(cos\left(\frac{\theta}{2}\right)|0\rangle + e^{i\varphi} sin\left(\frac{\theta}{2}\right)|1\rangle\right)$$

For purposes of visualization, the factor $e^{i\gamma}$ outside parenthesis, known as global phase factor, can be ignored, because it has no observable effect on the state of the qubit. Therefore, we can represent any qubit as a point on the surface of a sphere, called the Bloch sphere, and limit ourselves to the two angles φ and θ.

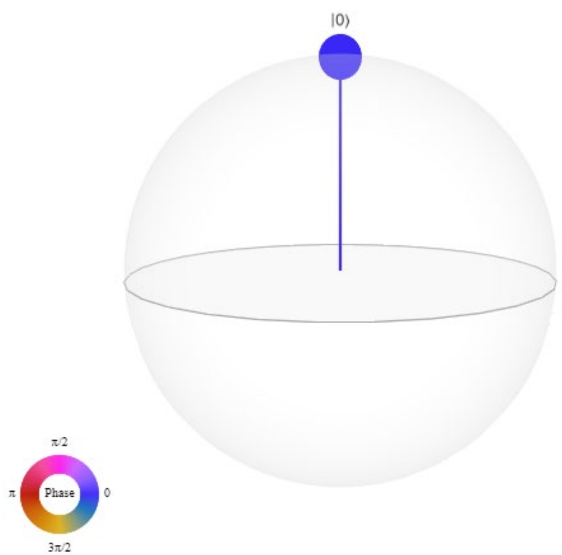
$$|\psi\rangle = cos\left(\frac{\theta}{2}\right)|0\rangle + e^{i\varphi}\ sin\left(\frac{\theta}{2}\right)|1\rangle$$

And using these two angles would allow us to represent any qubit as a point in the surface of the Bloch sphere as in the following image.



Bloch Sphere

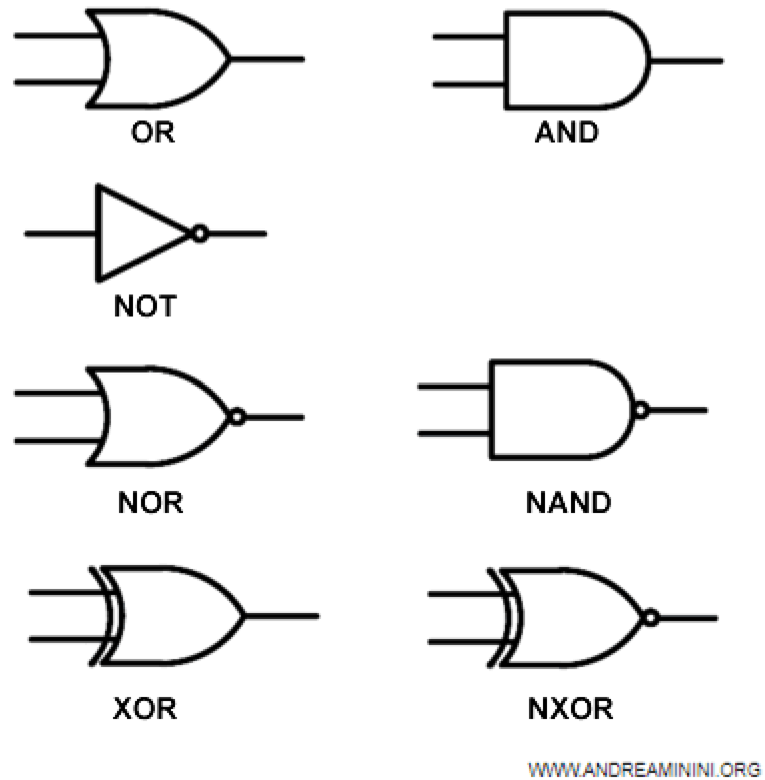
A qubit in the base state $|\mathbf{0}\rangle$ will be represented by an arrow pointing up (North Pole) in the Bloch sphere, as illustrated in the following figure.



Bloch sphere with a qubit at the $|\mathbf{0}\rangle$ state.

Ingredient 2: Quantum Gates

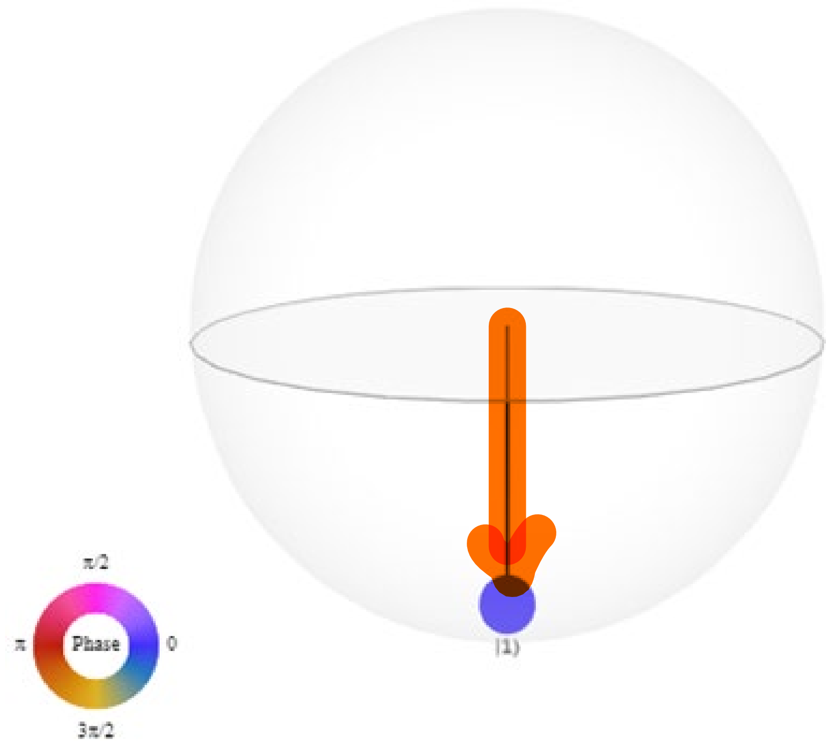
The second ingredient will be quantum gates. That is, the transformation of certain inputs in certain outputs according to some rules. These logic gates, such as NOT, AND, OR, , are well known in classical computer science using bits. But if we change from bits to qubits, how would they look like?



X Quantum Gate. This is the equivalent of the classical NOT. Its effect is to invert the state if the qubit. Thus if the qubit is in state $|0\rangle$the application of the X gate will change it to state and$|1\rangle$. If the qubit is in state $|1\rangle$ the X gate will change it $|0\rangle$. Quantum gates can be represented as matrix operations on qubits. The X gate is thus represented by the matrix:

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

If an X gate is applied to a qubit in state $|0\rangle$, the result of the operation can be represented by an arrow pointing down (South Pole) in the Bloch sphere.



Bloch sphere with a qubit at the $|1\rangle$ state.

Y and Z gates. The X gate is part of a family known as Pauli gates. In addition to the X gate, this family includes the Y gate, defined as

$$Y = \begin{bmatrix} 0 & -i \\ i & 0 \end{bmatrix}$$

and the Z gate, defined by

$$Z = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$$

These gates have the effect of rotation the qubit vector around x and y axis respectively.

H Gate. The Hadamard gate is another important one-qubit gate. Its operation is defined by the matrix:

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

where we can see that after applying it to qubits in states $|0\rangle$and $|1\rangle$we obtain

$$H|0\rangle = \frac{|0\rangle + |1\rangle}{\sqrt{2}}$$

$$H|1\rangle = \frac{|0\rangle - |1\rangle}{\sqrt{2}}$$

The H gate is important because it creates a **superposition of** states with equal amplitudes or probabilities. With this gate information becomes like Schrodinger's Cat which exists in two states at the same time. For us, this will mean that **we can represent information in a much more flexible way, a probabilistic way**, rather than having to rely only on a binary representation (like 0's and 1's) as in classical computers.

There are many more gates, but in this introduction, we focus only on these.

Ingredient 3: Quantum Circuit

The third ingredient is quantum circuits. That is, the set of operations that will transform some quantum information into another quantum information. In other words, we give qubits as inputs to a series of gates and, after doing the respective operations, we obtain some outputs. This **can be thought of as a set of matrix operations applied to a quantum system**.

And because the **elements of quantum circuits obey the laws of quantum mechanics, a quantum computer capable of efficiently running these circuits would be capable of using the powerful principles of the microscopic world (such as superposition and entanglement)** to solve problems in the macroscopic world. Conceptually what we describe above is an algorithm. When we want to implement this concept into a practical quantum computer it's better to think about it in terms of a quantum circuit, indicating the network of connections between qubits and quantum gates.

EXAMPLE if we wanted to do a simple operation such as flipping or inverting the value of a qubit from 0 to 1, what would be its quantum circuit representation?

Using the qubits and the quantum gates as described above, we can represent it as an input, some process and then an output. In particular, we could think about it in three steps:

STEP 1: INPUT

$$|\psi_0\rangle = |0\rangle = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$$

STEP 2: PROCESSING

$$X\,\psi_0 = \psi_1$$

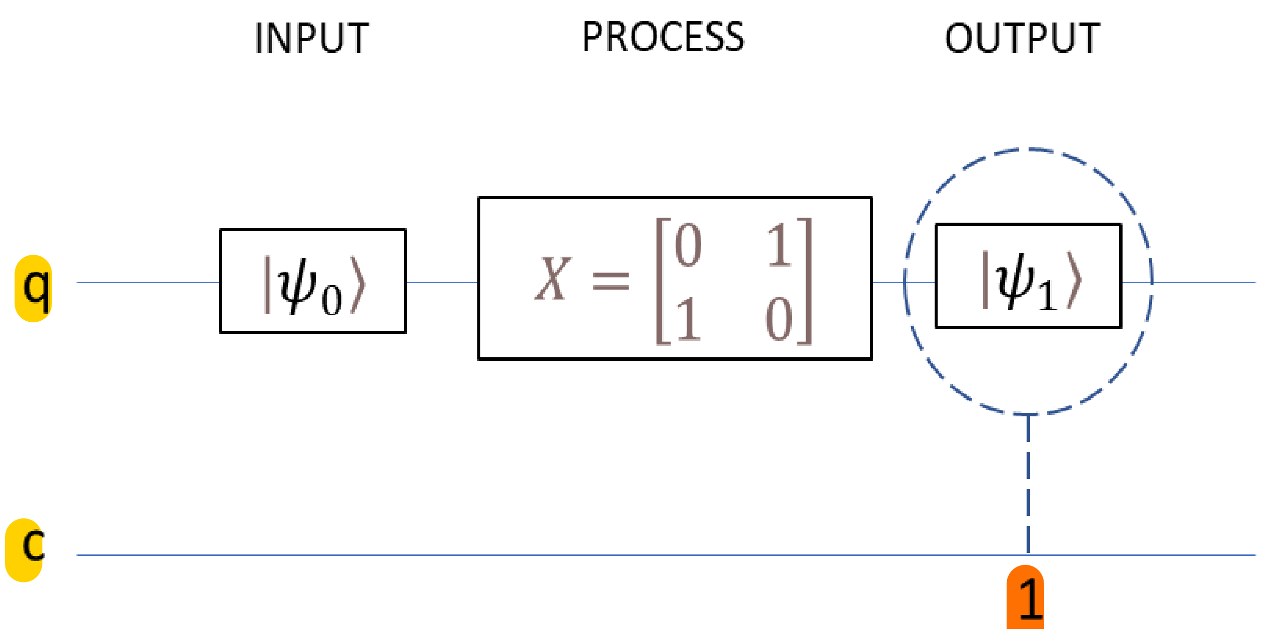
$$\begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} \begin{bmatrix} 1 \\ 0 \end{bmatrix} = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$$

STEP 3: OUTPUT

$$\text{Measure}(\psi_1) = 1$$

algorithm for flipping a quibit.

In graphical terms one might represent the above algorithm in terms of a circuit as follows:

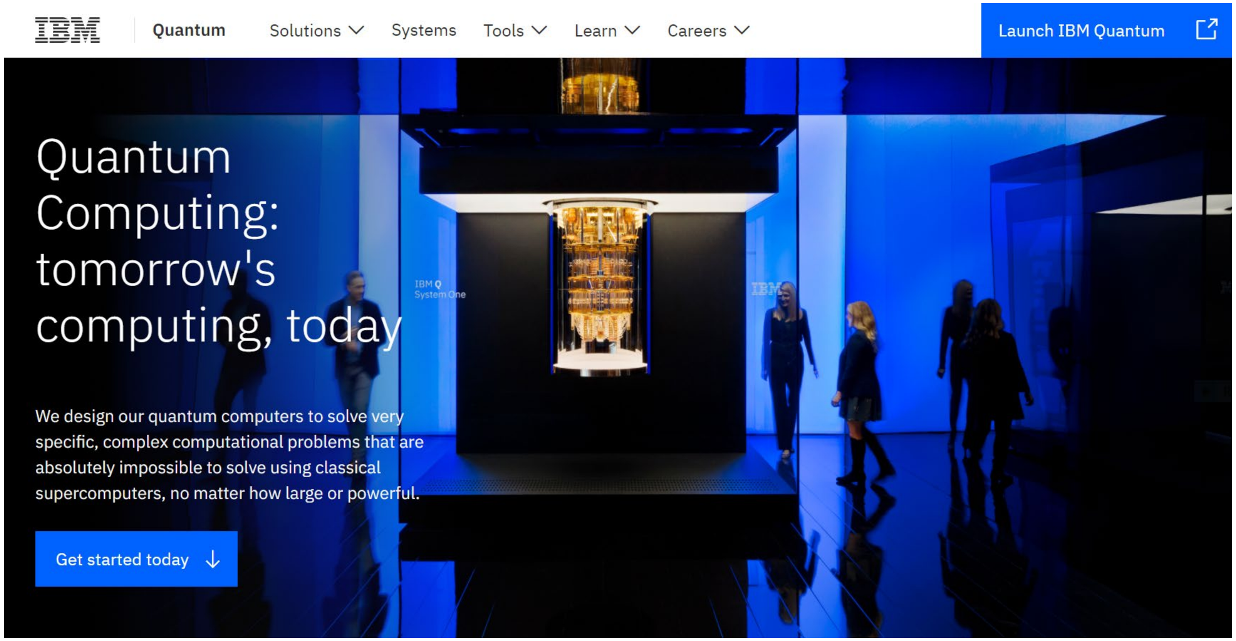


quantum circuit for flipping a quibit.

Where in **STEP 1** we define the input for the circuit, in this case a qubit in state $|\psi_0\rangle = |0\rangle$. We then apply a quantum NOT gate to it via a matrix multiplication in **STEP 2**. The result is now in another qubit $|\psi_1\rangle = |1\rangle$. In the final **STEP 3**, we ought to observe the result and measure it. From the theory of quantum mechanics we know that the act of measurement will make the qubit to collapse to a classical bit, in this case with a value of 1.

IBM Quantum

IBM Quantum is a web-based platform dedicated to the use of quantum computing for the public. It is the best place to start to learn about quantum computing in practice.



https://www.ibm.com/quantum-computing/

The IBM Quantum platform is composed of six parts.

[1] The *Dashboard,* which contains information about your personal profile and an overview of the recent circuits that you have worked with, as well as the jobs (runs) that these have been executed and the hardware systems that you have used. It's the homepage of the platform.

[2] The *Quantum Services* contains detailed information about the quantum computers that are made available to you by IBM.

[3] *Jobs* gives information about the programs that you have executed, including the ones pending and those completed.

[4] The *Quantum Composer* is the place where you can construct graphically quantum circuits by drag-and-drop their basic components (e.g. gates) into a blank page. From here you can also see qubits in the Bloch Sphere and see an histogram to assess their probabilities. The circuits represented in terms of a simplified assembly language type of code, called QASM, that can also bee seen here. You have the possibility to setup how you want to run your code, either in a simulator or in a areal quantum computer. You can send jobs to be executed with a button on this page.

[5] The *Quantum Lab* is where you can develop and run your quantum programs using Python and the Qiskit module developed by IBM. You can see a series of tutorials to explore various aspects of quantum computing. This page allows you to run these tutorials and/or your own programs interactively as Jupyter Notebooks.

[6] The next section *User Guides*, contains a wide variety of information about quantum computing in general and documentation about the various aspects of this platform in particular.

Lab 1:
Your first circuit step-by-step with IBM Quantum

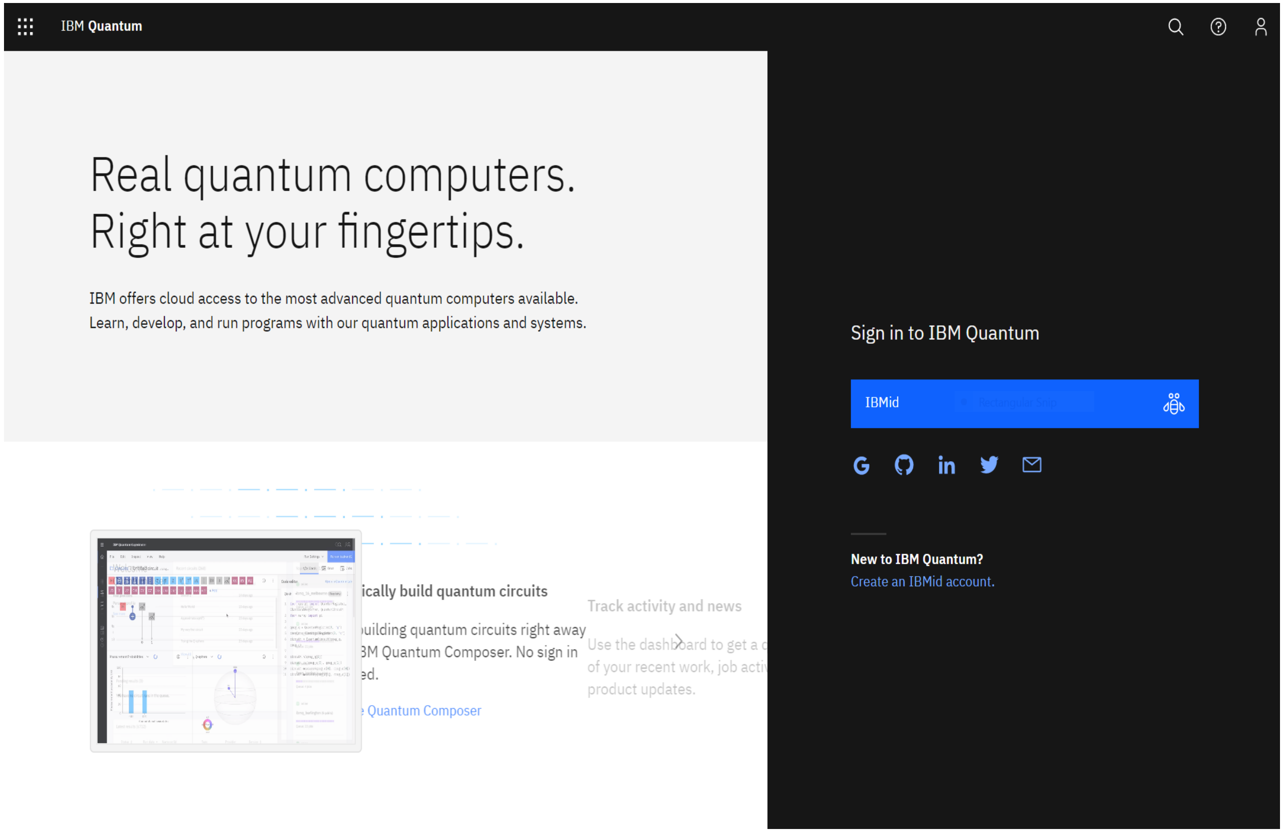
We are going to use throughout this course the environment offered by IBM which is called the IBM Quantum. In this exercise we are going to do together the simplest possible thing that one can do to a qubit: we are going to invert it. That is we are going to move it from quantum state $|0\rangle$ to quantum state $|1\rangle$, i.e. from pointing up to pointing down in the Bloch Sphere.

TASK: **To flip a single qubit from $|0\rangle$ to $|1\rangle$.**

(ONLINE) SOLUTION: **Create a quantum circuit with a single qubit and a X Gate in the online IBM Quantum platform**

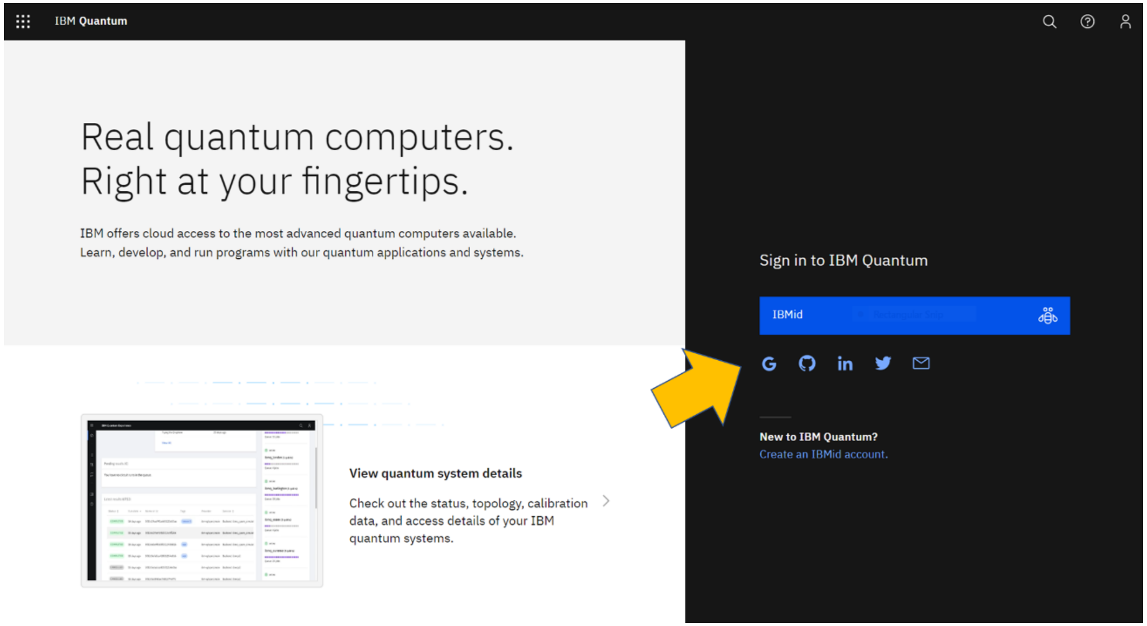
Step 1: Go to the IBM Quantum website

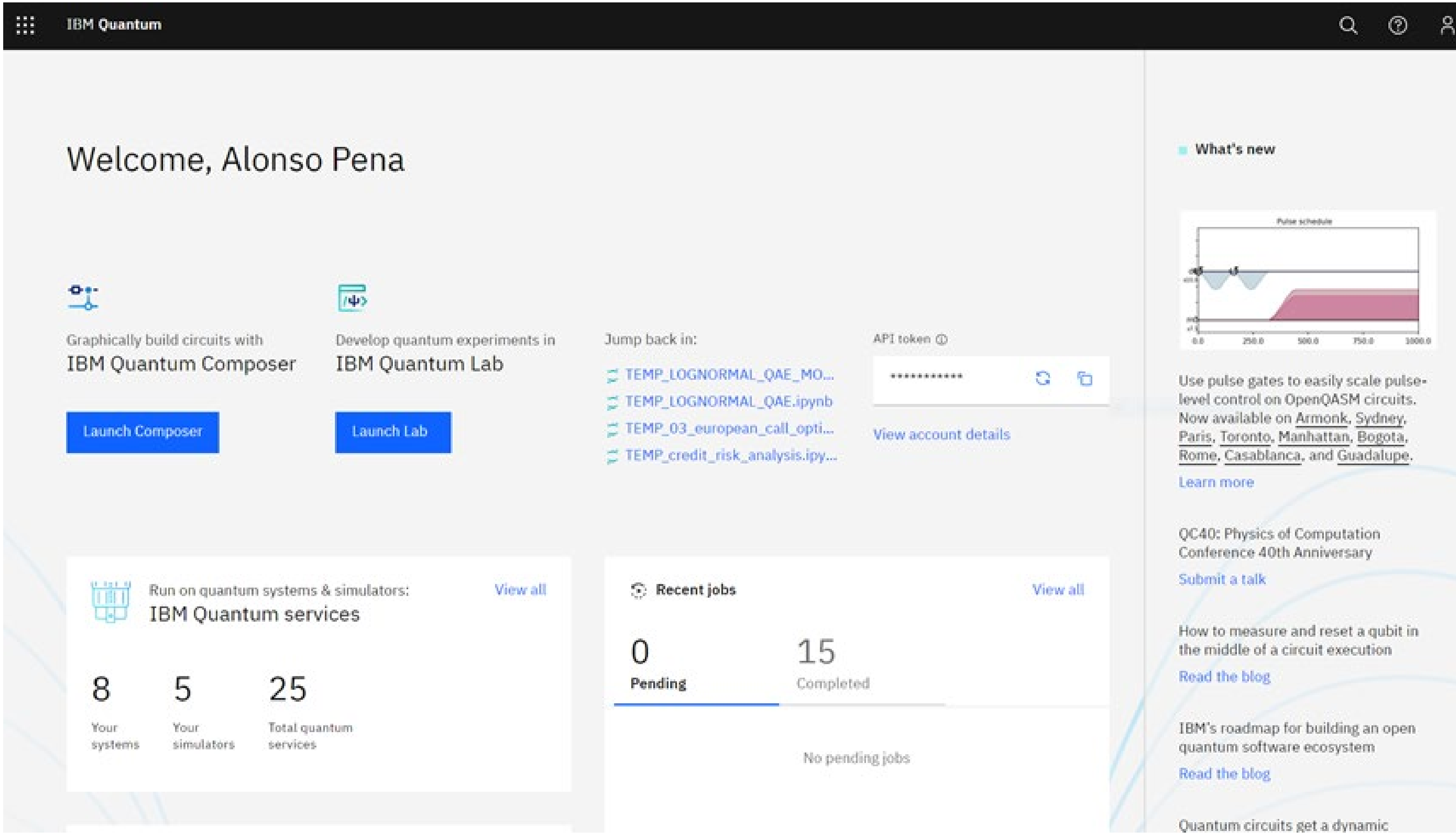
Visit the IBM Quantum Experience website https://quantum-computing.ibm.com/login. As illustrated in the next Figure, here is where you can access the various services offered by IBM for quantum computation.



Step 2: Register or sign-in into the system

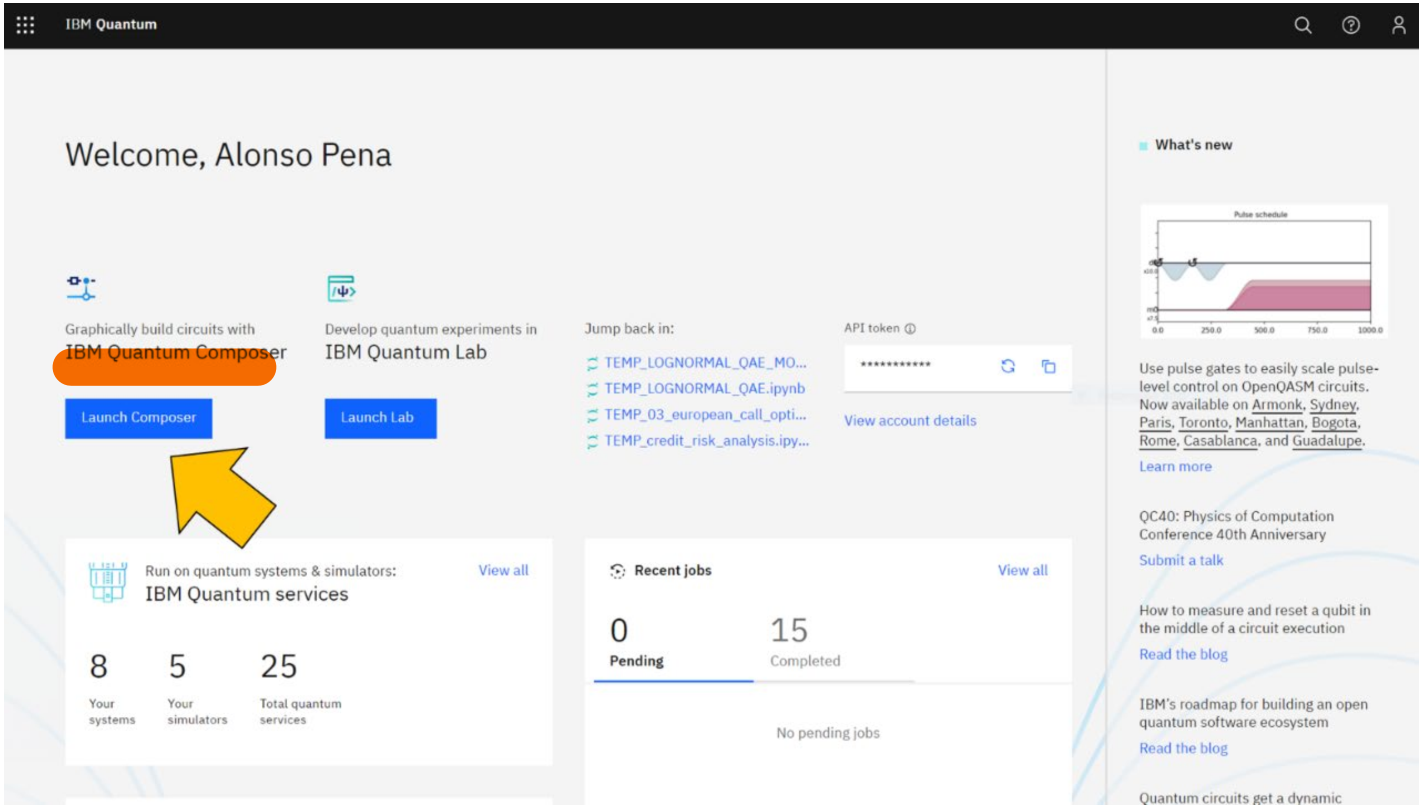
You ought to create a new **IBMid** which will allow you to use the environment. You can do this by filling the short registration form. Alternatively you can register by using your social profile from Google, LinkedIn or Twitter, amongst others.

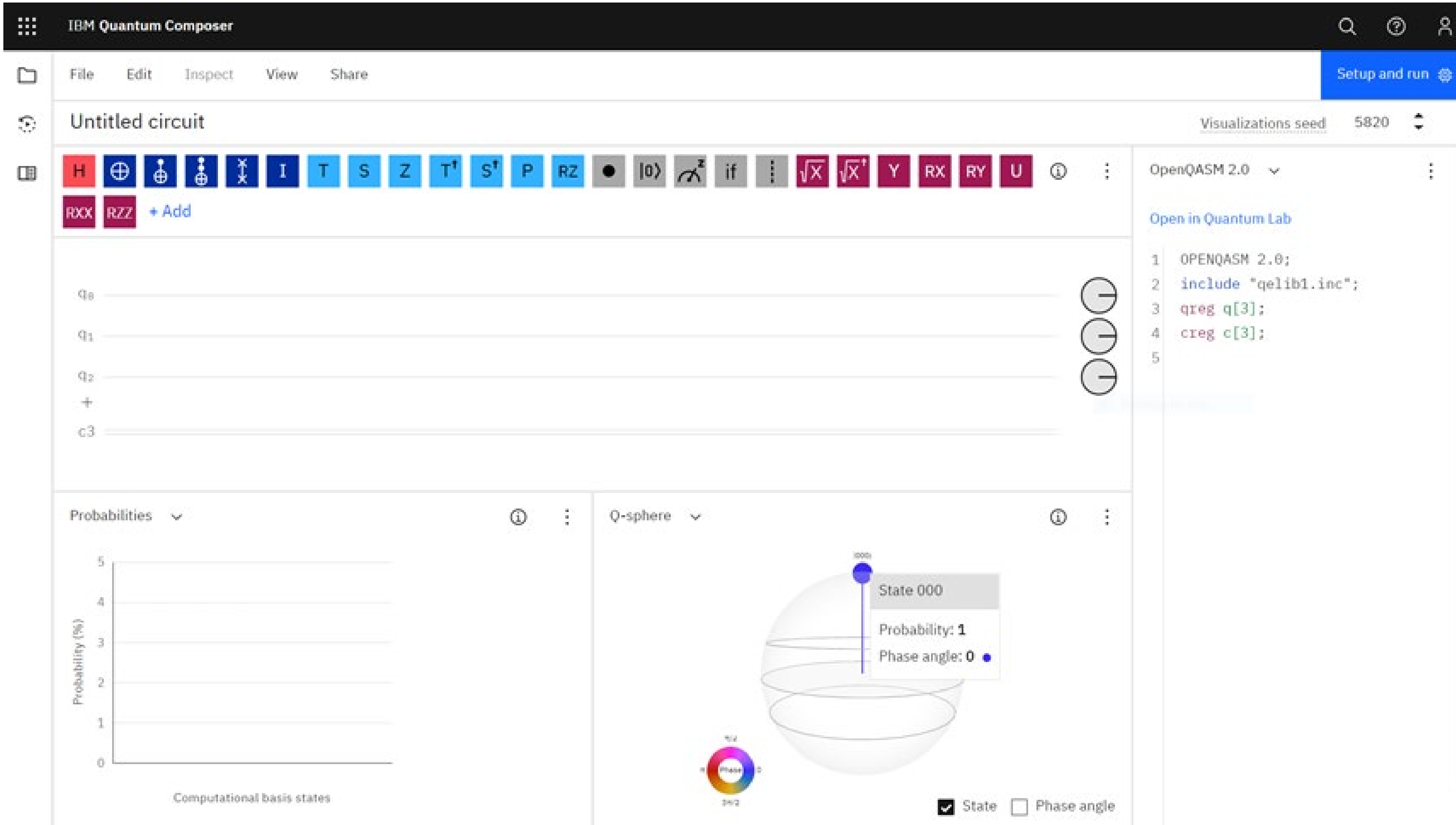



IBM Quantum
Welcome, Alonso Pena
Graphically build circuits with
IBM Quantum Composer
Launch Composer
Develop quantum experiments in
IBM Quantum Lab
Launch Lab
Jump back in:
TEMP_LOGNORMAL_QAE_MO...
TEMP_LOGNORMAL_QAE.ipynb
TEMP_03_european_call_opti...
TEMP_credit_risk_analysis.ipy...
API token
****
View account details
Run on quantum systems & simulators:
IBM Quantum services
View all
8
Your systems
5
Your simulators
25
Total quantum services
Recent jobs
View all
0
Pending
15
Completed
No pending jobs
What's new
Pulse schedule
Use pulse gates to easily scale pulse-level control on OpenQASM circuits. Now available on Armonk, Sydney, Paris, Toronto, Manhattan, Bogota, Rome, Casablanca, and Guadalupe.
Learn more
QC40: Physics of Computation Conference 40th Anniversary
Submit a talk
How to measure and reset a qubit in the middle of a circuit execution
Read the blog
IBM's roadmap for building an open quantum software ecosystem
Read the blog
Quantum circuits get a dynamic

Step 3: Go to the Quantum Composer

Go now to *IBM Quantum Composer* in order to construct our first circuit by clicking on the Launch Composer button as indicated in the following Figure.



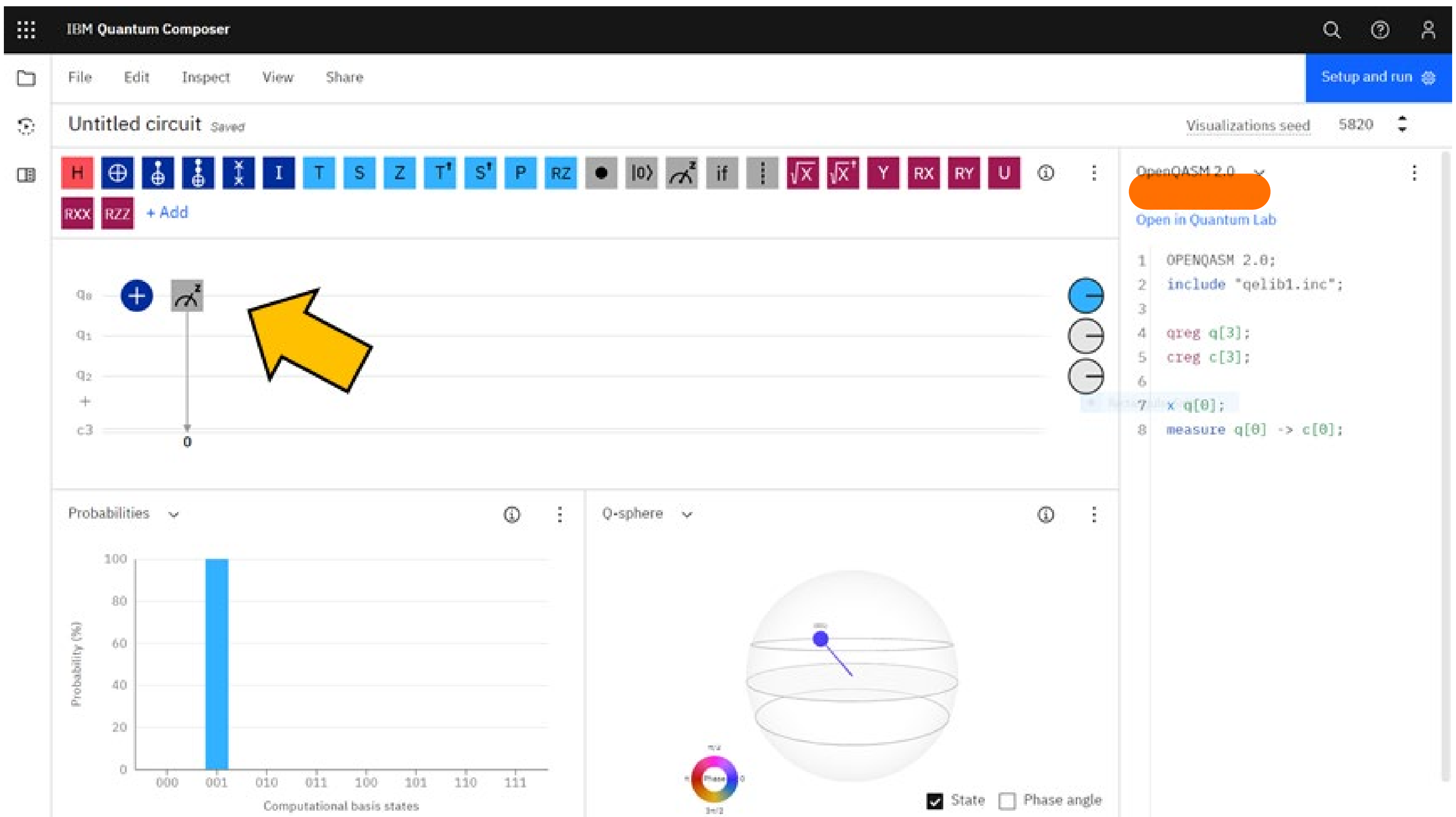


IBM Quantum Composer
File
Edit
Inspect
View
Share
Setup and run
Untitled circuit
Visualizations seed
5820
H
I
T
S
Z
P
RZ
if
Y
RX
RY
U
RXX
RZZ
+ Add
OpenQASM 2.0
Open in Quantum Lab
1 OPENQASM 2.0;
2 include "qelib1.inc";
3 qreg q[3];
4 creg c[3];
5
c3
Probabilities
Probability (%)
Computational basis states
Q-sphere
State 000
Probability: 1
Phase angle: 0
State
Phase angle

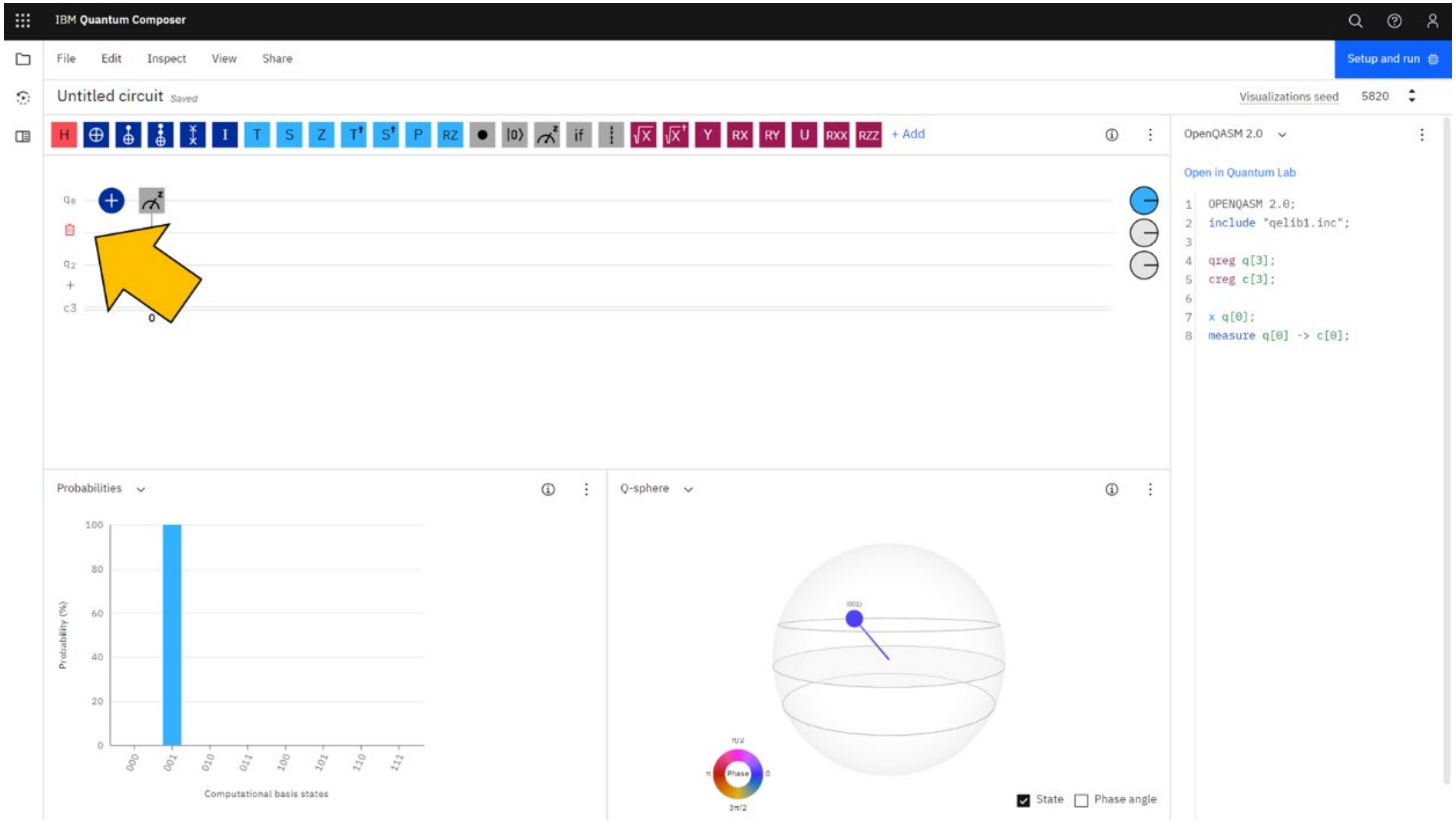
The coloured icons represent different types of quantum gates. The horizontal lines represent the cables to connect the quantum gates to the qubits and classical bits (indicated by *q* and *c*, respectively). The Bloch sphere is shown on the lower part as well as the statistical graph for the measurements. On the right the equivalent of the circuit is represented in a low-level code called QASM (Quantum Assembler Language).

Step 4: Create your first circuit

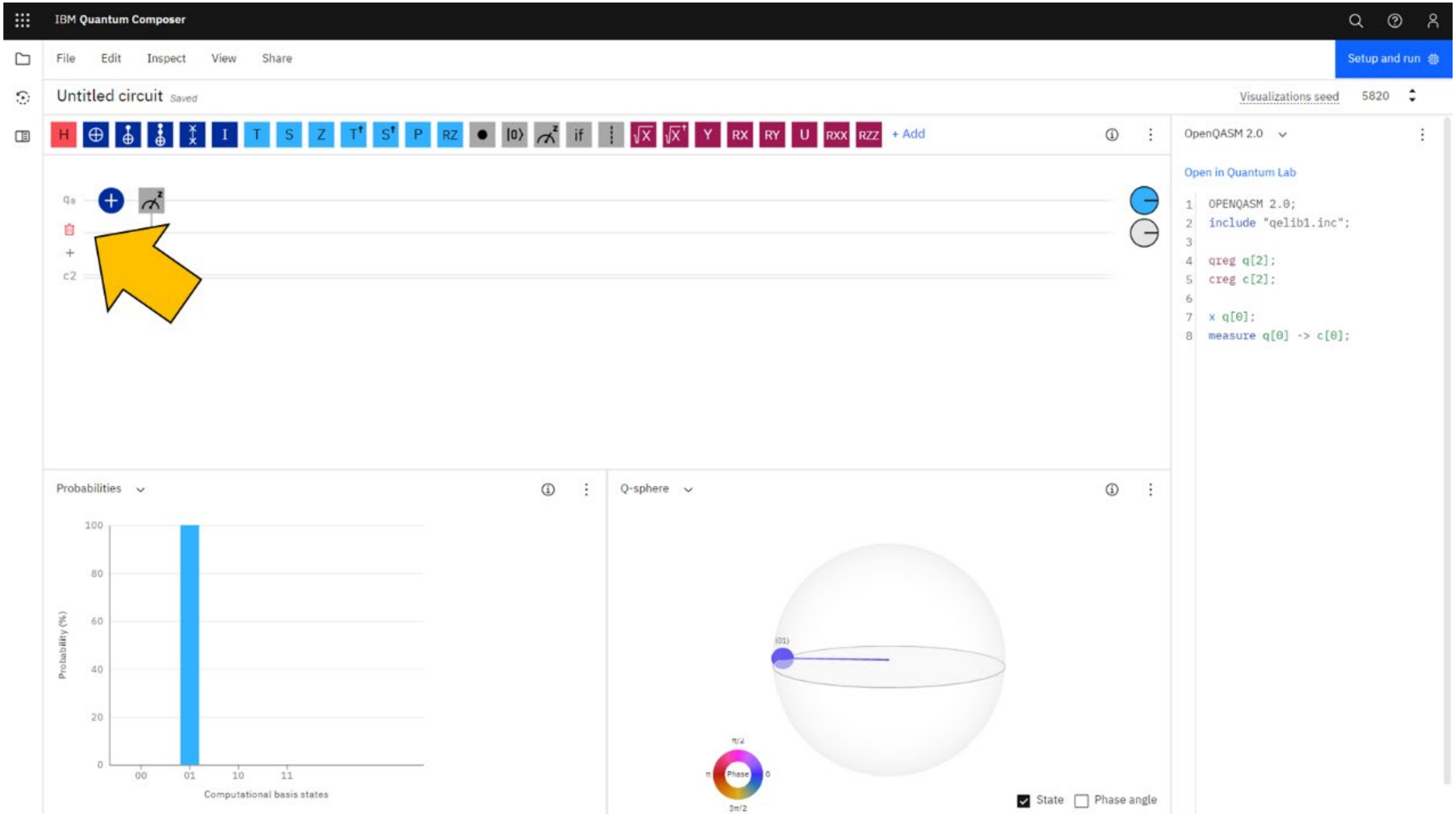
Into the lines indicating the circuit, drag the X gate (circle with cross icon) to q0, then the measurement to q0.



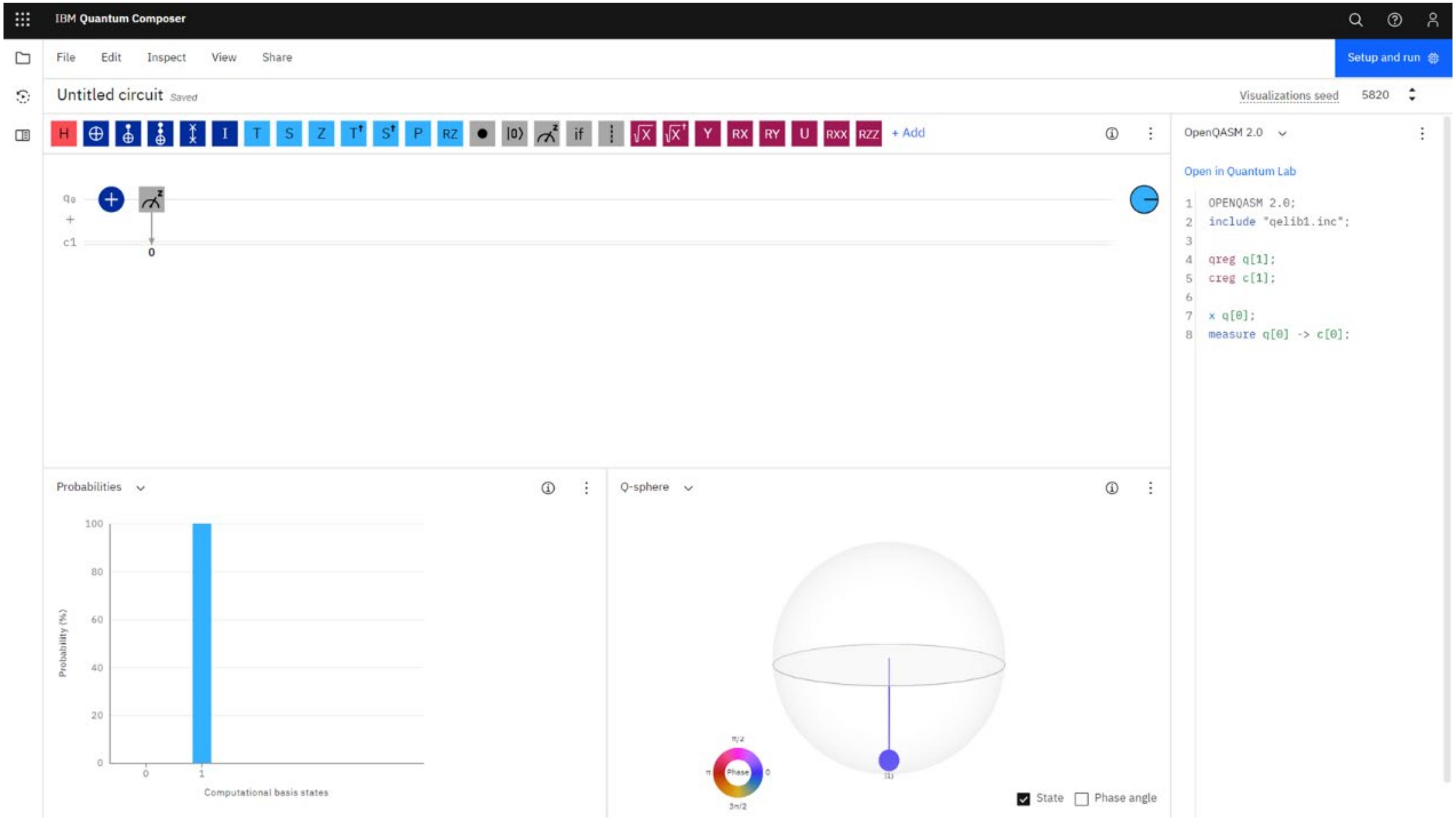
Now we need to eliminate the unnecessary qubits q1 and q2, that are present by default in the circuit design. By hovering directly above q1 a red rubbish bin icon will appear, click on it to delete:



Do the same for q2 to delete:

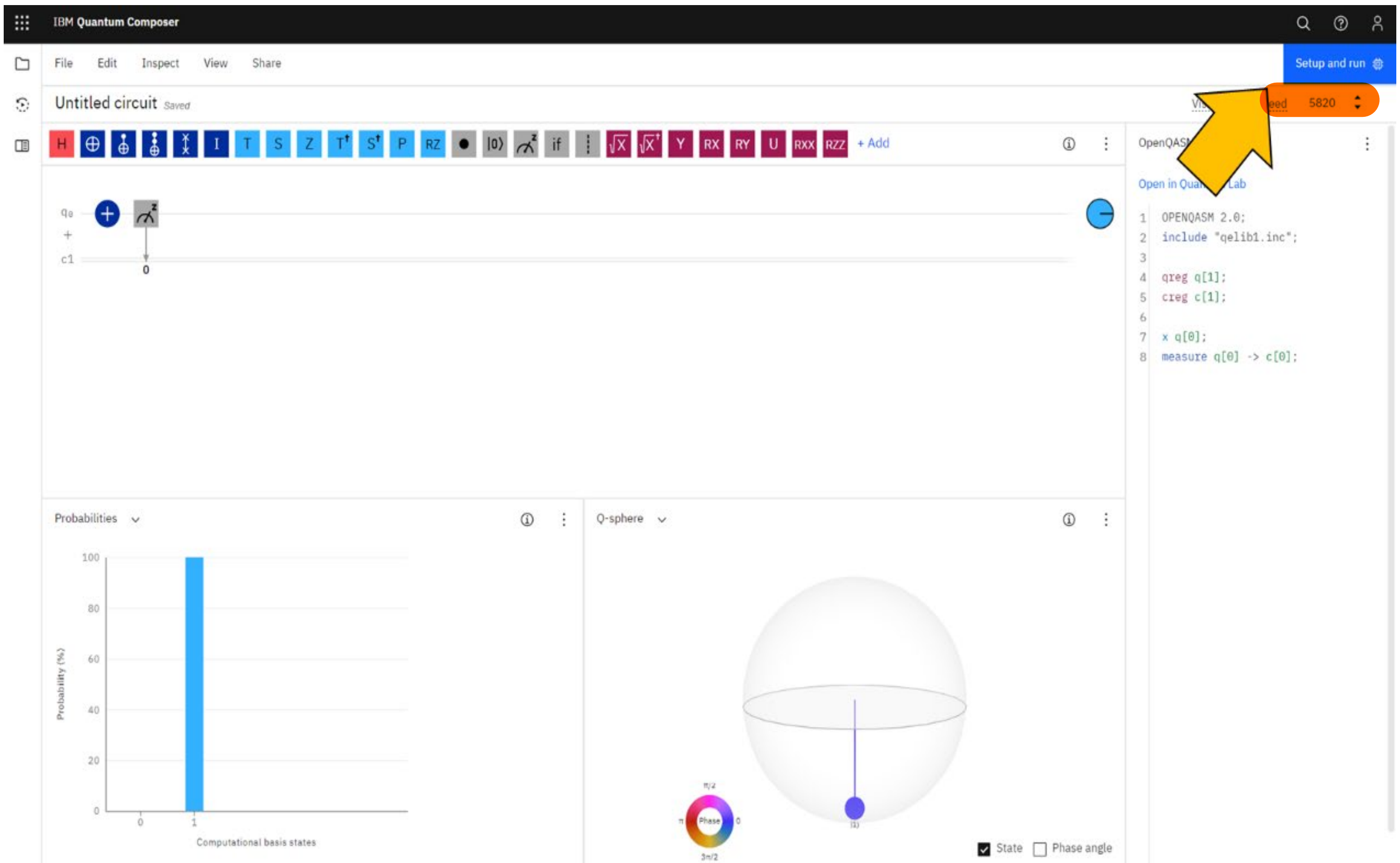


Your circuit is now looking like this

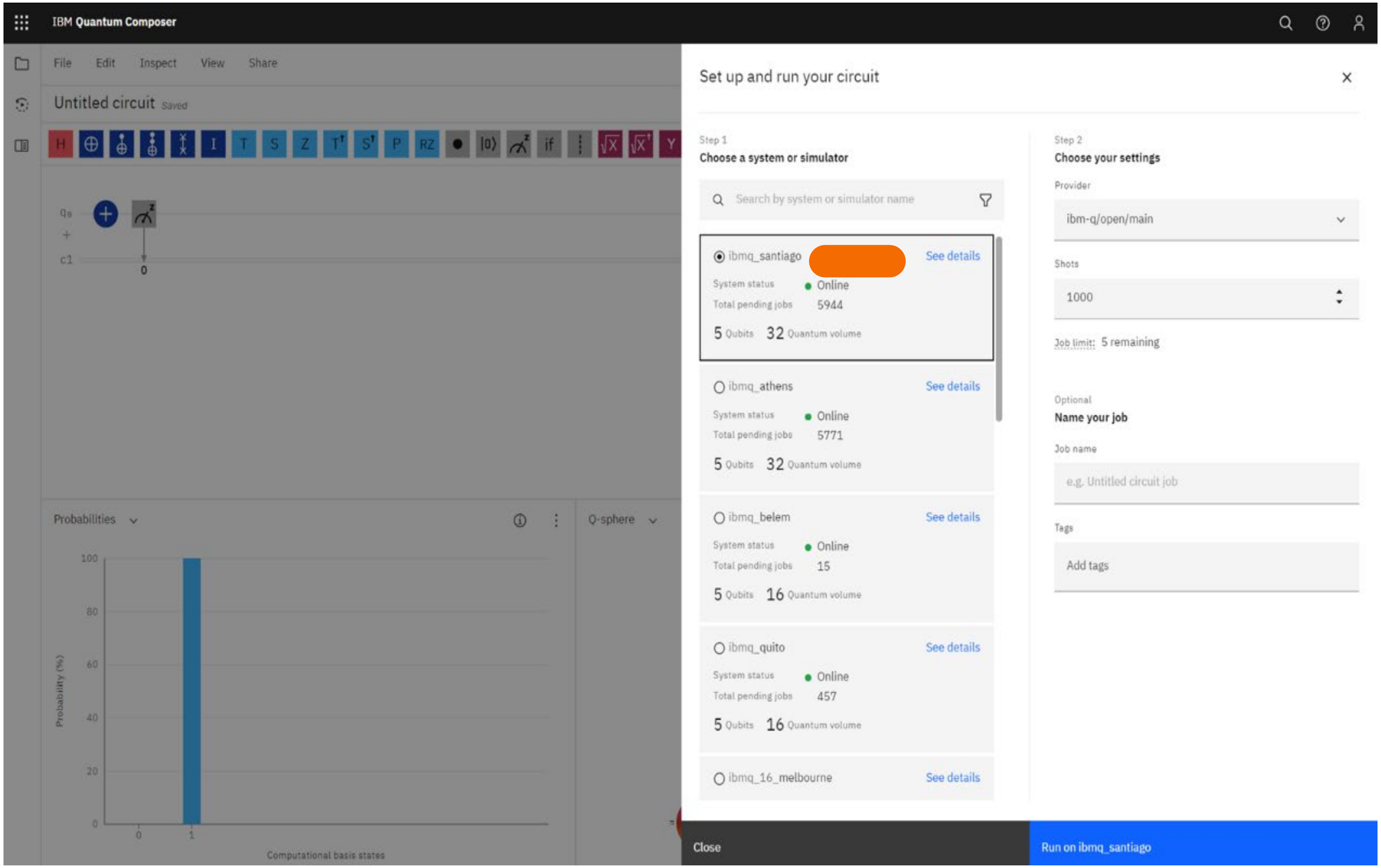


Step 5 : Setup your Circuit

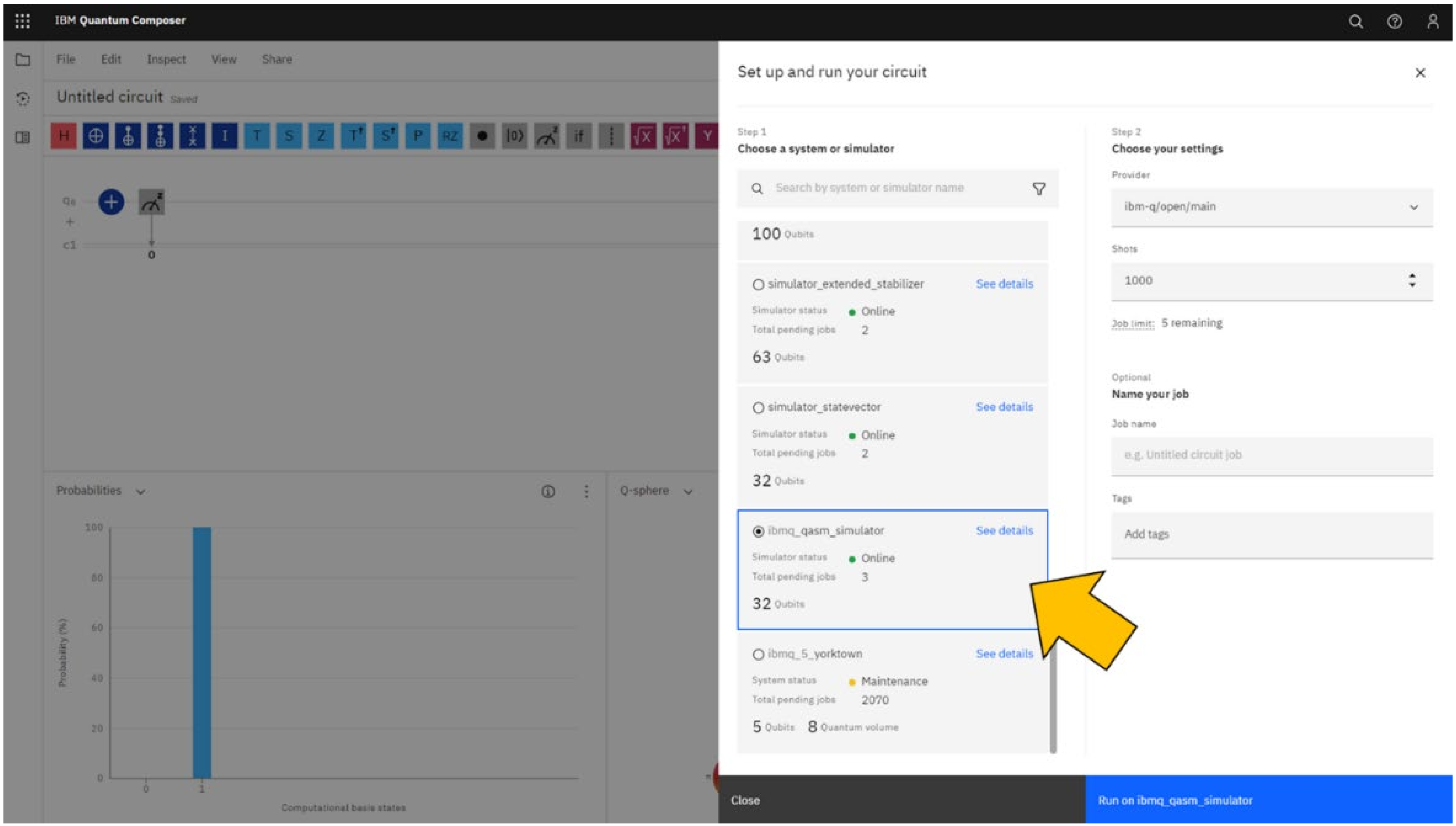
Select the parameters to run your circuit by clicking on the top right button:



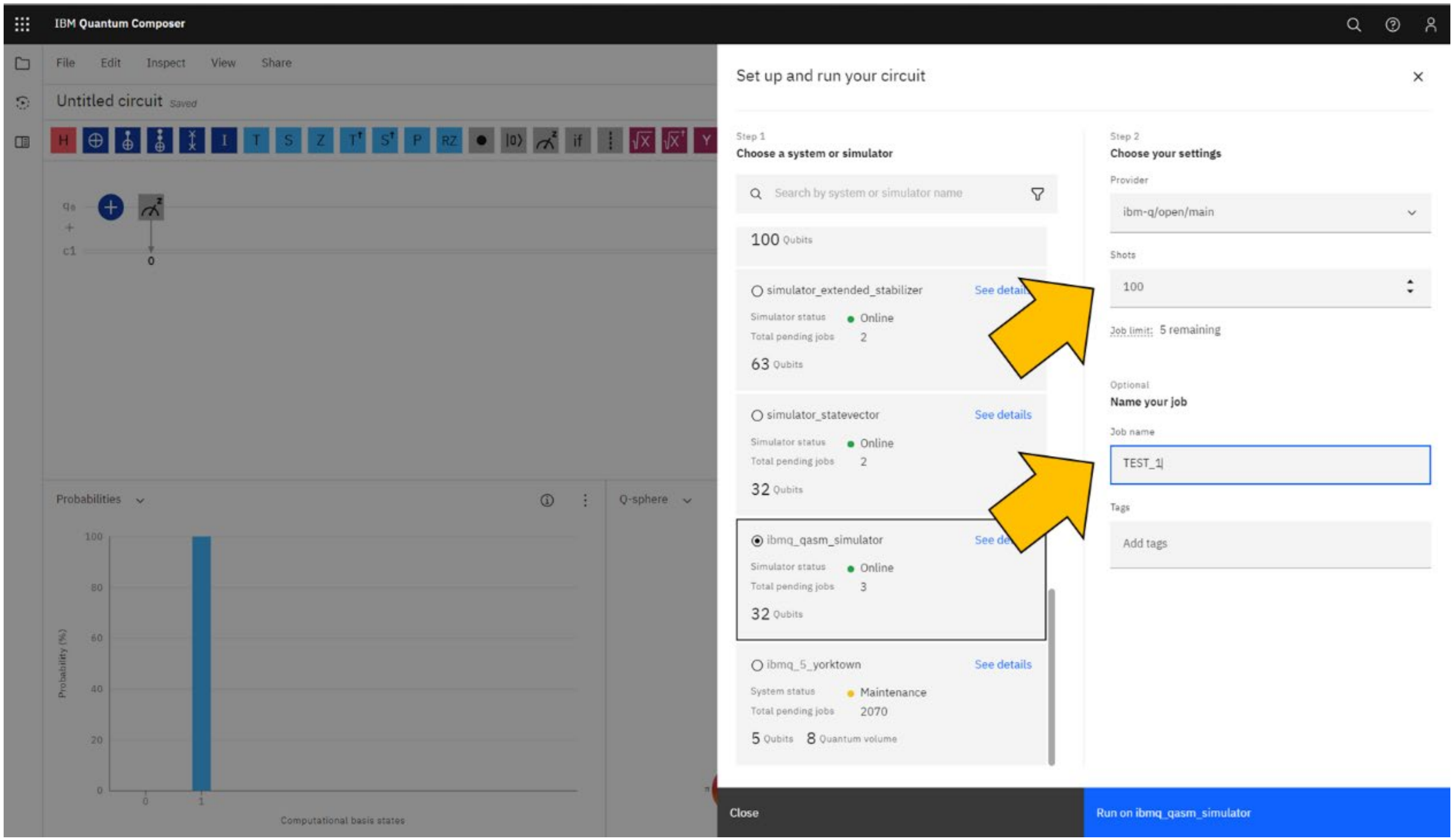
You should now see



Complete the information requested. In *Step 1: Choose a system or simulator,* select the **ibm_qasm_simulator**.

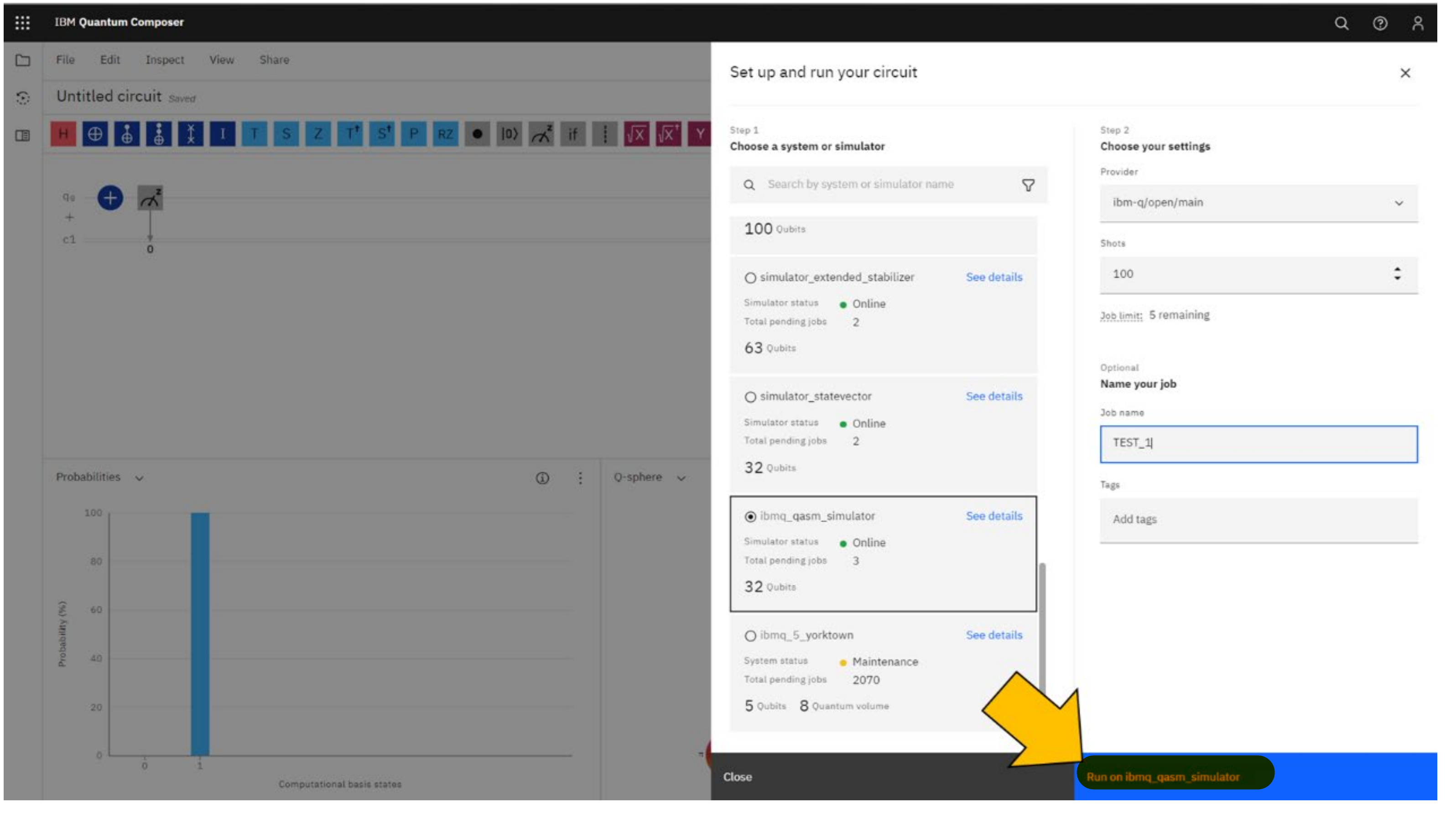


Then in *Step 2: Choose your settings*, type 100 to use 100 simulations or steps and name the circuit TEST_1.



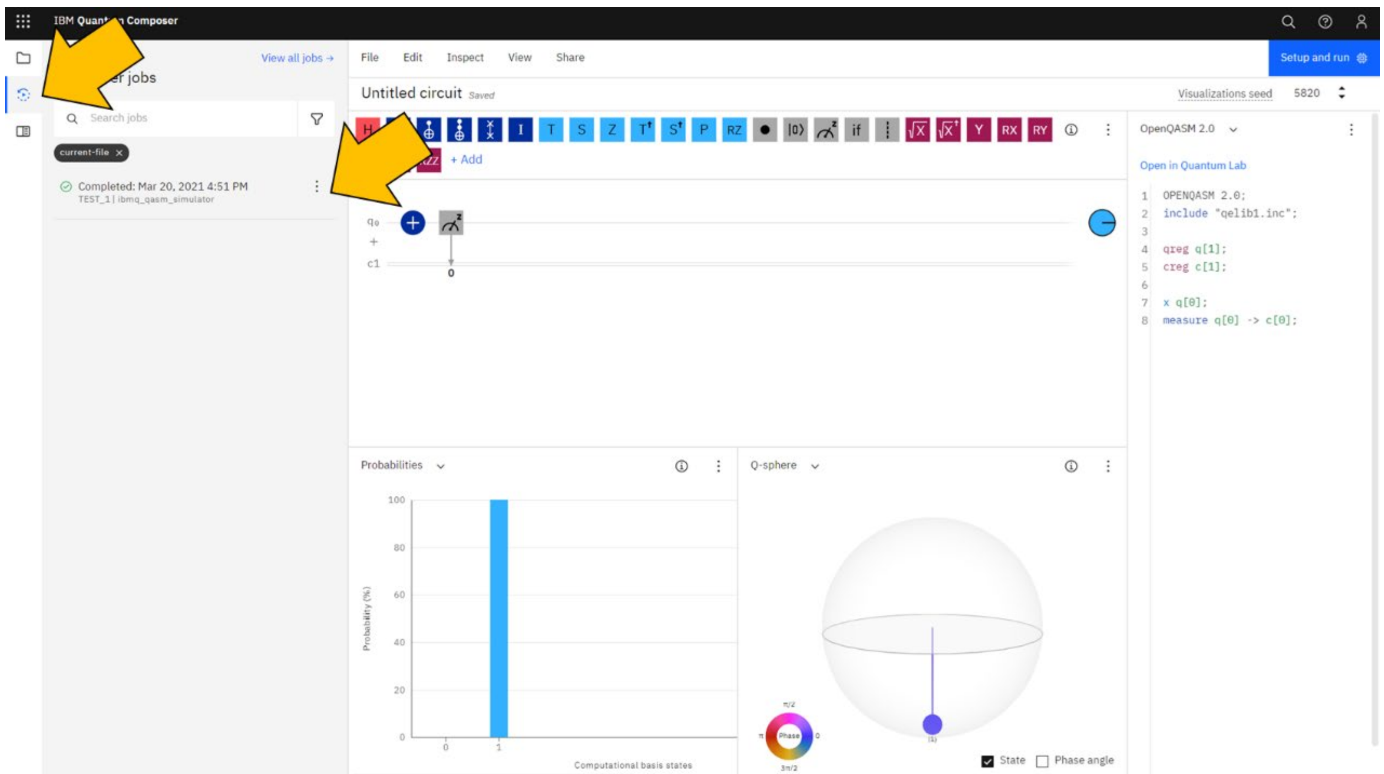
Step 6 Run your Circuit

Click on the bottom right button to run the ibm-qasm-simulator as below:



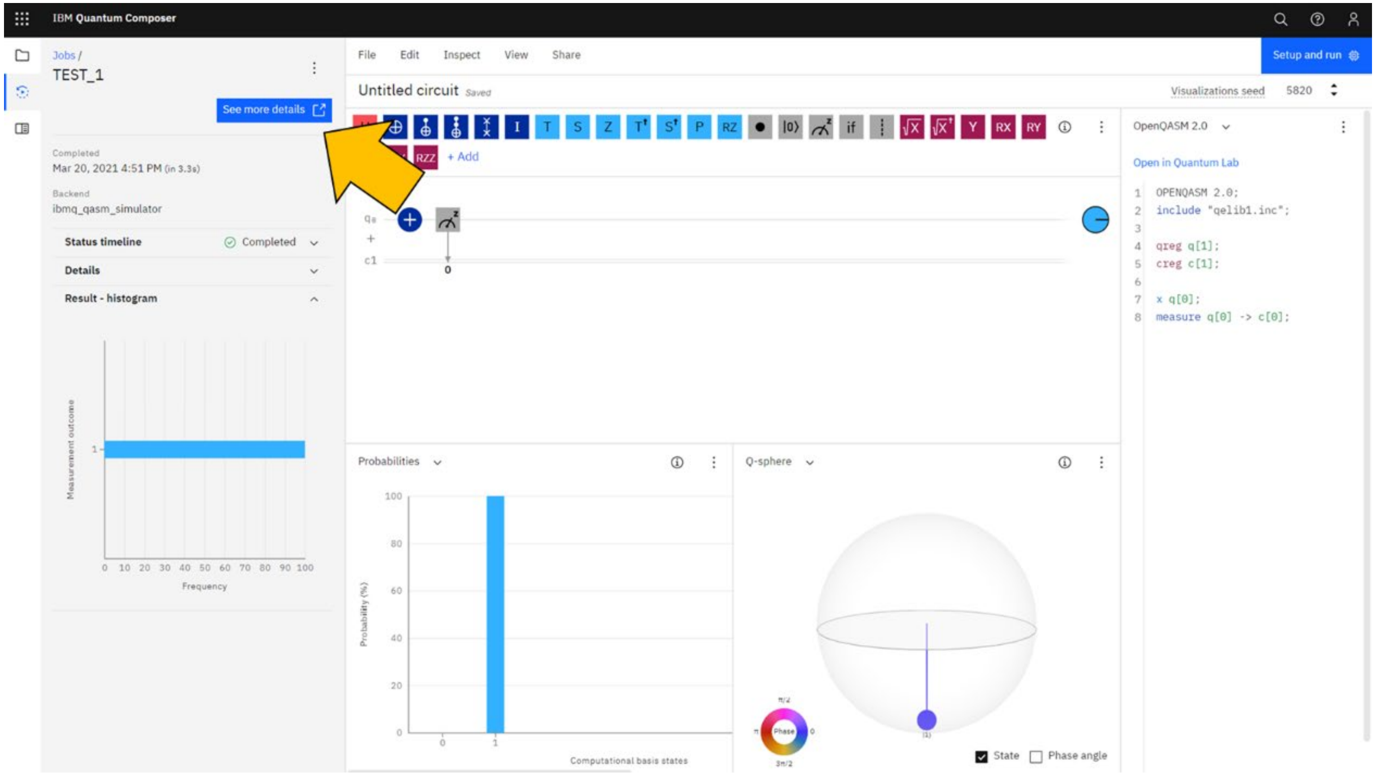
Step 7 Review the progress of your job

After a few seconds, click on the left button **Composer Jobs** to review the status of your job. In our case we have done a very simple circuit which will be calculated very quickly. For more complex jobs, more time will be required.

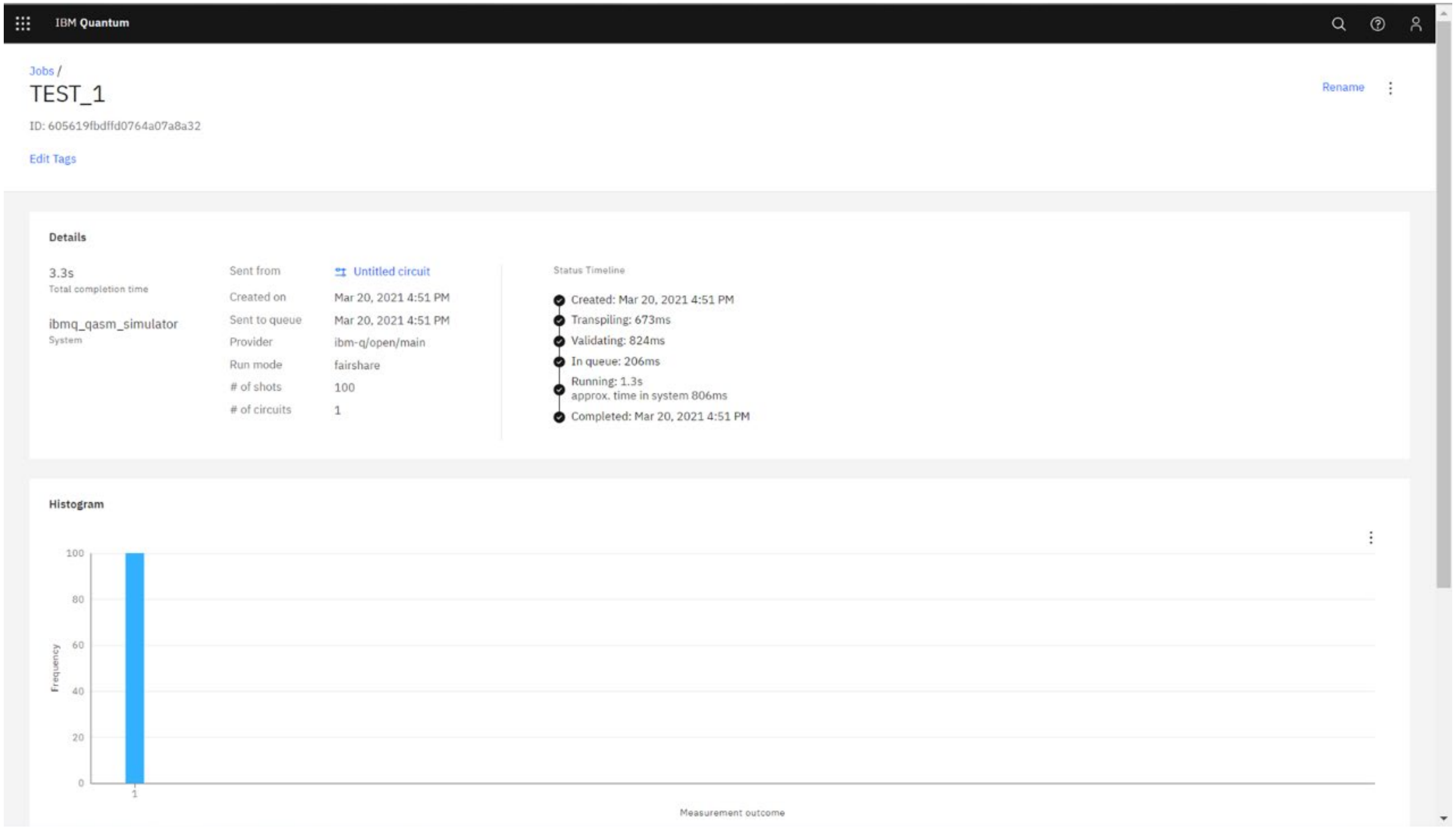


Step 8 : Get your simulation results

Clicking on the name of the job will open the results of the simulation in a new tab in your browser.



Clicking on the blue button “See More Details” will show more results in a new tab in the browser:



Congratulations! You have now created and executed your first quantum circuit. As you can see in the Histogram section, the probabilities of measuring a 1 in the qubit are 100%, just as we expected. In the next section, we will explore a complementary tool called Qiskit, which will allow us to do the same thing within Python.

Qiskit

Qiskit: an open-source framework for quantum computing

Qiskit is an open-source software development kit (SDK) for working with quantum computers. It is developed and maintained by IBM. It allows users to easily develop quantum programs as part of a Python environment. It is extremely flexible, allowing direct and detailed manipulation of circuits, pulses, and algorithms. These can then be run locally (in your own computer) or remotely (in one of the real quantum computers of IBM). Qiskit can be found in https://qiskit.org/.

Lab 2:
Your first circuit step-by-step with QISKIT

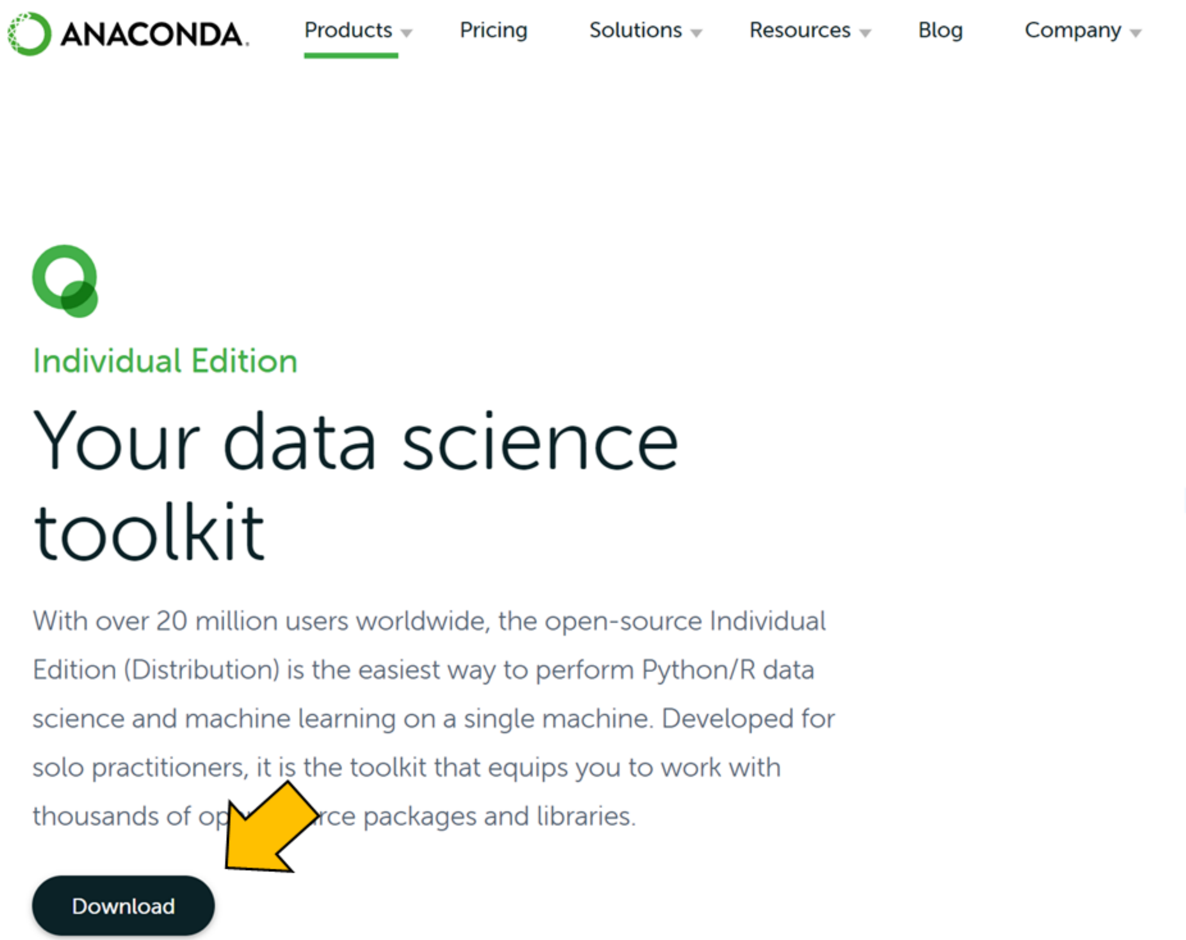
Lab 2: Your first circuit step-by-step with QISKIT

As we said, Qiskit then can be understood as module or library for Python, which allow us to run quantum programs. Note that it can be used for both: running the quantum program in a simulator or running the program in a real quantum computer. Here, we are going to repeat the exercise we did before with the IBM Quantum inLab 1, i.e. flipping a single qubit. But instead of running it online, we are going to run it in our own computer using our local Python environment.

TASK: **To flip a single qubit from $|0\rangle$ to $|1\rangle$.**

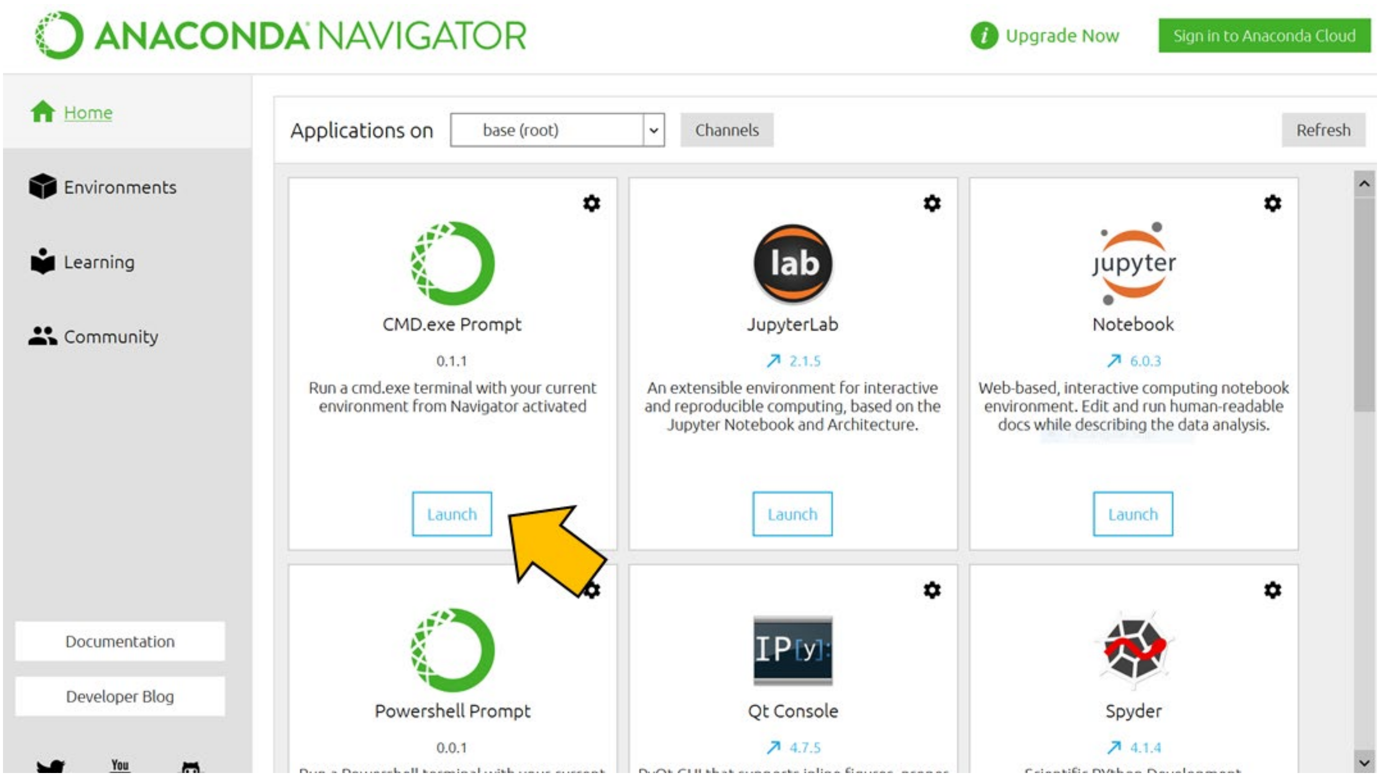
(LOCAL) SOLUTION: **Create a quantum circuit with a single qubit and a X Gate in Python using the module Qiskit.**

Step 1: Install Python in your computer



Step 2: Install the Qiskit module into your Python

Open the Anaconda Navigator and launch the CMD.exe Prompt.



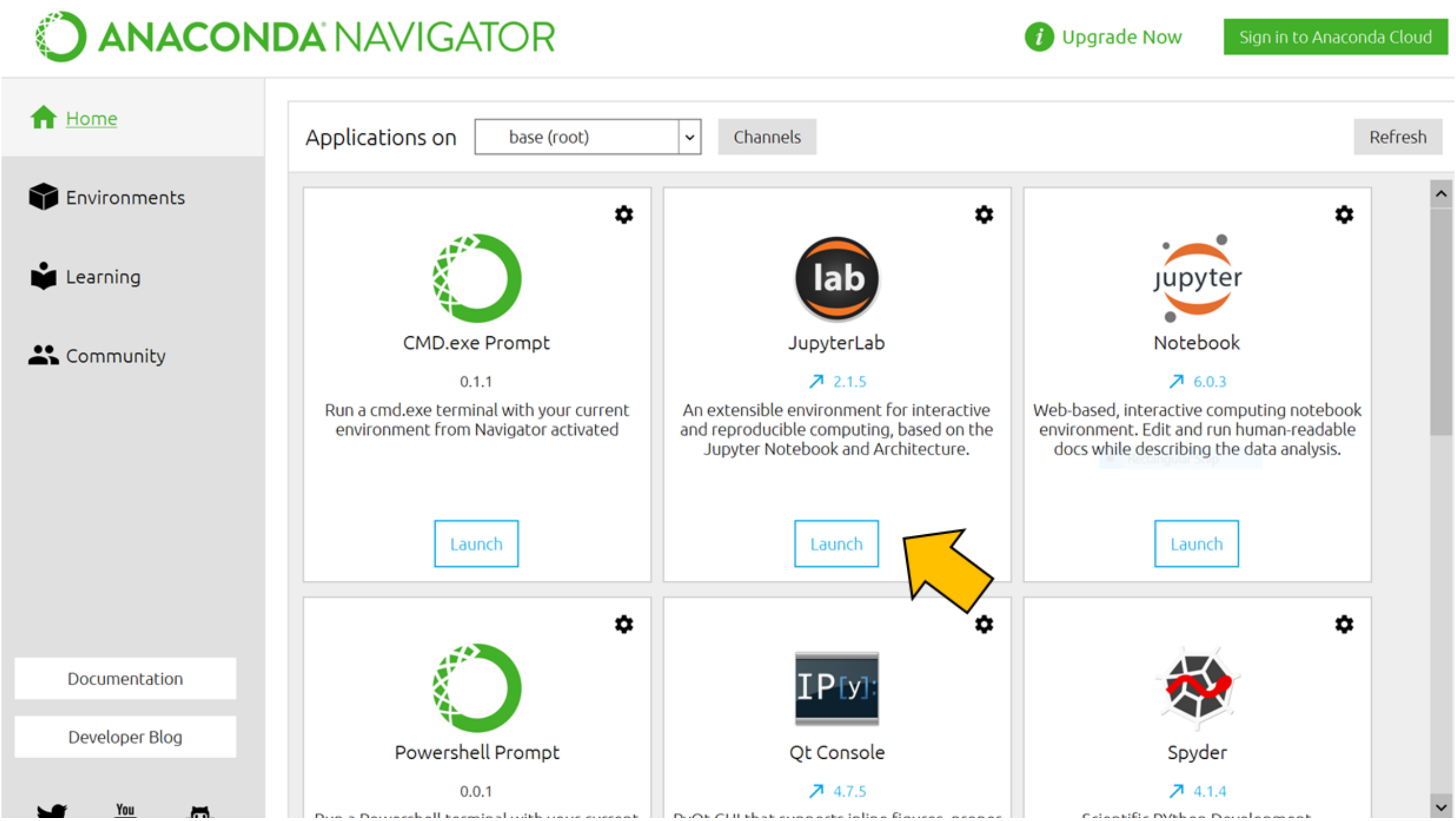
Step 3: Install the Qiskit tool into your local Python

Type in the command line: `pip install qiskit`

```
C:\WINDOWS\system32\cmd.exe - pip  install qiskit
Microsoft Windows [Version 10.0.19041.450]
(c) 2020 Microsoft Corporation. All rights reserved.

(base) C:\Users\apena>pip install qiskit
Collecting qiskit
  Downloading qiskit-0.23.1.tar.gz (4.1 kB)
Collecting qiskit-terra==0.16.1
  Downloading qiskit_terra-0.16.1-cp38-cp38-win_amd64.whl (7.8 MB)
     |████████████████████████████████| 7.8 MB 819 kB/s
Collecting qiskit-aer==0.7.1
  Downloading qiskit_aer-0.7.1-cp38-cp38-win_amd64.whl (24.0 MB)
     |████████████████████████████████| 24.0 MB 1.3 MB/s
Collecting qiskit-ibmq-provider==0.11.1
  Downloading qiskit_ibmq_provider-0.11.1-py3-none-any.whl (195 kB)
     |████████████████████████████████| 195 kB 1.3 MB/s
Collecting qiskit-ignis==0.5.1
  Downloading qiskit_ignis-0.5.1-py3-none-any.whl (204 kB)
     |████████████████████████████████| 204 kB 1.6 MB/s
Collecting qiskit-aqua==0.8.1
  Downloading qiskit_aqua-0.8.1-py3-none-any.whl (2.1 MB)
     |████████████████████████████████| 2.1 MB 1.1 MB/s
Collecting retworkx>=0.5.0
  Downloading retworkx-0.7.1-cp38-cp38-win_amd64.whl (527 kB)
     |████████████████████████████████| 527 kB 819 kB/s
Collecting dill>=0.3
  Downloading dill-0.3.3-py2.py3-none-any.whl (81 kB)
     |████████████████████████████████| 81 kB 862 kB/s
Requirement already satisfied: ply>=3.10 in c:\users\apena\anaconda3\lib\site-packages (from qiskit-terra==0.16.1->qiski
t) (3.11)
Requirement already satisfied: scipy>=1.4 in c:\users\apena\anaconda3\lib\site-packages (from qiskit-terra==0.16.1->qisk
```

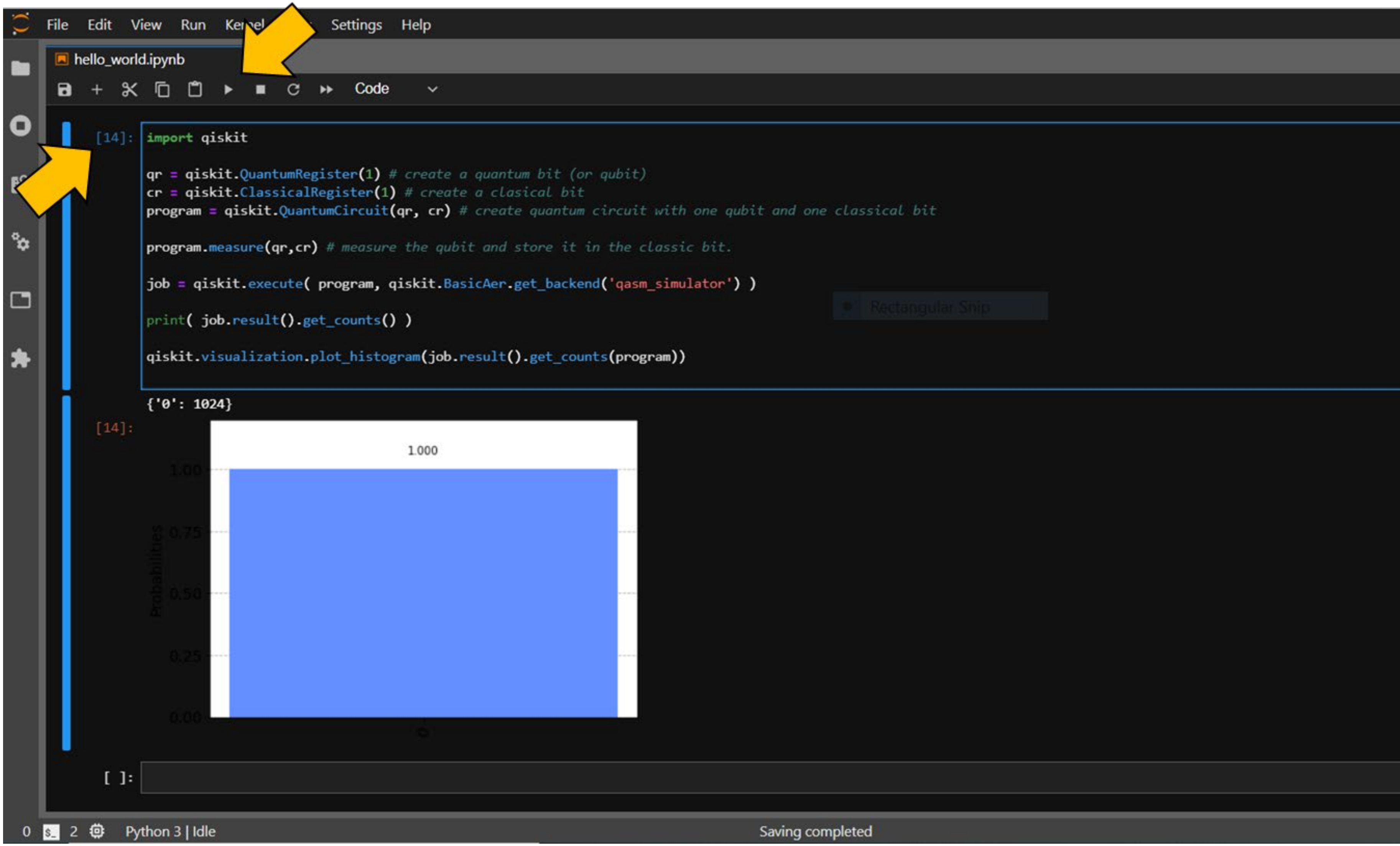
Step 4: Launch Jupyter Lab

From the Anaconda Explorer launch Jupyter Lab



Step 5: Type the code below into the first line of a Jupyter Lab Notebook and Run

```
import qiskit

qr = qiskit.QuantumRegister(1) # create qubit

cr = qiskit.ClassicalRegister(1) # create clasical bit

program = qiskit.QuantumCircuit(qr, cr) # create quantum circuit with one qubit
and one classical bit

program.x(qr[0]) # apply the X Gate to invert qubit

program.measure(qr,cr) # measure the qubit and store it in the classic bit


job = qiskit.execute( program, qiskit.BasicAer.get_backend('qasm_simulator') ) #
run job

print(job.result().get_counts()) # print numerical results

qiskit.visualization.plot_histogram(job.result().get_counts(program)) # draw
histogram
```


File Edit View Run Kernel Settings Help
hello_world.ipynb
Code
[14]:
import qiskit
qr = qiskit.QuantumRegister(1) # create a quantum bit (or qubit)
cr = qiskit.ClassicalRegister(1) # create a clasical bit
program = qiskit.QuantumCircuit(qr, cr) # create quantum circuit with one qubit and one classical bit
program.measure(qr,cr) # measure the qubit and store it in the classic bit.
job = qiskit.execute(program, qiskit.BasicAer.get_backend('qasm_simulator'))
print(job.result().get_counts())
qiskit.visualization.plot_histogram(job.result().get_counts(program))
{'0': 1024}
[14]:
1.000
[ ]:
0
2
Python 3 | Idle
Saving completed

Well done! Your result indicates that the simulation has been called 1024 times (the so-called shots in the IBM Q Experience parlance) and that in all cases the result is that the qubit has been flipped from 0 to 1.

References

Main reference book for quantum computing:

Michael A. Nielsen, Isaac L. Chuang. Quantum Computation and Quantum Information: 10th Anniversary Edition. Cambridge University Press, 2010.

On quantum computing in general:

Robert S. Sutor. Dancing with Qubits: How quantum computing works and how it can change the world. Packt Publishing, 2019

Noson S. Yanofsky, Mirco A. Mannucci. Quantum Computing for Computer Scientists. Cambridge University Press, 2008.

Wolfgang Scherer. Mathematics of Quantum Computing: An Introduction. Springer-Nature, 2019.

Rajendra K. Bera. The Amazing World of Quantum Computing. Springer Nature, 2020.

On using IBM solutions:

Robert Loredo. Learn Quantum Computing with Python and IBM Quantum Experience. Packt Publishing, 2020.

Hassi Norlén. Quantum Computing in Practice with Qiskit and IBM Quantum Experience. Packt Publishing, 2020.

Online Courses:

Quantum Computing Fundamentals, MIT xPRO

https://learn-xpro.mit.edu/quantum-computing

Understanding Quantum Computers

https://www.futurelearn.com/courses/intro-to-quantum-computing

Research Papers:

Woerner, S., Egger, D.J. Quantum risk analysis. npj Quantum Inf 5, 15 (2019).

D. Egger, R. Garcia Gutierrez, J. Cahue Mestre and S. Woerner, "Credit Risk Analysis using Quantum Computers" in IEEE Transactions on Computers, vol. , no. 01, pp. 1-1, 5555, 2019.

Jacak, J.E., Jacak, W.A., Donderowicz, W.A. et al. Quantum random number generators with entanglement for public randomness testing. Sci Rep 10, 164 (2020).

Patrick Rebentrost, Brajesh Gupt, and Thomas R. Bromley. Quantum computational finance: Monte Carlo pricing of financial derivatives. Phys. Rev. A 98, 022321, 2018.

Nikitas Stamatopoulos, Daniel J. Egger, Yue Sun, Christa Zoufal, Raban Iten, Ning Shen, and Stefan Woerner. Option Pricing using Quantum Computers. Quantum 4, 291 (2020).

Panagiotis K. Barkoutsos, Giacomo Nannicini, Anton Robert, Ivano Tavernelli, and Stefan Woerner. Improving Variational Quantum Optimization using CVaR. Quantum 4, 256 (2020).

Appendix: The Word in the Street

BARCLAYS

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Quantum computing

Researchers have known about the theoretical potential of quantum computing for decades, but it is only in recent years that quantum computers have been developed with sufficient power to start exploiting the technology.

In essence, quantum computing is a powerful new technology that will allow us to solve certain problems that are more complicated than classical computers currently allow. For example, it could potentially complete complex calculations in seconds that could take years to finish on a classical computer.

This can be a challenging topic to get to grips with from a beginner's perspective, so in the boxes below, we have given an easy-to-understand introduction to the technology. They cover an overview of the fundamental building blocks of quantum computing, and provide answers to some of the most frequently answered questions about the technology.

https://home.barclays/who-we-are/innovation/quantum-computing/

Quantum computing at Barclays today

We are currently conducting experiments that focus on some very specific challenges we come across in the banking industry, which will help us learn how quantum computing could benefit particular types of work that we do.

For example, our initial tests focused on how quantum computing could potentially help us to optimise the settlement of batches of securities transactions.

Another important aspect of the quantum computing work we are doing relates to risk mitigation, and how to behave responsibly in finding new uses for the technology.

Crédit Agricole successfully experiments with quantum computing

by Ray Fernandez in Banking
on January 26, 2023, 9:56 AM EST

As financial institutions continue to invest in quantum computing, the French bank announced two successful experiments for derivatives and credit calculations.

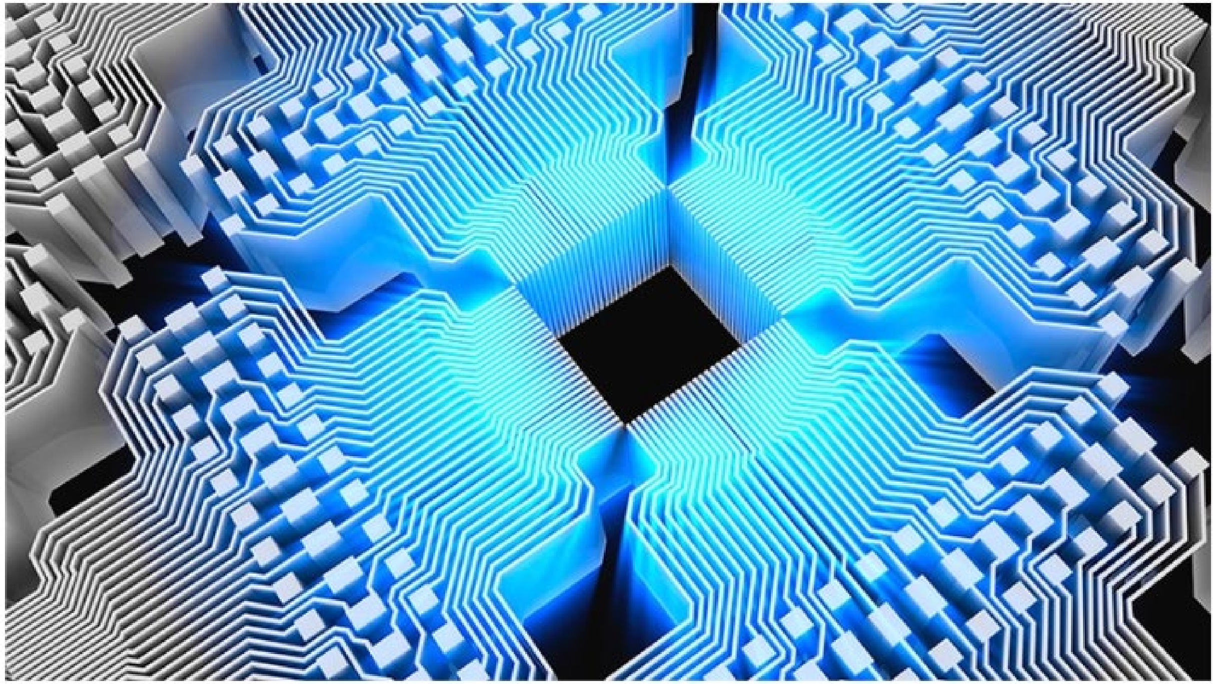
The two experiments, which began in mid-2021, aimed to evaluate the contribution of an algorithmic approach inspired by quantum computing and quantum computers' potential in two areas: The valuation of financial products and the assessment of credit risks.

"These two proofs of concept demonstrated the potential and reality of quantum computing for finance, despite these technologies still being in their infancy," said Ali El Hamidi, the project's sponsor at Crédit Agricole. "We took advantage of this initiative to start developing the internal skills to prepare for a technological breakthrough. If it happens, it will have a direct and decisive impact on competitiveness in our sector."

https://www.techrepublic.com/article/credit-agricole-experiments-quantum/

Goldman Sachs

Engineering Quantum Algorithms



Goldman Sachs introduces quantum algorithms developed by its Research and Development Engineering team that could allow the firm to price financial instruments at quantum speeds.

Quantum algorithms could do complex financial calculations with blazing speed. Finance was one of the first domains to embrace Big Data, and the drive to innovate continues. Much of the science behind the pricing of financial assets involves simulating large numbers of different statistical

https://www.goldmansachs.com/careers/possibilities/quantum-computing/

Quantum algorithms could do complex financial calculations with blazing speed. Finance was one of the first domains to embrace Big Data, and the drive to innovate continues.

In the financial markets, computing speed is a giant advantage. That’s why Goldman Sachs has brought on foremost researchers to guide the firm in harnessing the power of quantum computing and applying it to our processes.

Our engineers are hard at work developing tools that will help rapidly assess the markets and, at times, alter the way we price some financial instruments.

EY Building a better working world

Insights Services Industries Careers About us

Press release

14 Apr. 2023 | London, GB

EY and IBM expand strategic alliance into quantum computing

Press contact

Barbara Dimajo

Assistant Director, Media Relations and Social Media Ecosystems, Ernst & Young LLP

Related topics

- **Provides EY teams access to IBM quantum systems and furthers their engagement in the quantum ecosystem as part of the IBM Quantum Network**
- **Presents opportunity to create quantum computing programs for organizations and develop applications to solve complex business challenges**

The EY organization and IBM (NYSE: IBM) today announced that EY Global Services Limited will be joining the IBM Quantum Network, further enabling EY teams to explore solutions with IBM that could help resolve some of today's most complex business challenges. The EY organization will gain access to IBM's fleet of quantum computers over the cloud, and will become part of the IBM Quantum Network's community of organizations working to advance quantum computing.

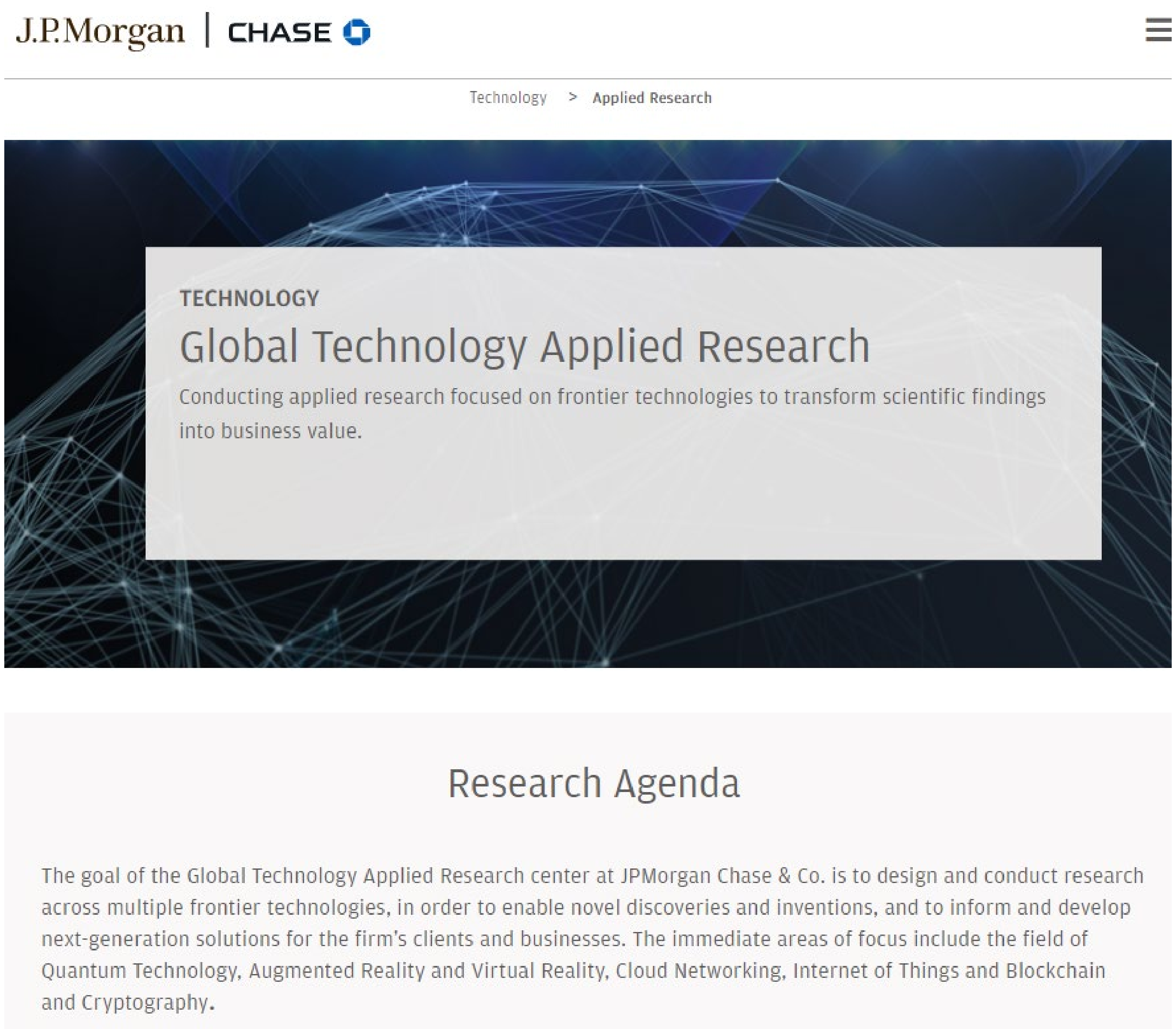
Quantum computing is a rapidly emerging technology that harnesses the laws of quantum mechanics to solve problems that today's most powerful supercomputers cannot practically solve. EY teams will leverage their access to the world's largest fleet of quantum computers to explore solutions to enterprise challenges across finance, oil and gas, healthcare, and government.

The EY organization established its own Global Quantum Lab last year with a mission to harness quantum value in the domains of trust, transformation and sustainability.

Using IBM quantum technology, EY teams plan to conduct leading-class practice research to uncover transformative use cases, including:

the reduction of CO2 emissions from classical computing, the improvement of safety and accuracy of self-driving cars, and most critically, integrate quantum benefits into organizations' mainstream systems for data processing and enterprise decision making.

https://www.ey.com/en_au/news/2023/04/ey-and-ibm-expand-strategic-alliance-into-quantum-computing



J.P.Morgan | CHASE

Technology > Applied Research

TECHNOLOGY

Global Technology Applied Research

Conducting applied research focused on frontier technologies to transform scientific findings into business value.

Research Agenda

The goal of the Global Technology Applied Research center at JPMorgan Chase & Co. is to design and conduct research across multiple frontier technologies, in order to enable novel discoveries and inventions, and to inform and develop next-generation solutions for the firm's clients and businesses. The immediate areas of focus include the field of Quantum Technology, Augmented Reality and Virtual Reality, Cloud Networking, Internet of Things and Blockchain and Cryptography.

https://www.jpmorgan.com/technology/applied-research

JPMorgan Chase is one of the first financial institutions worldwide to invest in quantum computing and to build an internal team of scientists to work on new quantum algorithms and applications to address business use cases in finance, AI, optimization and cryptography.

To date, the program has produced new quantum algorithms for use cases such as portfolio optimization, option pricing, risk analysis, and numerous applications in the realm of Machine Learning, ranging from fraud detection to Natural Language Processing.

The ultimate goal is to implement quantum solutions for the firm's relevant use cases and embrace an industry-leading position in the chase for quantum advantage and quantum supremacy.

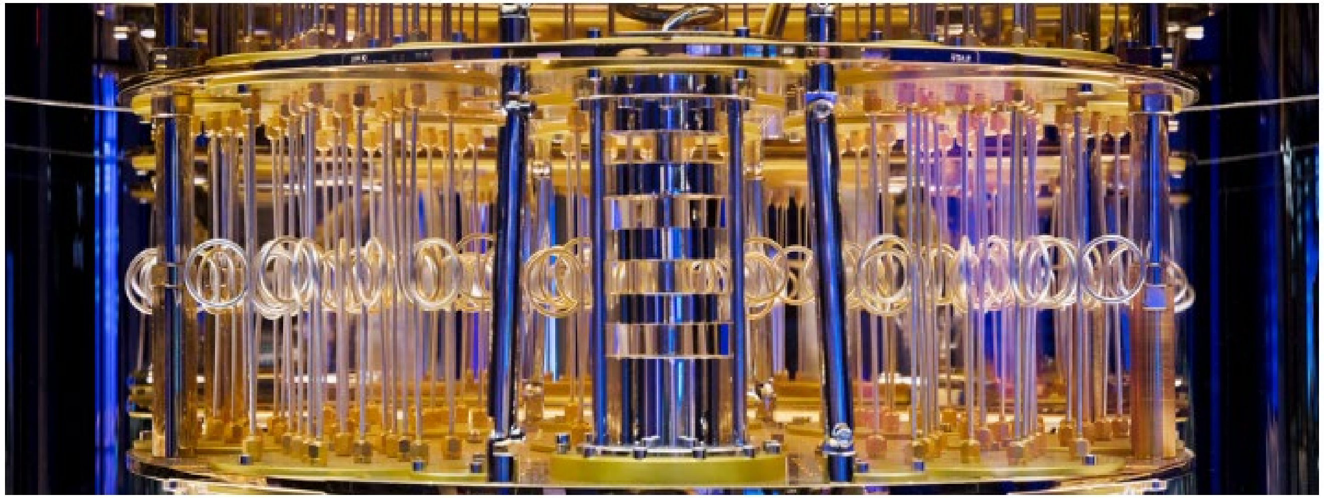
IBM

HSBC Working with IBM to Accelerate Quantum Computing Readiness

Bank envisions application of quantum capabilities for priorities such as pricing and portfolio optimisation, sustainability, risk and fraud

Expands internal talent with quantum specialists

Mar 29, 2022



The new three-year collaboration is designed to bolster HSBC's expertise in quantum computing and ensure its organizational readiness to take full advantage of the technology.

HSBC will explore the use of quantum computing for pricing and portfolio optimisation, to advance its net zero goals, and to mitigate risks, including identifying and addressing fraudulent activity. The bank will upskill colleagues in quantum technology through internal training programmes, as well as actively recruiting quantum computing research scientists, to build a dedicated capability within its innovation team.

https://newsroom.ibm.com/2022-03-29-HSBC-Working-with-IBM-to-Accelerate-Quantum-Computing-Readiness

1QBit

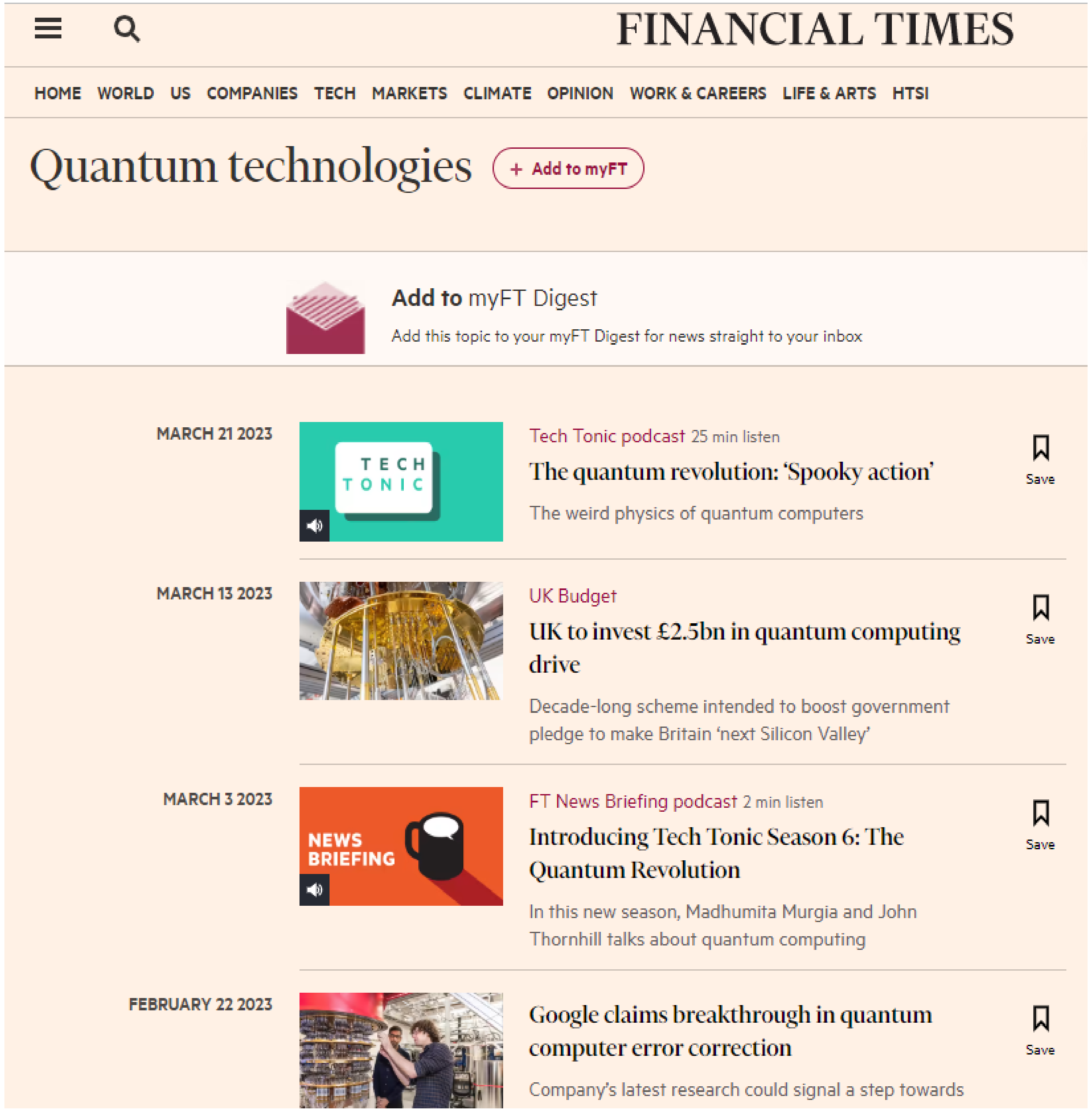
Minimizing Financial Risk Using Quantum Computing

The study of finance relies on making the best possible decisions despite future uncertainty. There is always risk when making financial decisions, and it goes hand in hand with return. A core problem in computational finance is risk minimization, and classical computers (that is, non-quantum computers) are often used to solve this problem using a variety of algorithms. But such methods are not always the solution. It will be explained below why there are limitations to using classical computers to solve challenging real-world financial problems, and what is being done to overcome these limitations by means of quantum computing.

… quantum amplitude estimation has been shown to provide a quadratic speed-up over classical Monte Carlo simulations for portfolio optimization.[2] To illustrate, a quadratic speed-up means that if a conventional Monte Carlo method has a runtime of one hour, the quantum amplitude estimation algorithm would only take around one minute to achieve the same result.

Even modest speedups for optimizing risk–return problems can have a large impact in terms of financial reward. So, it is likely that quantum computing will continue to be used as a tool to study computational finance, especially as quantum technology matures.

https://1qbit.com/blog/market-sentiment-meter-msm/minimizing-financial-risk-using-quantum-computing/



https://www.ft.com/quantum-technologies

The Plan for Quantum will more than double the funding that is available to researchers in industry and universities under the present £1bn National Quantum Technologies Programme, according to Whitehall insiders.

The programme, to be announced by chancellor Jeremy Hunt in Wednesday's Budget, is intended to put more money behind a government pledge to turn Britain into "the next Silicon Valley".

The National Quantum Computing Centre, nearing completion on the Harwell Campus in Oxfordshire, will play a leading role in the expanded programme. But the government aims to distribute support around the country as part of a push to create a "future network of research hubs".

Quantum Information Processing (2023) 22:51
https://doi.org/10.1007/s11128-022-03777-2

Quantum computing for financial risk measurement

Sascha Wilkens[1] · Joe Moorhouse[2]

Received: 12 February 2022 / Accepted: 25 November 2022

Abstract
Quantum computing allows a significant speed-up over traditional CPU- and GPU-based algorithms when applied to particular mathematical challenges such as optimisation and simulation. Despite promising advances and extensive research in hard- and software developments, currently available quantum systems are still largely limited in their capability. In line with this, practical applications in quantitative finance are still in their infancy. This paper analyses requirements and concrete approaches for the application to risk management in a financial institution. On the examples of Value-at-Risk for market risk and Potential Future Exposure for counterparty credit risk, the main contribution lies in going beyond textbook illustrations and instead

https://inspirehep.net/literature/2624855

- Pricing of standard ('vanilla'), path-dependent (e.g. barrier and Asian) and multi-asset options in a Black-Scholes [9] and local volatility [28] framework [4, 18, 33, 38, 51, 54, 64, 72, 73, 75, 76, 80]
- Pricing of options under a stochastic volatility [16] and jump-diffusion process [95]
- Pricing of American-style options [27, 62]
- Pricing of interest-rate derivatives with a multi-factor model [58, 84]
- Pricing of collateralised debt obligations (CDOs) [83]
- Estimation of risk measures such as VaR (see also Sect. 4), Conditional VaR (CVaR) [91] and the corresponding risk contributions [63]
- Estimation of credit risk (Economic Capital) [30]
- Sensitivity analysis for a (business) risk model at an exchange [15]

- Portfolio optimisation—construction of ‘optimal’ portfolios, for instance, in terms of the best trade-off between expected return and risk [6, 26, 46, 56, 70, 87, 88]
- Time series forecasting [31]
- (High-frequency) trading and arbitrage [21, 94]
- Credit scoring and classification [61]
- Handling of transaction settlements (i.e. the exchange of securities and cash between parties) at a clearing house [13]