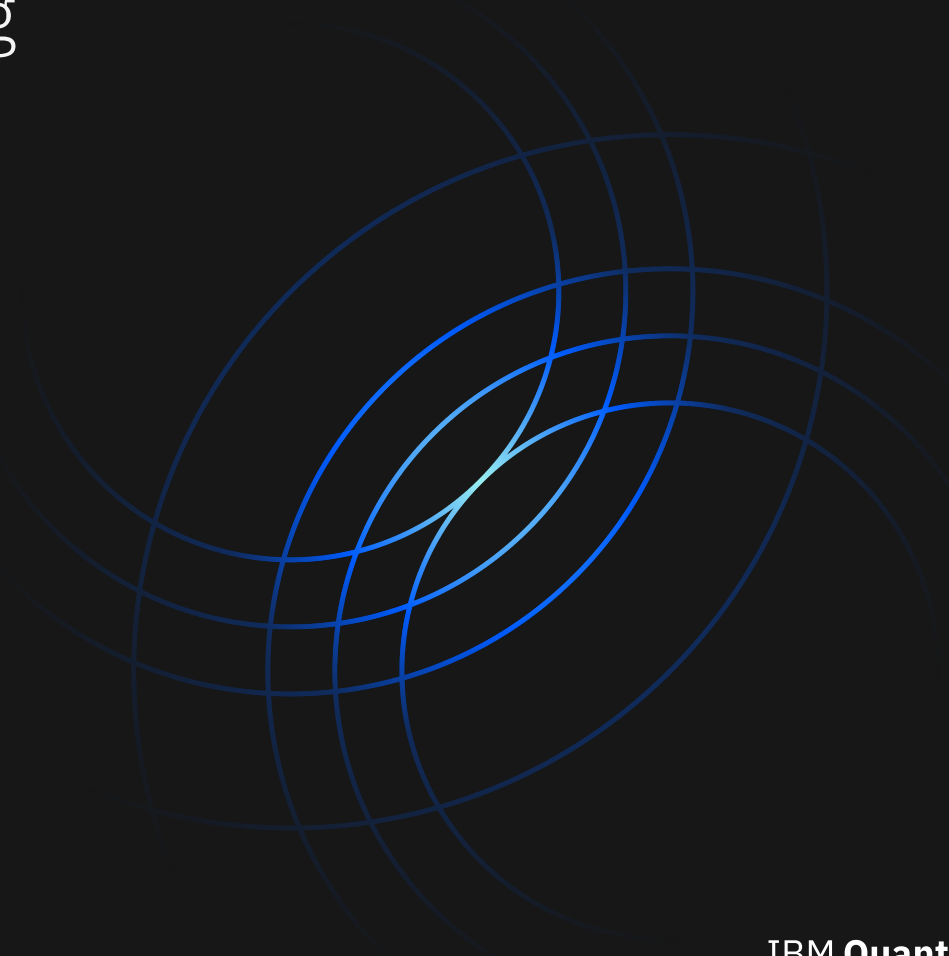
# IBM Quantum Computing

IBM Quantum Ambassador





IBM **Quantum**

# Agenda

09:30-10:00
IBM Quantum Strategy and Roadmap

10:00-11:00
IBM Quantum website and Circuit Composer

BREAK 15’

11:15-12:15
Qiskit overview and quantum programming basics

BREAK 15’

12:30-13:30
A practical application - VQE notebook

**Pietro Rizzo**
Enterprise Strategy Manager

**Federico Mattei**
Innovation and Technical Leader

**Federico Accetta**
Cloud Engineer

**Luca Crippa**
Public Cloud Technical Specialist

# IBM **Quantum** – On the cloud since May 2016

Over 400,000 registered users have run …

over 2 TRILLION hardware quantum circuits in total, and users run …

over 4 BILLION hardware quantum circuits on a typical day on …

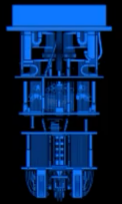
more than 25 quantum computing systems on the IBM Cloud, and written over

1500+ scientific and research papers.

Quantum developer

IBM Cloud

IBM Quantum Systems



# Frictionless development for quantum computing



Developer using classical

Developer using quantum

Same tools
Same languages
Same code

# Development Roadmap

Executed by IBM
On target

IBM Quantum

| | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | Beyond 2026 |
|---|---|---|---|---|---|---|---|---|
| | Run quantum circuits on the IBM cloud | Demonstrate and prototype quantum algorithms and applications | Run quantum programs 100x faster with Qiskit Runtime | Bring dynamic circuits to Qiskit Runtime to unlock more computations | Enhancing applications with elastic computing and parallelization of Qiskit Runtime | Improve accuracy of Qiskit Runtime with scalable error mitigation | Scale quantum applications with circuit knitting toolbox controlling Qiskit Runtime | Increase accuracy and speed of quantum workflows with integration of error correction into Qiskit Runtime |
| Model Developers | | | | | Prototype quantum software applications → Quantum software applications | | Machine learning \| Natural science \| Optimization | |
| Algorithm Developers | | Quantum algorithm and application modules | | | Quantum Serverless | | | |
| | | Machine learning \| Natural science \| Optimization | | | Intelligent orchestration | Circuit Knitting Toolbox | Circuit libraries | |
| Kernel Developers | Circuits | | Qiskit Runtime | | | | | |
| | | | | Dynamic circuits | Threaded primitives | Error suppression and mitigation | | Error correction |
| System Modularity | Falcon 27 qubits | Hummingbird 65 qubits | Eagle 127 qubits | Osprey 433 qubits | Condor 1,121 qubits | Flamingo 1,386+ qubits | Kookaburra 4,158+ qubits | Scaling to 10K-100K qubits with classical and quantum communication |
| | | | | | Heron 133 qubits x p | Crossbill 408 qubits | | |

# The three key metrics for measuring quantum computing performance



## Scale

Measured by **number of qubits** which indicates the amount of information we can encode in the quantum system.

High coherence, high reliability, lower cost

| 2020 | 2021 | 2022 |
|---|---|---|
| 65 qubits | 127 qubits | 433 qubits |

## Quality

Measured by **Quantum Volume** which indicates quality of circuits and how faithfully circuits are implemented in hardware.

Need low operation errors, meaning large Quantum Volume

| 2020 | Today | 2022 |
|---|---|---|
| 32 QV | 512 QV | 1024 QV |

## Speed

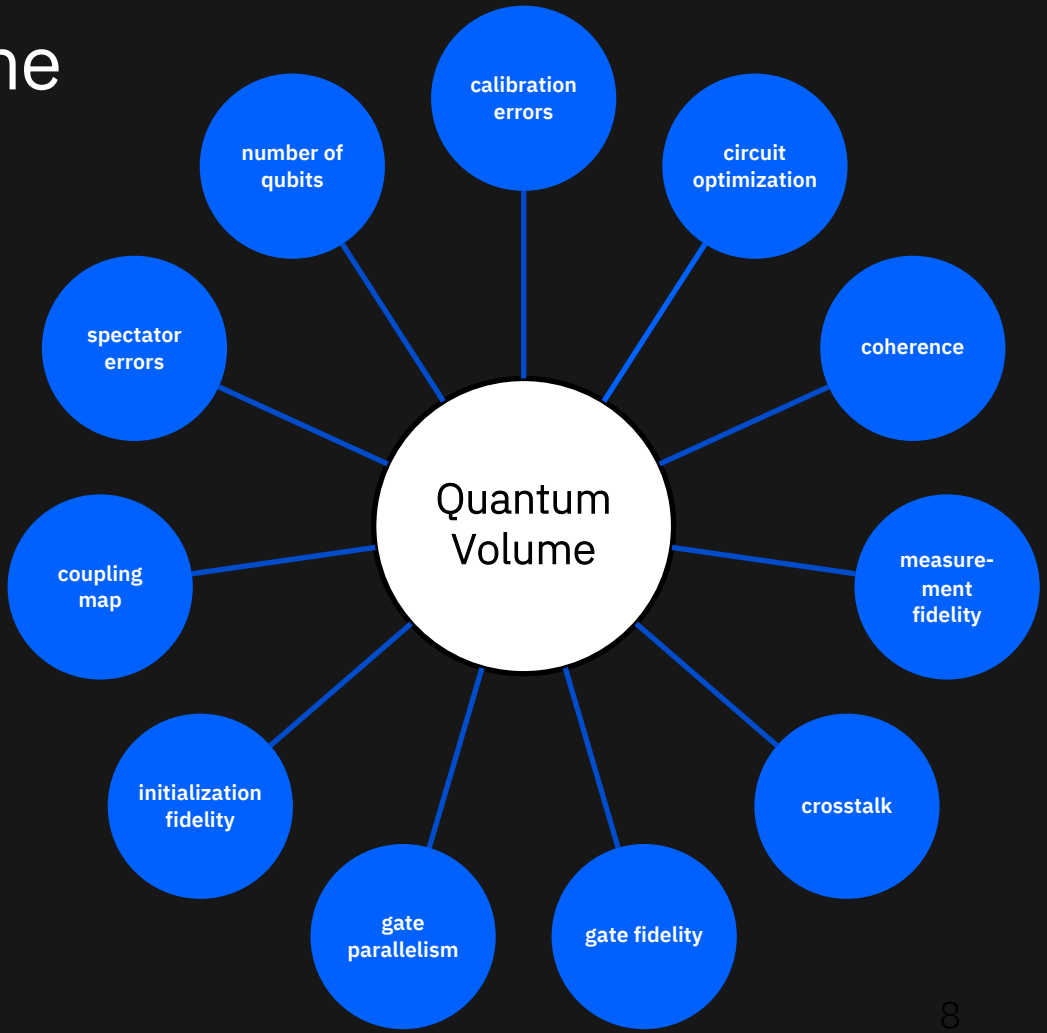
Measured by **CLOPS (Circuit Layer Operations Per Second)** which indicates how many circuits can run on hardware in a given time.

Seamless synchronization of quantum and classical circuits increases execution rate

| 2020 | Today | 2022 |
|---|---|---|
| 200 (Inferred) | 1.4K CLOPS | 10K CLOPS |

# Quantum Volume

**Many factors contribute to the performance of the overall system**



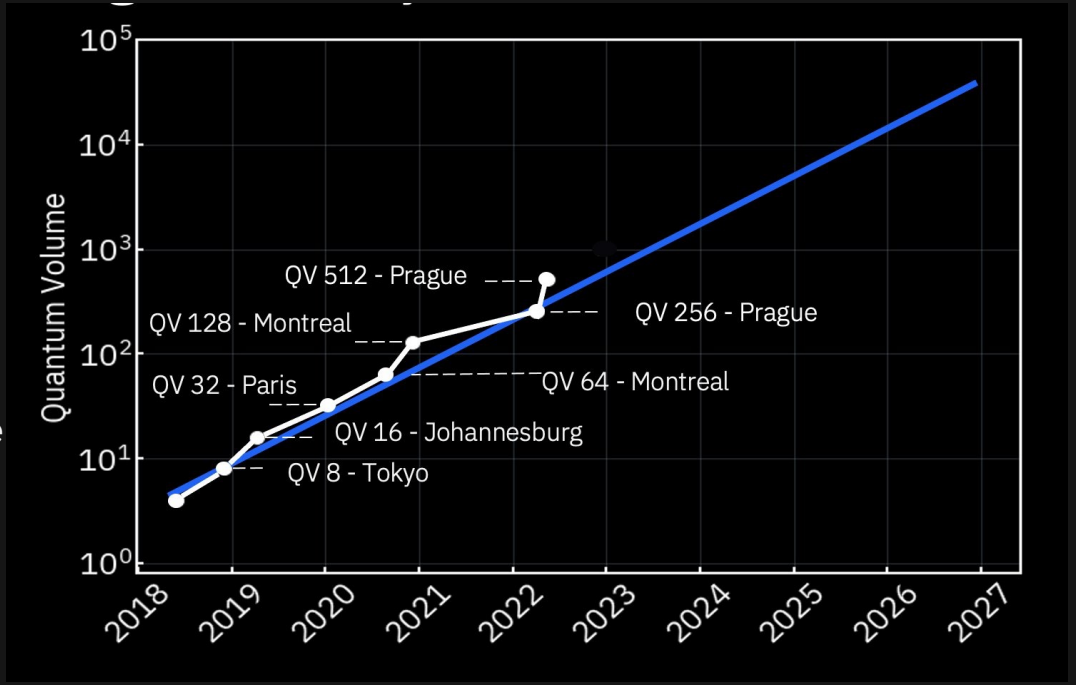
# Ahead of the curve on quality



We have committed to doubling quantum volume every year. So far, we are a little ahead of pace.

Today, improvements largely come from improving physical error rates.

When we introduce quantum error correction, there will be an inflection point where Quantum Volume will increase much faster due to software (encoded) scaling.



# IBM Quantum Network Today

**219 total**

18 industry partners

24 hubs

60 members

52 startups

65 academic members and partners

## Partners

BP
Boeing
Bosch
Capgemini SE
Credit Mutuel
Daimler
E.ON
Erste Group Bank AG
ExxonMobil
Goldman Sachs
HSBC
JP Morgan Chase
JSR Corporation
LG Corporation
Samsung Advanced Institute of Technology
Tokyo Electron Limited
Wells Fargo
Woodside Energy Ltd

## Hubs

Arizona State University
Brookhaven National Lab
Bundeswehr University Munich
CERN
Cleveland Clinic Foundation
Deutsches Elektronen Synchrotron
Fraunhofer
KEIO University
Korea Quantum Computing Corporation
Lantik SA
Los Alamos National Laboratory
National Taiwan University
North Carolina State University
Oak Ridge National Lab
Pacific Northwest National Lab
Poznan Supercomputing and Networking Center
Quebec PINQ2
Science and Technology Facilities Council Daresbury
Sungkyunkwan University
United States Air Force Research Lab
University of Melbourne
University of Sherbrooke
University of Tokyo
Yonsei University

## Members

Amgen
Anthem
Argonne National Lab
Assured Information Security
CMC Microsystems
Carnegie Mellon Software Engineering Institute
Cognizant
Consiglio Nazionale delle Ricerche - Istituto di calcolo e reti ad alte prestazioni
DIC Corporation
Deloitte
Fermi National Accelerator Laboratory
Fidelity Investments
Flightprofiler
Fraunhofer members
GE Global Research
General Atomics
Hitachi Ltd
III Taiwan
Industrial Technology Research Institute
Infosys
Istituto Italiano di Tecnologia
Lawrence Berkeley National Laboratory (Berkeley Lab)
Lockheed Martin
Mitsubishi Chemical Corporation
Mitsubishi UFJ Financial Group
Mizuho Bank
Molecular Forecaster Inc
National Institute for Nuclear Physics
RIKEN National Research and Development Agency
Sandia National Labs
Sony
Sumitomo Mitsui Trust Bank Limited
System Vertrieb Alexander GmbH
TNO
Tech Mahindra Limited
Toshiba
Toyota
Toyota Central RD Labs
United States Naval Research Laboratory
Yokogawa Electric Corporation

## Startups

1Qbit Systems
AIQTECH Inc
Agnostiq Inc
Aliro Quantum
Applied Quantum Computing
Apply Science
Beit
Blueqat
Boxcat Inc
Cambridge Quantum Computing
Classiq
ColdQuanta
ColibriTD
Entangled Networks Ltd.
Entropica Labs
Equal1
First Quantum
HQS Quantum Simulations
Horizon Quantum Computing
JoS Quantum
Keysight
Kipu Quantum
Max Kelsen
Menten AI
Miraex
Multiverse Computing
NetraMark Corp
Nordic Quantum Computing Group
Opacity
Phasecraft
ProteinQure
Q-Ctrl
QC Ware
QEDMA Quantum Computing
Qu & Co
Quantfi
Quantum MADS
Quantum Machines
Quantum South
Quantum Technology Foundation of Thailand
QuantumNET
Qunasys
Rahko
SoftwareQ
Solid State AI
SpinUp AI
Strangeworks
Super Tech Labs
Xanadu
Zapata Computing Inc
Zurich Instruments
qBraid Co

## Academic

Aalto University
Boston University
Bowie State University
Centrum Wiskunde & Informatica
Chalmers University of Technology
Clemson University
Cornell University
ETH Zurich
Florida State University
Georgia Institute of Technology
Hampton University
Hanyang University
Harvard University
Howard University
Indian Institute of Technology - Madras IIT
Johns Hopkins University
Korea Advanced Institute of Science and Technology
Korea University
Maastricht University
Massachusetts Institute of Technology
Morehouse College
Morgan State University
National University of Singapore
Netherlands Organization for Applied Scientific Research
Netherlands eScience Center
New Mexico State University
New York University
North Carolina AT State University
Northeastern University
Northwestern University
Pohang University of Science and Technology
Prairie View AM University
Princeton University
Purdue University
Saarland University
Seoul National University
Southern University and A&M College
Stanford University
Stony Brook University
Surf
Swiss Federal Institute of Technology Lausanne
The University of Texas at Austin
Turku University
Tuskegee University
Ulsan National Institute of Science and Technology
United States Naval Postgraduate Military University
University of Amsterdam
University of Basque Country
University of Chicago
University of Georgia
University of Illinois at Urbana Champaign
University of Innsbruck
University of Madrid
University of Minho
University of Montpellier
University of New Mexico
University of Oxford
University of South Carolina
University of Southern California
University of Tennessee
University of Washington
University of Waterloo
University of Witwatersrand Johannesburg
University of the District of Columbia Community College
Virginia Tech



*Current as of 2022-11-18 14:27:01*

# Quantum applications span three general areas



**Simulating Quantum Systems**

Quantum chemistry
Material science
High energy physics

**Artificial Intelligence**

Better model training
Pattern recognition
Fraud detection

**Optimization / Monte Carlo**

Portfolio optimization
Risk analysis
Loans & credit scoring
Monte Carlo-like applications

# Daimler



**Quantum Computing for Materials Discovery and Manufacturing Optimization**

Daimler and IBM have recently published a series of papers demonstrating progress toward using quantum computers to model material systems including Lithium-sulfur that are relevant to advancing the performance of batteries. The teams have also demonstrated applications in manufacturing defect analysis and product recommendation.

“Developing and perfecting these hypothetical batteries could unlock a billion-dollar opportunity.”

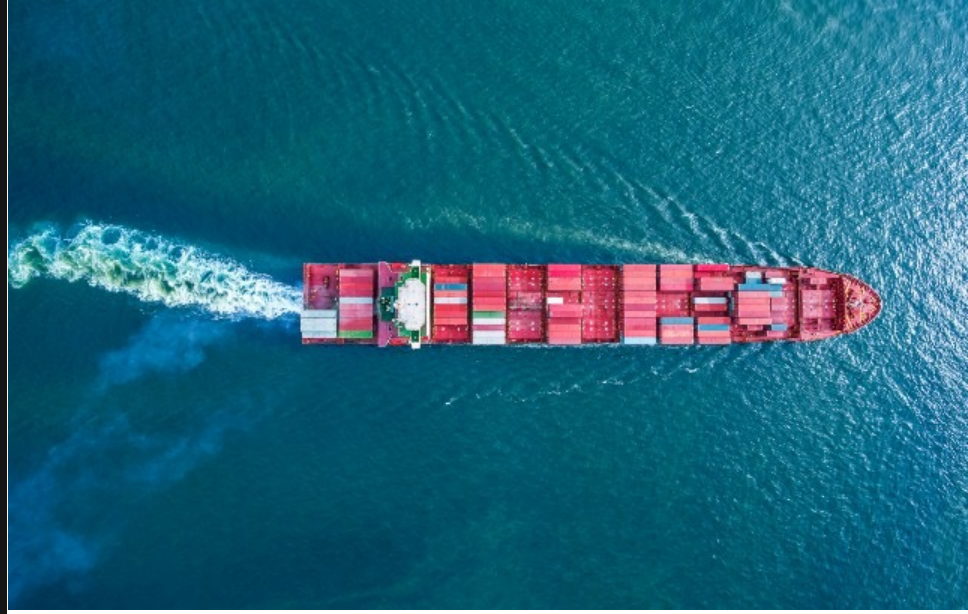
**Benjamin Boeser**
[Former] Director of Innovation Management, Silicon Valley at Mercedes-Benz R&D North America

# ExxonMobil

**Maritime Routing's Mind-Boggling Math**

In 2021 more than 500 LNG (liquified natural gas) ships are used to transport critical fuel supplies across the oceans. Together, they make thousands of journeys per year to destination ports where the LNG is deployed to power critical infrastructure.

Finding optimal routes for a fleet of such ships can be a mind-bendingly complex optimization problem.



Quantum computers take a new approach to addressing this sort of complexity, with the potential to find solutions that classical supercomputer alone cannot handle. Industry leaders like Exxon are getting involved now to explore how blending classical and quantum computing techniques might solve big, complex, pressing global challenges.

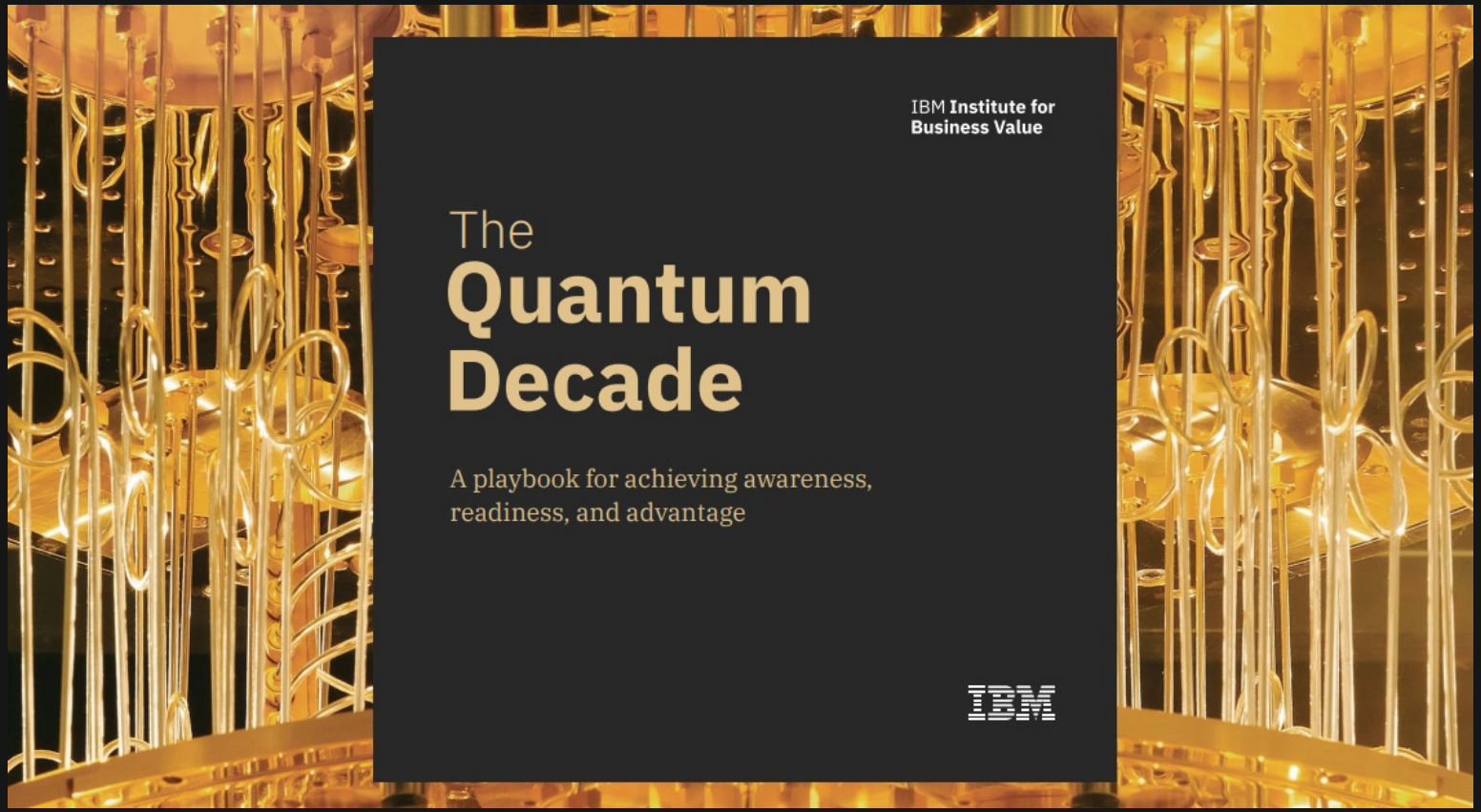
# JP Morgan Chase

**Quantum Computing for the Financial Services Industry**

Recently, JPMC and IBM used Quantum Amplitude Estimation, a Monte Carlo-like sampling algorithm, to compute European option pricing, pricing path depend options, showing a quadratic speed-up versus a classical Monte Carlo approach.


European derivative pricing on a Quantum computer implements the Black-Scholes model using a Quantum Machine Learning Algorithm, namely a quantum Generative Adversarial Network (qGAN). The qGAN utility loads the log-normal probability distribution and models the spot price of an asset underlying a European call option.

The resulting model can then be integrated into a Quantum Amplitude Estimation based algorithm to evaluate the expected payoff.




https://www.ibm.com/thought-leadership/institute-business-value/report/quantum-decade

# 2022 Announcements

**01**
**Scale**
- ↳ Reaching 433 qubits with our latest processor, Osprey
- ↳ >3x the number of connected qubits of Eagle

**02**
**Quality**
- ↳ Median T1 3x increase for large birds
- ↳ 512 QV with Falcon r10

**03**
**Speed**
- ↳ From 1k → 10K CLOPS (x4 improvement in speed)

**04**
**Error Suppression**
- ↳ Reduce errors with dynamical decoupling

**05**
**Error Mitigation**
- ↳ Simple cost vs accuracy trade-offs via resilience level

**06**
**Dynamic Circuits**
- ↳ Construct dynamic circuits in Qiskit
- ↳ Execute OpenQASM3 or Qiskit dynamic circuits on IBM Quantum hardware

**07**
**Quantum Network Now 200+**
- ↳ with new members uptownBasel, Bosch, Crédit Mutuel, Vodafone

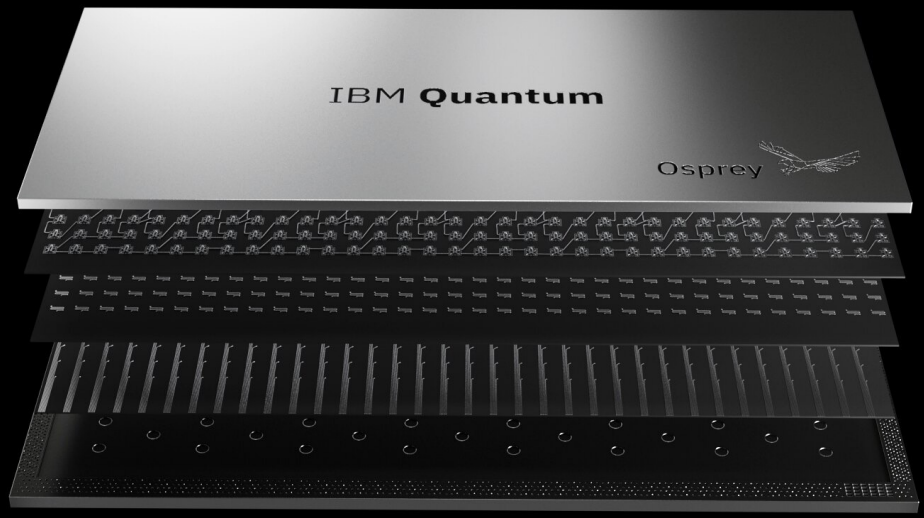
**08**
**Quantum Safe**
- ↳ New Quantum Safe Services offering
- ↳ IBM protocols adopted by NIST
- ↳ IBM & Vodafone partnering for Telco transformation

**09**
**Quantum Serverless & Circuit Knitting**
- ↳ Alpha release Circuit Knitting
- ↳ Alpha release Quantum Serverless

**10**
**Quantum-centric Supercomputing**
- ↳ Modularity to scale Communication & computing Quantum Middleware

**11**
**IBM Quantum System Two**
- ↳ The building block for Quantum-centric supercomputing

**12**
**100x100 challenge**
- ↳ We will offer 100 qubits at 100 gate depth by end of 2024



# IBM **Quantum**