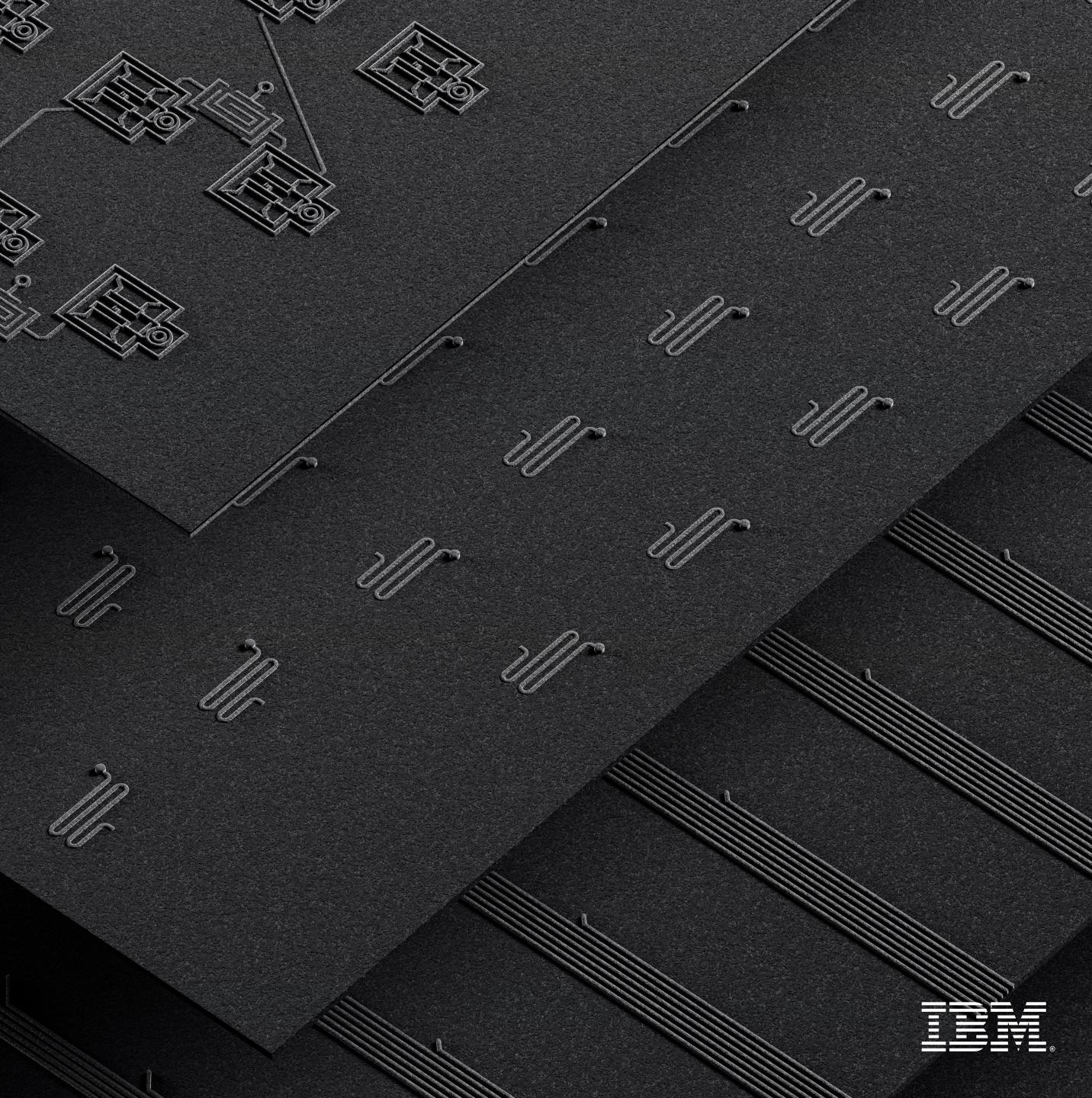
Development & Innovation Roadmap



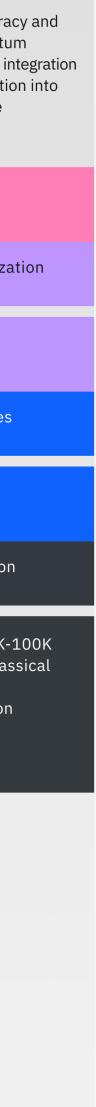
Development roadmap

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 speed of quantum workflows with inte of error correction Qiskit Runtime
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		 27 qubits Second Second Se	65 qubits		Osprey 433 qubits	Condor 1,121 qubits Heron 133 qubits x p 33 qubits x p	Flamingo 1,386+ qubits	Kookaburra Image: Comparison of the second of the seco	Scaling to 10K-10 qubits with classi and quantum communication
		 27 qubits Second Second Se	65 qubits		Osprey 🤗	Condor 1,121 qubits Heron 133 qubits x p 33 qubits x p	Flamingo 1,386+ qubits	Kookaburra Image: Comparison of the second of the seco	Scaling to 10K-10 qubits with classi and quantum communication

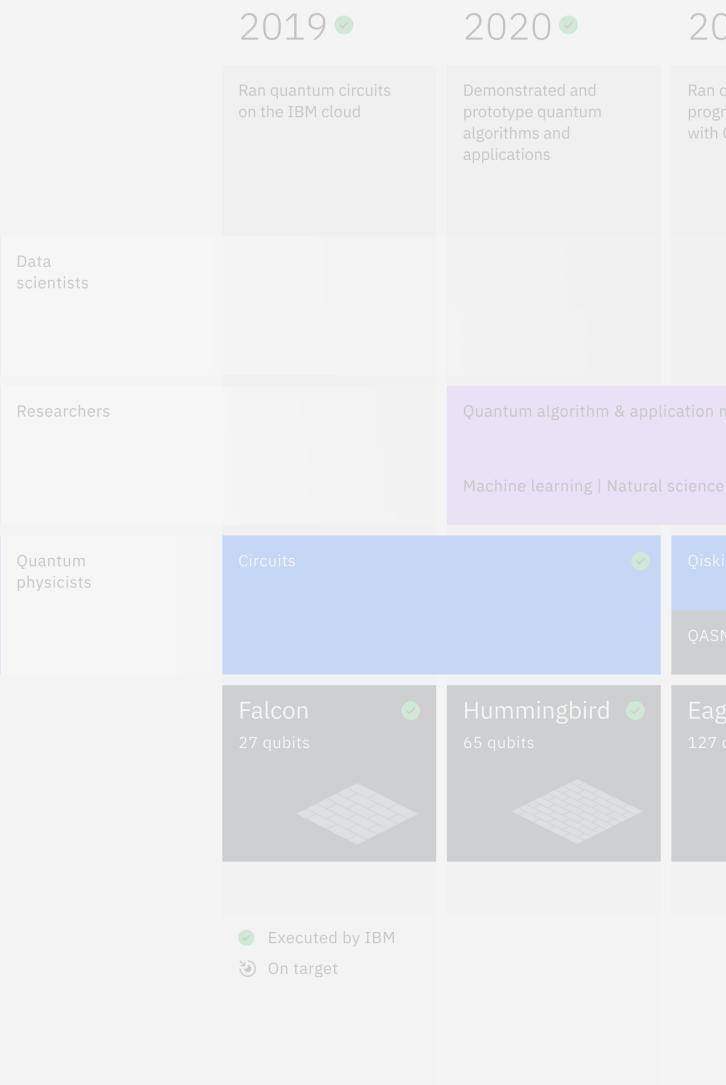




Development roadmap

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.



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grams 100x faster n 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 accurac speed of quantun workflows with int of error correction Qiskit Runtime
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		Threaded primitives 🕹			
gle 📀 7 qubits	Osprey 433 qubits	Condor 1,121 qubits	Flamingo 300 1,386+ qubits	Kookaburra 4,158+ qubits	Scaling to 10K-1 qubits with class and quantum communication
		Heron 33 qubits x p	Crossbill 408 qubits		

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.

2020 2021 20 2016-2019 • Ran quantum circuits on Released Enhanced quantum Broug execution speed the IBM Quantum Platform multi-dimensional circu roadmap publicly by 100x with more with initial aim Qiskit Runtime focused on scaling Data scientists Researchers Quantum physicists Qiskit Runtime \checkmark IBM Quantum Experience QASM 3 Dyr circ Ea Early Falcon Canary Benchmarking Ben 5 qubits 27 qubits 127 Albatross 16 qubits Penguin 20 qubits Prototype 53 qubits Executed by IBM 🕑 On target

IBM Quantum

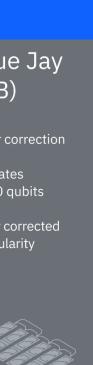
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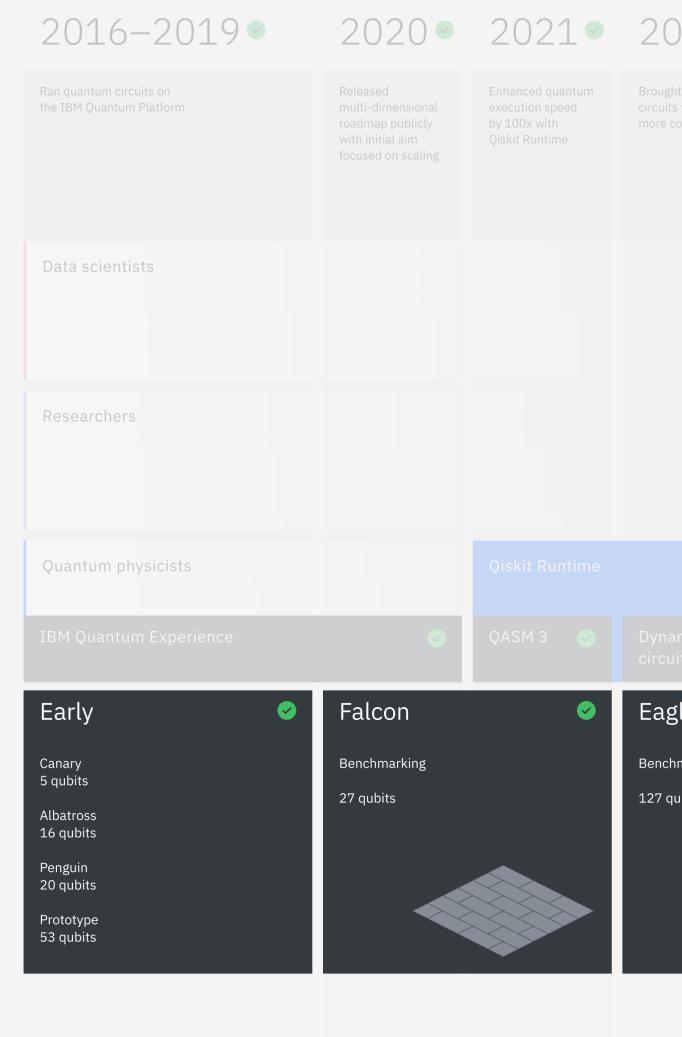




What we have accomplished: Hardware

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.



Executed by IBM

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IBM Quantum

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Looking forward: Hardware

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.

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IBM Quantum

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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.

2016-2019 •	2020 🛛	2021 •	20
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 c circuits to more con
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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.

2016-2019 •	2020 🛛	2021 •	20
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 of circuits to more con
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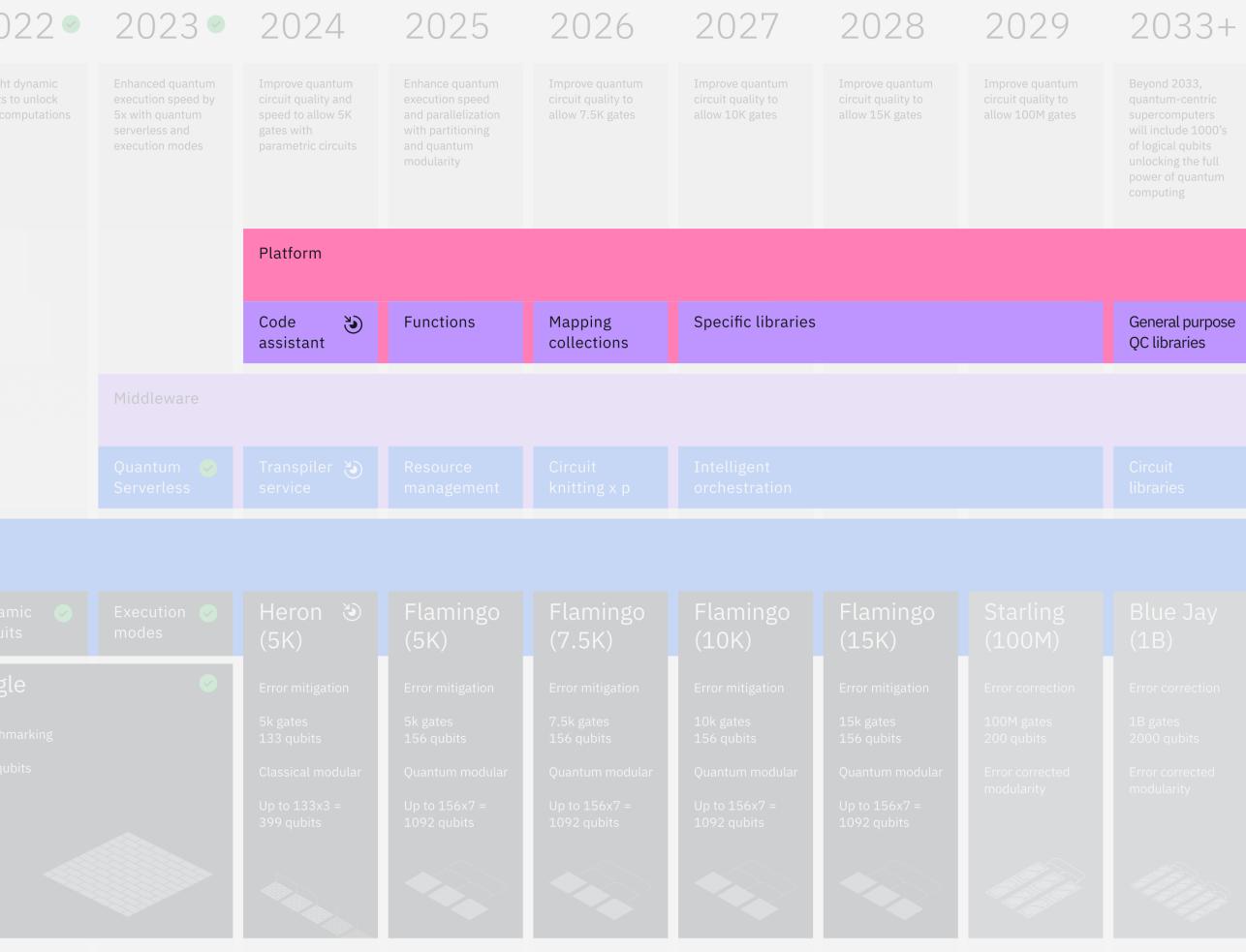
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What we have accomplished: Software

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.

	2016-2019	2020 •	2021 0	20
	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 circuits more co
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Looking forward: Software

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

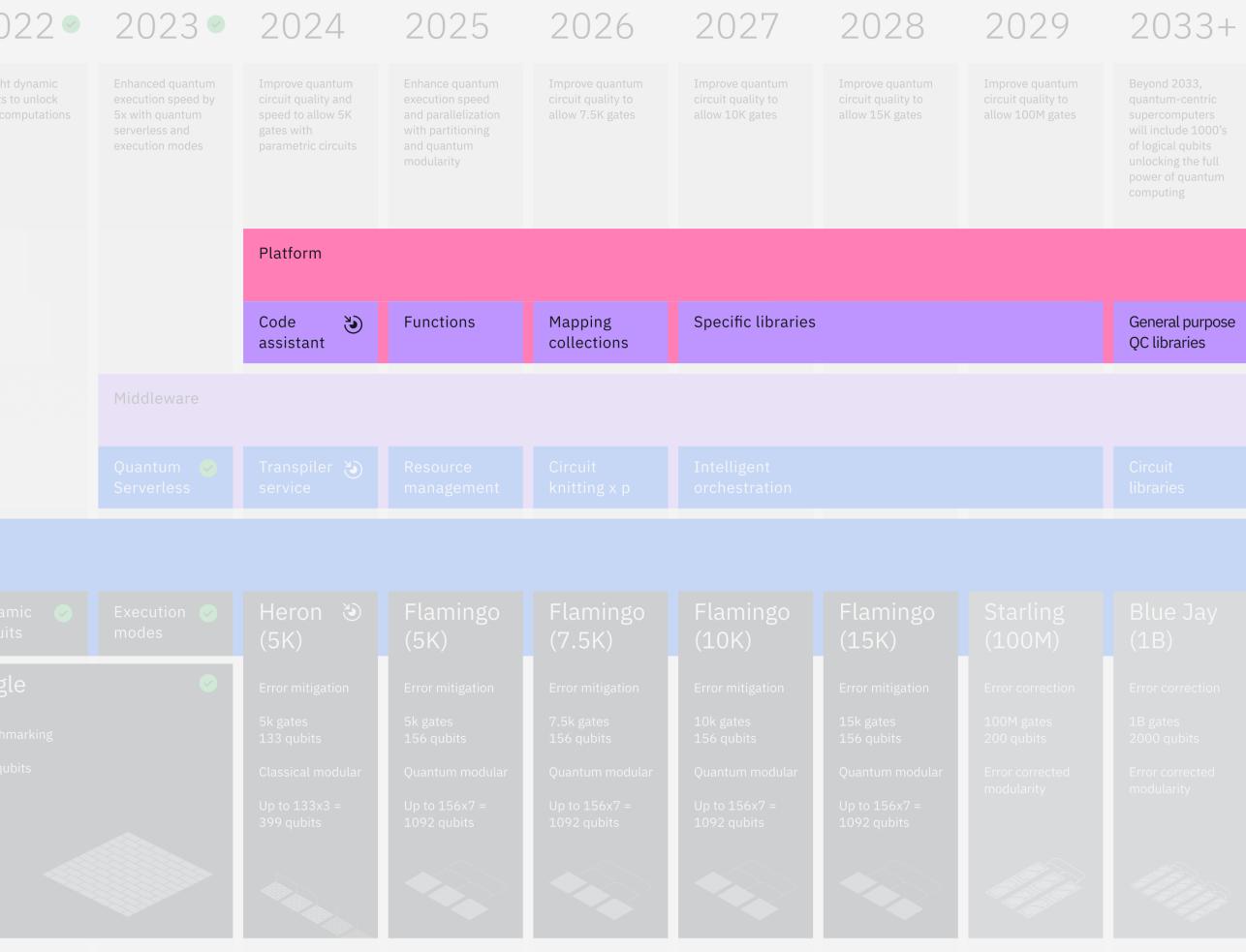
2026 will bring mapping collections so users can start automating the process of mapping their specific use cases to quantum circuits.

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.

2016-2019	2020 •	2021 •	20
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 circuits more co
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Innovation roadmap

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.

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Innovation roadmap

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.

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Innovation roadmap

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 AIassisted 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 2020 20 Application < IBM Qiskit \checkmark Software Quantum modules innovation Rι Experience Circuit and Modules for operator API with domain specific compilation to multiple targets application and algorithm workflows Hardware Executed by IBM 🕑 On target

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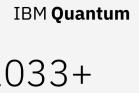


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Development Roadmap

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						IBM Quantum / ©) 2024 IBI



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