Development & Innovation Roadmap

IBM **Quantum**

Development roadmap

IBM **Quantum**

Back in 2020, IBM released an ambitious roadmap for maturing and scaling quantum technology.

This roadmap set us on course to deliver a 1,000+ qubit chip in just three years while developing software and services necessary to run applications on quantum systems.

	2019 ✓	2020 ✓	2021 ✓	2022 ✓	2023	2024	2025	2026
	Ran quantum circuits on the IBM cloud	Demonstrated and prototype quantum algorithms and applications	Ran quantum programs 100x faster with Qiskit Runtime	Brought dynamic circuits to Qiskit Runtime to unlock more computations	Enhance 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
Data scientists					Prototype quantum software functions (On target)		Quantum software functions; Machine learning | Natural science | Optimization	
Researchers		Quantum algorithm & application modules ✓; Machine learning | Natural science | Optimization ✓			Middleware (On target); Quantum Serverless (On target)	Intelligent orchestration	Circuit knitting toolbox	Circuit libraries
Quantum physicists	Circuits ✓		Qiskit Runtime; QASM 3 ✓	Dynamic circuits ✓	Threaded primitives (On target)	Error suppression & mitigation		Error correction
	Falcon ✓ 27 qubits	Hummingbird ✓ 65 qubits	Eagle ✓ 127 qubits	Osprey ✓ 433 qubits	Condor (On target) 1,121 qubits	Flamingo (On target) 1,386+ qubits	Kookaburra (On target) 4,158+ qubits	Scaling to 10K-100K qubits with classical and quantum communication
					Heron (On target) 133 qubits x p	Crossbill (On target) 408 qubits		

✓ Executed by IBM

On target

Development roadmap

IBM **Quantum**

By 2023, our research and development work made it possible to use quantum computers as tools to run circuits beyond the reach of brute-force classical computation. We could also begin thinking about implementing error correction.

We realized: it was time for a bigger roadmap.

	2019	2020	2021	2022	2023	2024	2025	2026
	Ran quantum circuits on the IBM cloud	Demonstrated and prototype quantum algorithms and applications	Ran quantum programs 100x faster with Qiskit Runtime	Brought dynamic circuits to Qiskit Runtime to unlock more computations	Enhance 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
Data scientists					Prototype quantum software functions		Quantum software functions; Machine learning | Natural science | Optimization (2025–2026)	
Researchers		Quantum algorithm & application modules; Machine learning | Natural science | Optimization (2020–2022)			Middleware; Quantum Serverless	Intelligent orchestration	Circuit knitting toolbox	Circuit libraries
Quantum physicists	Circuits (2019–2020)		Qiskit Runtime (2021–2026); QASM 3	Dynamic circuits	Threaded primitives	Error suppression & mitigation (2024–2025)		Error correction
	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		

Executed by IBM

On target

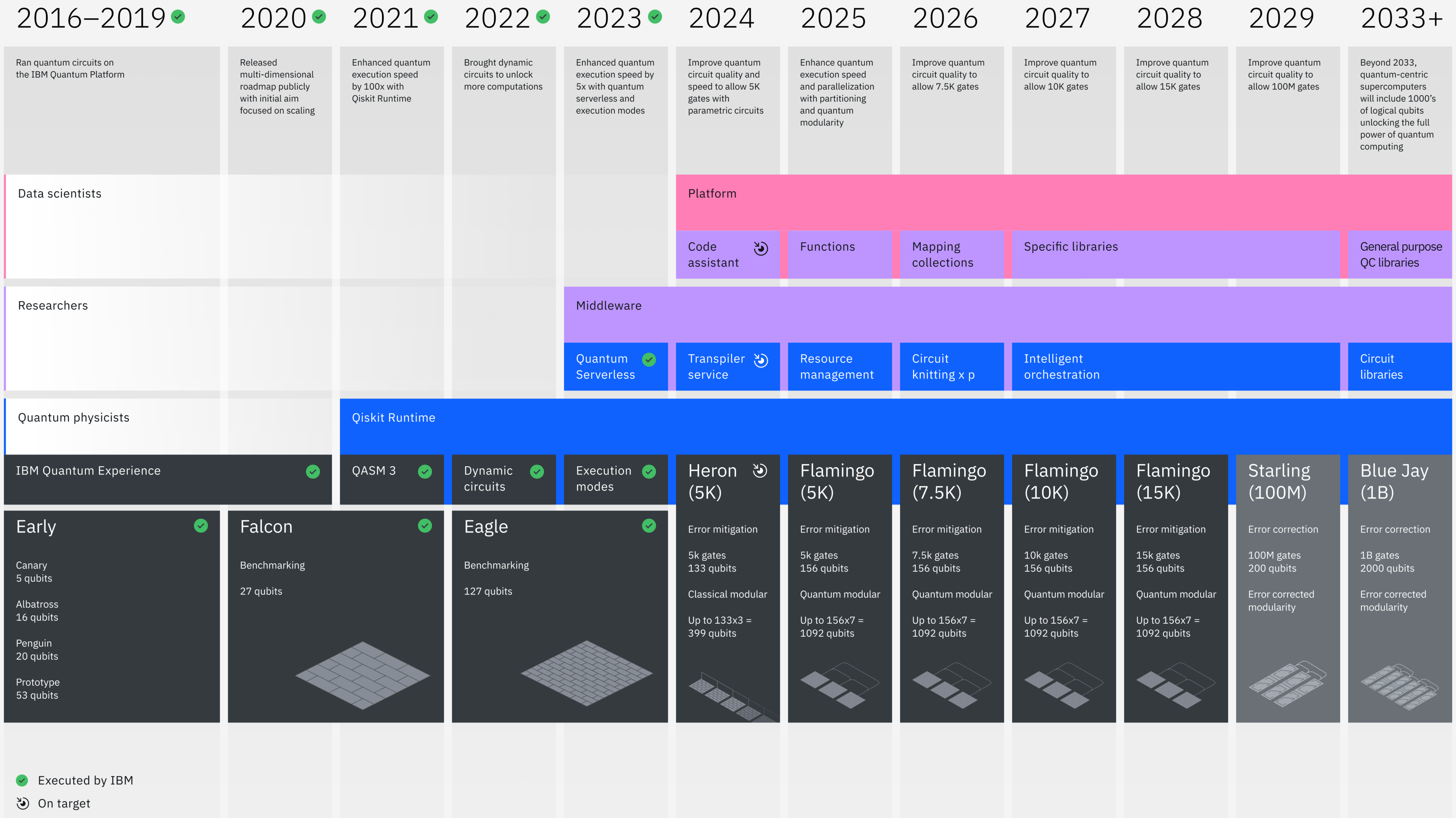
Development roadmap: Updated

Our updated development roadmap charts our course for delivering client-facing systems and services. It now focuses both on qubit count and on the size of the circuits that our systems can run, tracked by the number of gates in those circuits.

You can start exploring quantum utility today, and this roadmap shows how the quantum workload size available for that exploration will increase.

Our challenge is to develop the tools that users need to explore quantum utility and unlock the full power of quantum-centric supercomputing by 2033.

We will also incorporate advances in machine learning and generative AI to turbocharge our software's performance.

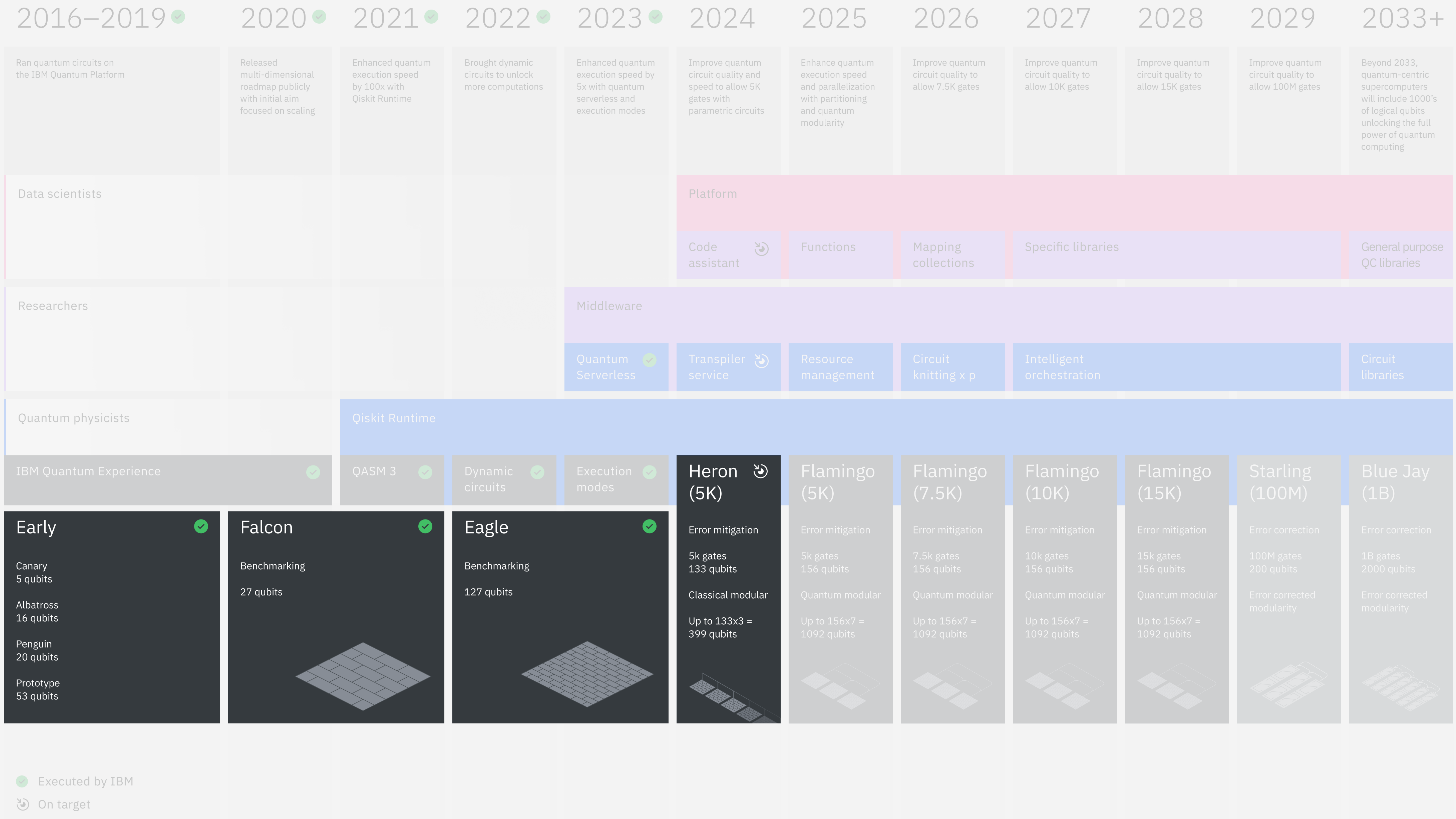


What we have accomplished: Hardware

IBM **Quantum**

From 2020 to 2023, we focused on solving single-chip scaling with the IBM Quantum Falcon, Hummingbird, Eagle, Osprey, and Condor chips.

In 2023, we debuted the IBM Quantum Heron chip, which uses tunable couplers to achieve our lowest error rates yet. Heron will serve as the basis for modular scaling of quantum processors. In 2024, Heron will be capable of running 5,000 gates.



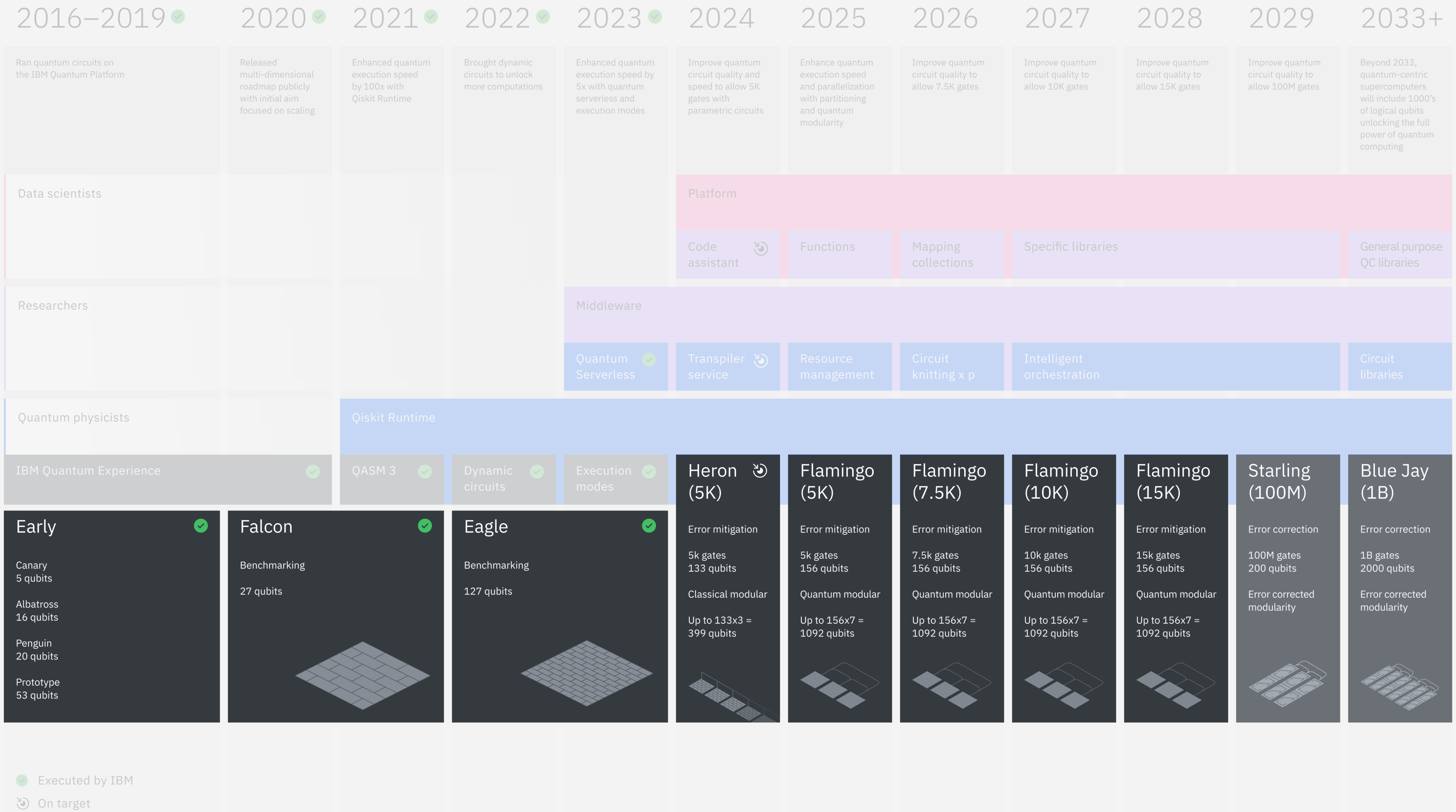
Looking forward: Hardware

IBM **Quantum**

Now, we use error mitigation and interconnects to run larger circuits so users can look for quantum advantages in their domains. Through classical and quantum modularity, we plan to achieve an IBM Quantum Flamingo system capable of running 15,000 gates with the help of error mitigation by 2028.

We foresee advances in quantum error correction allowing us to debut IBM Quantum Starling, a system capable of running circuits with 100 million gates on 200 logical qubits, by 2029. In 2033, we will debut IBM Quantum Blue Jay, a system capable of running circuits with a billion gates on 2,000 logical qubits.

As we roll out error correction, developers need not change how they write quantum programs. They will simply notice that they can run longer workloads.



IBM **Quantum**

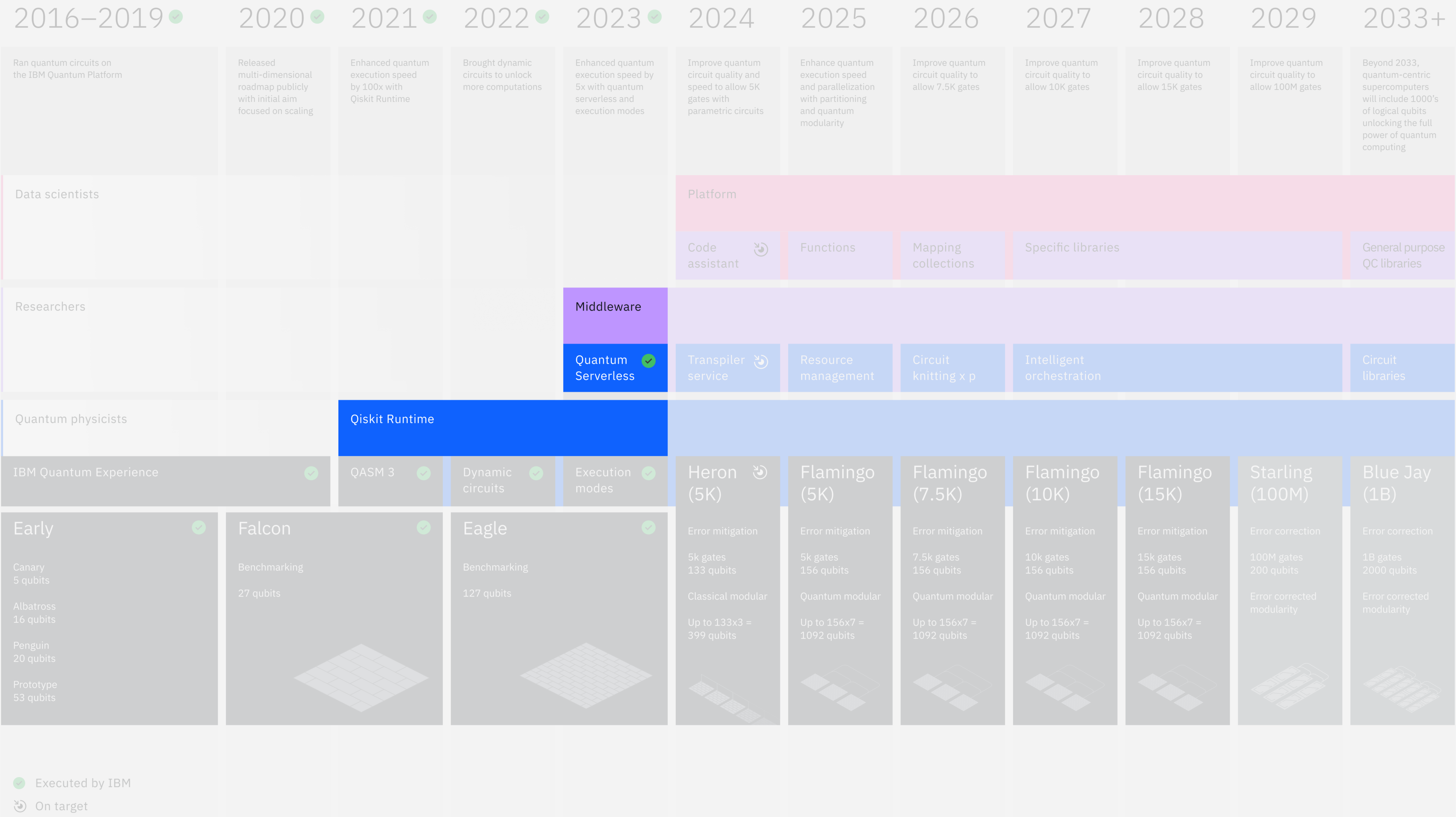
What we have accomplished: Execution and orchestration

Running quantum workloads requires infrastructure that coordinates quantum resources with near-time and real-time classical resources.

Since 2016, we have worked to create Qiskit and a variety of application libraries to show our users what coding a quantum computer looks like.

In 2021, we released Qiskit Runtime, a service allowing users to orchestrate their programs across IBM Quantum processors and the cloud.

In 2023, we introduced middleware for quantum tools to automate and optimize heterogeneous compute tasks. That included quantum serverless to provision users the exact quantum resources they need, when they need them.



IBM **Quantum**

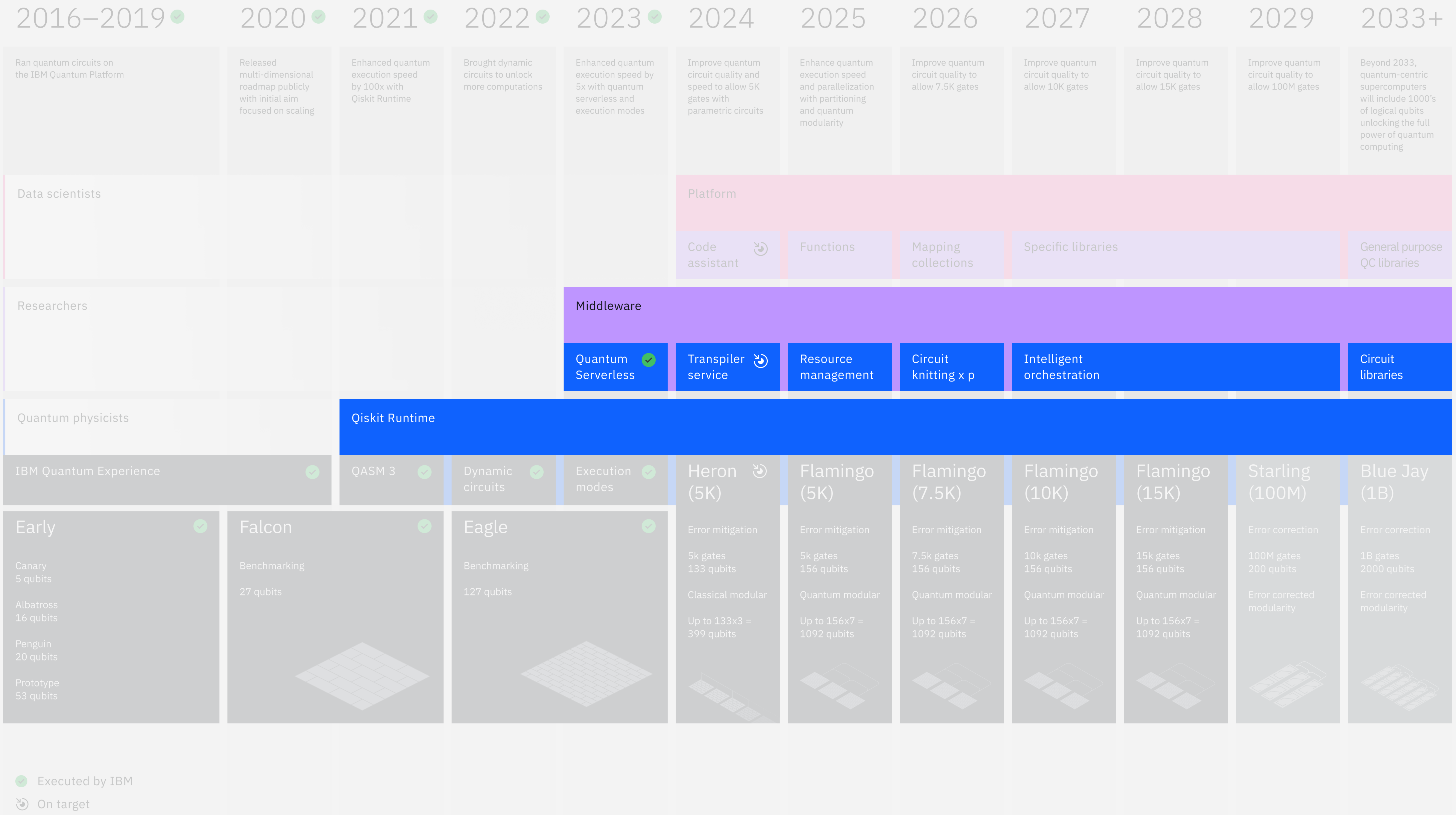
Looking forward: Execution and orchestration

In 2024, our AI-powered transpiler service will optimize circuits with fewer gates.

In 2025, we will introduce resource management tools to facilitate system partitioning and enable parallel execution.

2026 will bring us circuit knitting across parallel quantum processors—the ability to decompose quantum circuits into shorter circuits, run them in parallel, and then stitch them back together with classical hardware. Circuit knitting will bring performance gains and let you run complex algorithms sooner.

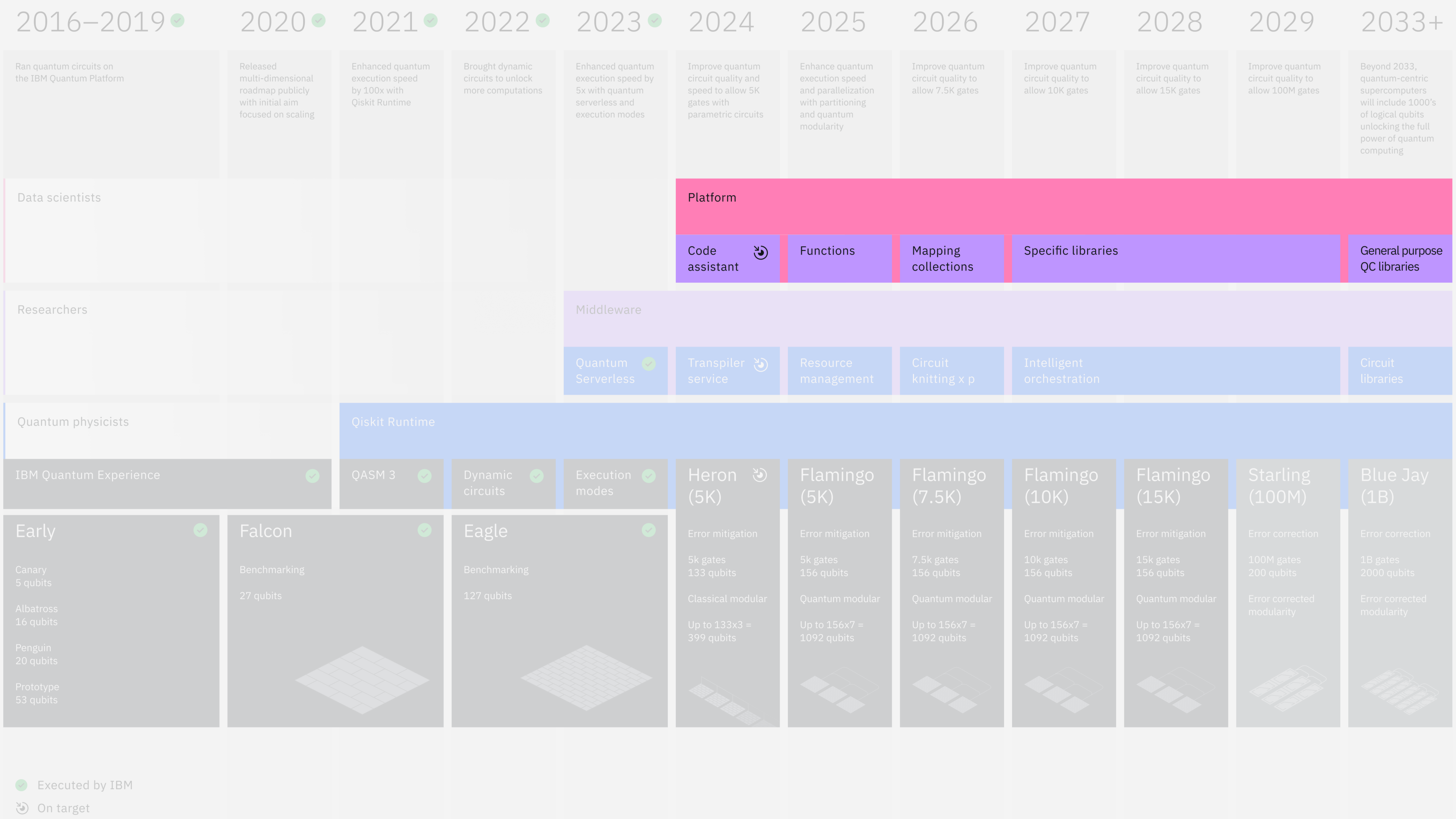
From 2027 onward, we will focus on intelligent orchestration: optimizing workflows to combine classical and quantum efficiently, thus improving performance.



What we have accomplished: Software

Useful quantum computing requires performant software. We're committed to maturing Qiskit into a software stack capable of running utility-scale circuits on cloud-based quantum resources. As we say, Qiskit + IBM Quantum systems = work.

In 2023, we aggregated Qiskit documentation and learning resources into the IBM Quantum Platform to create a single Qiskit source of truth.



Looking forward: Software

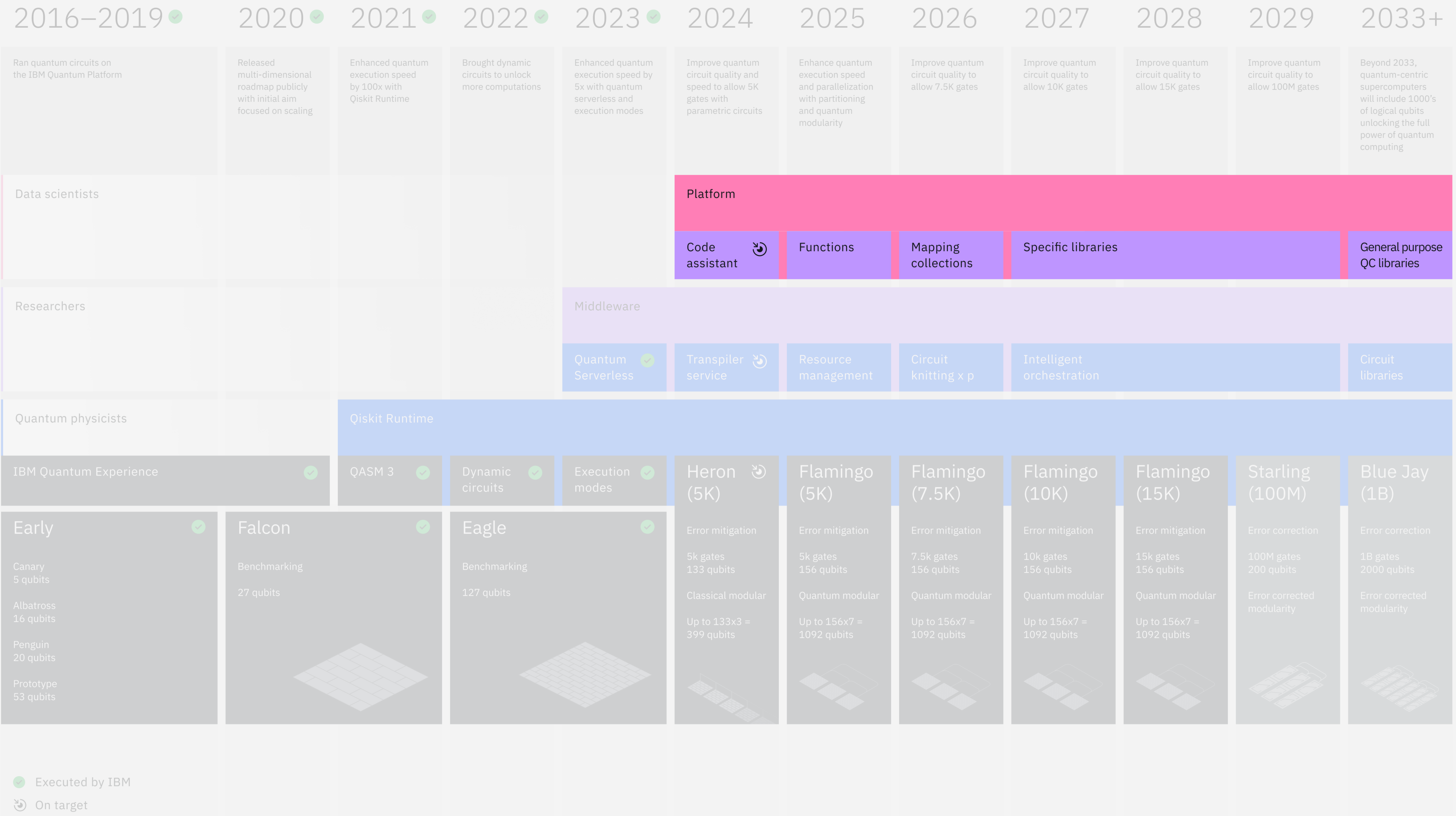
IBM **Quantum**

In 2025, we will introduce quantum functions so users can create and share reusable blocks of Qiskit code.

2026 will bring mapping collections so users can start automating the process of mapping their specific use cases to quantum circuits.

From 2027 onward, we will work alongside clients to build use-case-specific libraries as quantum advantages emerge for a variety of use cases.

By 2033, we expect to see general-purpose quantum computing libraries that users can incorporate into a wide variety of quantum applications.



Innovation roadmap

IBM **Quantum**

We remain committed to the transparent development of IBM quantum hardware and software. This includes showing off scientific discoveries required to clear roadblocks in the field.

Therefore, in 2023, we also announced our innovation roadmap. This roadmap features internal releases of hardware and software to enable the subsequent milestones on our development roadmap.

Some technologies on our innovation roadmap will be internal proofs-of-concept to inform future development. Others will be prototypes for eventual release.

	2016–2019 ✓		2020 ✓	2021 ✓	2022 ✓	2023 ✓	2024	2025	2026	2027	2028	2029
	Ran quantum circuits on the IBM Quantum Platform		Released multi-dimensional roadmap publicly with initial aim focused on scaling	Enhanced quantum execution speed by 100x with Qiskit Runtime	Brought dynamic circuits to unlock more computations	Enhanced quantum execution speed by 5x with quantum serverless and execution modes	Improve quantum circuit quality and speed to allow 5K gates with parametric circuits	Enhance quantum execution speed and parallelization with partitioning and quantum modularity	Improve quantum circuit quality to allow 7.5K gates	Improve quantum circuit quality to allow 10K gates	Improve quantum circuit quality to allow 15K gates	Improve quantum circuit quality to allow 100M gates
Software innovation	**IBM Quantum Experience** ✓	**Qiskit** ✓ Circuit and operator API with compilation to multiple targets	**Application modules** ✓ Modules for domain specific application and algorithm workflows	**Qiskit Runtime** ✓ Performance and abstraction through primitives	**Quantum Serverless** ✓ Demonstrate concepts of quantum-centric supercomputing	**AI-enhanced quantum** ✓ Prototype demonstrations of AI-enhanced circuit transpilation	**Resource management** ◎ System partitioning to enable parallel execution	**Scalable circuit knitting** Circuit partitioning with classical reconstruction at HPC scale	**Error correction decoder** Demonstration of a quantum system with real-time error correction decoder			
Hardware innovation	**Early** ✓ Canary 5 qubits Albatross 16 qubits Penguin 20 qubits Prototype 53 qubits	**Falcon** ✓ Demonstrate scaling with I/O routing with bump bonds	**Hummingbird** ✓ Demonstrate scaling with multiplexing readout	**Eagle** ✓ Demonstrate scaling with MLW and TSV	**Osprey** ✓ Enabling scaling with high density signal delivery	**Condor** ✓ Single system scaling and fridge capacity	**Flamingo** ◎ Demonstrate scaling with modular connectors	**Kookaburra** Demonstrate scaling with nonlocal c-coupler	Demonstrate path to improved quality with logical memory	**Cockatoo** Demonstrate path to improved quality with logical communication	**Starling** Demonstrate path to improved quality with logical gates	
						Heron ✓ Architecture based on tunable-couplers	**Crossbill** ◎ Demonstrate m-couplers					

✓ Executed by IBM

◎ On target

Innovation roadmap

IBM **Quantum**

Our hardware innovations focus on building interconnects that allow us to scale processors and parallelize quantum workloads while laying a foundation for quantum error correction.

In 2024, we will demonstrate m-couplers to seam chips together and l-couplers to connect chips over longer distances with Crossbill and Flamingo, respectively.

In 2025 and 2026, we will develop c-couplers capable of linking distant qubits on the same chip as required by error correction schemes for a concept called Kookaburra.

2027 and 2028 further pave a path to error correction. Cockatoo will debut logical communication and Starling will be able to run logical gates on error-corrected logical qubits.

	2016–2019		2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
	Ran quantum circuits on the IBM Quantum Platform		Released multi-dimensional roadmap publicly with initial aim focused on scaling	Enhanced quantum execution speed by 100x with Qiskit Runtime	Brought dynamic circuits to unlock more computations	Enhanced quantum execution speed by 5x with quantum serverless and execution modes	Improve quantum circuit quality and speed to allow 5K gates with parametric circuits	Enhance quantum execution speed and parallelization with partitioning and quantum modularity	Improve quantum circuit quality to allow 7.5K gates	Improve quantum circuit quality to allow 10K gates	Improve quantum circuit quality to allow 15K gates	Improve quantum circuit quality to allow 100M gates
Software innovation	IBM Quantum Experience	Qiskit Circuit and operator API with compilation to multiple targets	Application modules Modules for domain specific application and algorithm workflows	Qiskit Runtime Performance and abstraction through primitives	Quantum Serverless Demonstrate concepts of quantum-centric supercomputing	AI-enhanced quantum Prototype demonstrations of AI-enhanced circuit transpilation	Resource management System partitioning to enable parallel execution	Scalable circuit knitting Circuit partitioning with classical reconstruction at HPC scale	Error correction decoder Demonstration of a quantum system with real-time error correction decoder			
Hardware innovation	Early Canary 5 qubits Albatross 16 qubits Penguin 20 qubits Prototype 53 qubits	Falcon Demonstrate scaling with I/O routing with bump bonds	Hummingbird Demonstrate scaling with multiplexing readout	Eagle Demonstrate scaling with MLW and TSV	Osprey Enabling scaling with high density signal delivery	Condor Single system scaling and fridge capacity	Flamingo Demonstrate scaling with modular connectors	Kookaburra Demonstrate scaling with nonlocal c-coupler	Demonstrate path to improved quality with logical memory	Cockatoo Demonstrate path to improved quality with logical communication	Starling Demonstrate path to improved quality with logical gates	
						Heron Architecture based on tunable-couplers	Crossbill Demonstrate m-couplers					

Executed by IBM: 2016–2019, 2020, 2021, 2022, 2023; IBM Quantum Experience, Qiskit, Application modules, Qiskit Runtime, Quantum Serverless, AI-enhanced quantum, Early, Falcon, Hummingbird, Eagle, Osprey, Condor, Heron

On target: Resource management, Flamingo, Crossbill

Innovation roadmap

IBM **Quantum**

Our software innovations will support the execution of large circuits on modular quantum computers and build the tools for a frictionless developer experience, rising to the Development Roadmap in the following years.

In 2023, we showed our plan to incorporate AI into quantum computing workflows with AI-assisted circuit transpilation.

In 2024 and 2025, we will prototype new tools for resource management and scalable circuit knitting for parallel execution and classical reconstruction of circuits at the HPC scale.

In 2026, we will prototype a real-time error correction decoder for later error corrected systems.

2016–2019
Ran quantum circuits on the IBM Quantum Platform
- Software innovation: IBM Quantum Experience
- Software innovation: Qiskit – Circuit and operator API with compilation to multiple targets
- Hardware innovation: Early – Canary 5 qubits; Albatross 16 qubits; Penguin 20 qubits; Prototype 53 qubits
- Hardware innovation: Falcon – Demonstrate scaling with I/O routing with bump bonds

2020
Released multi-dimensional roadmap publicly with initial aim focused on scaling
- Software innovation: Application modules – Modules for domain specific application and algorithm workflows
- Hardware innovation: Hummingbird – Demonstrate scaling with multiplexing readout

2021
Enhanced quantum execution speed by 100x with Qiskit Runtime
- Software innovation: Qiskit Runtime – Performance and abstraction through primitives
- Hardware innovation: Eagle – Demonstrate scaling with MLW and TSV

2022
Brought dynamic circuits to unlock more computations
- Software innovation: Quantum Serverless – Demonstrate concepts of quantum-centric supercomputing
- Hardware innovation: Osprey – Enabling scaling with high density signal delivery

2023
Enhanced quantum execution speed by 5x with quantum serverless and execution modes
- Software innovation: AI-enhanced quantum – Prototype demonstrations of AI-enhanced circuit transpilation
- Hardware innovation: Condor – Single system scaling and fridge capacity
- Hardware innovation: Heron – Architecture based on tunable-couplers

2024
Improve quantum circuit quality and speed to allow 5K gates with parametric circuits
- Software innovation: Resource management – System partitioning to enable parallel execution
- Hardware innovation: Flamingo – Demonstrate scaling with modular connectors
- Hardware innovation: Crossbill – Demonstrate m-couplers

2025
Enhance quantum execution speed and parallelization with partitioning and quantum modularity
- Software innovation: Scalable circuit knitting – Circuit partitioning with classical reconstruction at HPC scale
- Hardware innovation: Kookaburra – Demonstrate scaling with nonlocal c-coupler

2026
Improve quantum circuit quality to allow 7.5K gates
- Software innovation: Error correction decoder – Demonstration of a quantum system with real-time error correction decoder
- Hardware innovation: Kookaburra – Demonstrate path to improved quality with logical memory

2027
Improve quantum circuit quality to allow 10K gates
- Hardware innovation: Cockatoo – Demonstrate path to improved quality with logical communication

2028
Improve quantum circuit quality to allow 15K gates
- Hardware innovation: Starling – Demonstrate path to improved quality with logical gates

2029
Improve quantum circuit quality to allow 100M gates

Executed by IBM
On target

Development Roadmap

IBM **Quantum**

2016–2019 ✓
Ran quantum circuits on the IBM Quantum Platform

2020 ✓
Released multi-dimensional roadmap publicly with initial aim focused on scaling

2021 ✓
Enhanced quantum execution speed by 100x with Qiskit Runtime

2022 ✓
Brought dynamic circuits to unlock more computations

2023 ✓
Enhanced quantum execution speed by 5x with Quantum Serverless and execution modes

2024
Improve quantum circuit quality and speed to allow 5K gates with parametric circuits

2025
Enhance quantum execution speed and parallelization with partitioning and quantum modularity

2026
Improve quantum circuit quality to allow 7.5K gates

2027
Improve quantum circuit quality to allow 10K gates

2028
Improve quantum circuit quality to allow 15K gates

2029
Improve quantum circuit quality to allow 100M gates

2033+
Beyond 2033, quantum-centric supercomputers will include 1000's of logical qubits unlocking the full power of quantum computing

---

Data scientists

Platform

- Code assistant (2024)
- Functions (2025)
- Mapping collections (2026)
- Specific libraries (2027–2029)
- General purpose QC libraries (2033+)

Researchers

Middleware

- Quantum Serverless ✓ (2023)
- Transpiler service (2024)
- Resource management (2025)
- Circuit knitting x p (2026)
- Intelligent orchestration (2027–2029)
- Circuit libraries (2033+)

Quantum physicists

Qiskit Runtime

- IBM Quantum Experience ✓ (2016–2020)
- QASM 3 ✓ (2021)
- Dynamic circuits ✓ (2022)
- Execution modes ✓ (2023)

Processors:

- **Early** ✓ — Canary 5 qubits; Albatross 16 qubits; Penguin 20 qubits; Prototype 53 qubits
- **Falcon** ✓ — Benchmarking; 27 qubits
- **Eagle** ✓ — Benchmarking; 127 qubits
- **Heron (5K)** — Error mitigation; 5k gates; 133 qubits; Classical modular; 133x3 = 399 qubits
- **Flamingo (5K)** — Error mitigation; 5k gates; 156 qubits; Quantum modular; 156x7 = 1092 qubits
- **Flamingo (7.5K)** — Error mitigation; 7.5k gates; 156 qubits; Quantum modular; 156x7 = 1092 qubits
- **Flamingo (10K)** — Error mitigation; 10k gates; 156 qubits; Quantum modular; 156x7 = 1092 qubits
- **Flamingo (15K)** — Error mitigation; 15k gates; 156 qubits; Quantum modular; 156x7 = 1092 qubits
- **Starling (100M)** — Error correction; 100M gates; 200 qubits; Error corrected modularity
- **Blue Jay (1B)** — Error correction; 1B gates; 2000 qubits; Error corrected modularity

Innovation Roadmap

Software innovation

- **IBM Quantum Experience** ✓
- **Qiskit** ✓ — Circuit and operator API with compilation to multiple targets
- **Application modules** ✓ — Modules for domain specific application and algorithm workflows
- **Qiskit Runtime** ✓ — Performance and abstraction through primitives
- **Quantum Serverless** ✓ — Demonstrate concepts of quantum-centric supercomputing
- **AI-enhanced quantum** ✓ — Prototype demonstrations of AI-enhanced circuit transpilation
- **Resource management** — System partitioning to enable parallel execution
- **Scalable circuit knitting** — Circuit partitioning with classical reconstruction at HPC scale
- **Error correction decoder** — Demonstration of a quantum system with real-time error correction decoder

Hardware innovation

- **Early** ✓ — Canary 5 qubits; Penguin 20 qubits; Albatross 16 qubits; Prototype 53 qubits
- **Falcon** ✓ — Demonstrate scaling with I/O routing with bump bonds
- **Hummingbird** ✓ — Demonstrate scaling with multiplexing readout
- **Eagle** ✓ — Demonstrate scaling with MLW and TSV
- **Osprey** ✓ — Enabling scaling with high density signal delivery
- **Condor** ✓ — Single system scaling and fridge capacity
- **Heron** ✓ — Architecture based on tunable-couplers
- **Flamingo** — Demonstrate scaling with modular connectors
- **Crossbill** — Demonstrate m-couplers
- **Kookaburra** — Demonstrate scaling with nonlocal c-coupler; Demonstrate path to improved quality with logical memory
- **Cockatoo** — Demonstrate path to improved quality with logical communication
- **Starling** — Demonstrate path to improved quality with logical gates

IBM