TQCI Seminar@QUEST-IS2025,4th Dec., 2025

Installation and Operation of on-premises Quantum Computers in JHPC-Quantum project

Mitsuhisa Sato

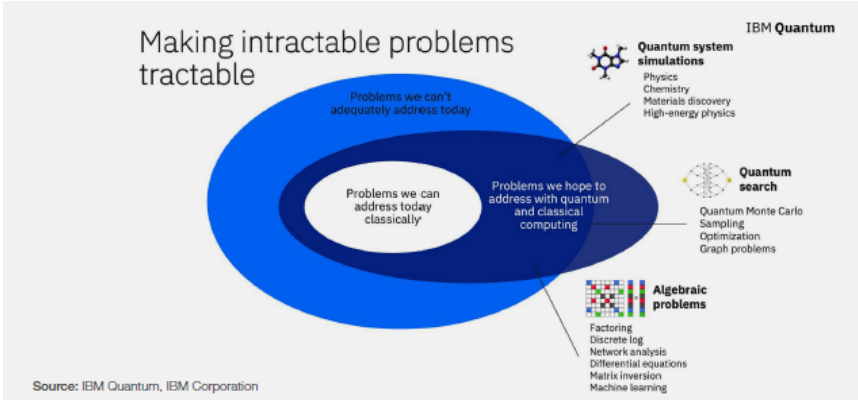
Division Director, Quantum HPC Hybrid Computing Platform Division

RIKEN Center for Computational Science (R-CCS), JAPAN

JHPC-quantum

QCSC (Quantum Centric Supercomputing) Why QC-HPC hybrid computing?

- **Many problems can be solved using supercomputers (HPC), but problems requiring exponential execution time cannot be solved even with supercomputers.**
  - Quantum simulation, optimization, graph problems, cryptanalysis, factorization ….



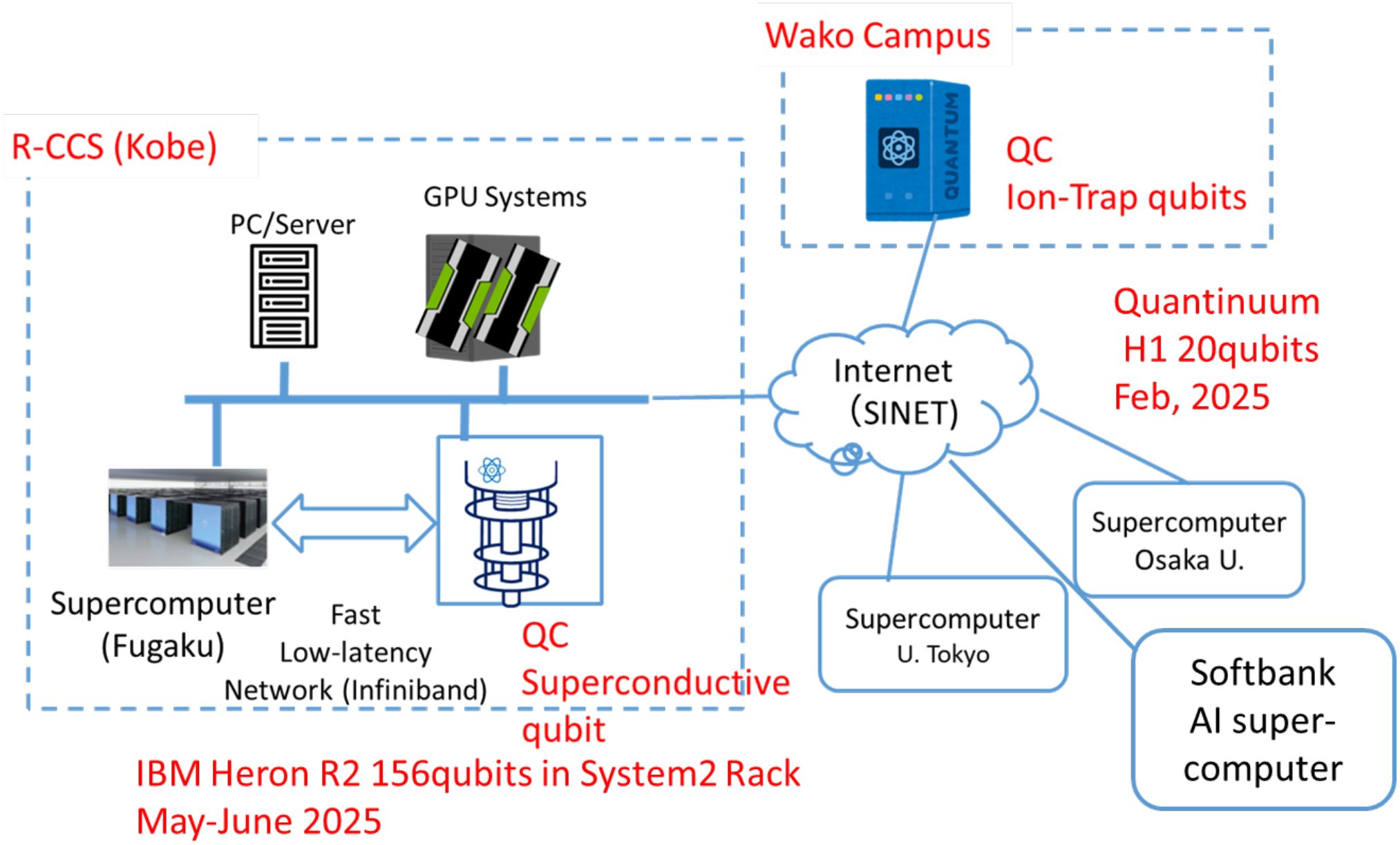
- **When solving large and realistic scientific problems using QC, combining with HPC is required for many computation including preprocessing, postprocessing, etc.**
  - In quantum many-body problems, the computation that generates the model is well-suited to supercomputers and sufficiently fast. Considering realistic speed and scalability, replacing everything with a quantum computer is not practical.
  - In the future, when inputting quantum states at scales of hundreds or thousands of qubits, HPC will be necessary to prepare these states.
- **Particularly in quantum chemistry and material science, combining QC with existing quantum chemistry applications (approximate solution methods) on HPC is essential.**
  - Effective use of QC involves first obtaining a “variational state approximately close to the true ground state” using HPC, then making use of the quantum computer.
  - Similarly, for energy calculations on large molecules, it is necessary to identify the portions truly requiring QC, and this requires HPC

JHPC Quantum project

- **NEDO-funded project: "*Research and Development of quantum-supercomputers hybrid computing platform for exploration of uncharted computable capabilities*"**
  - Project Period: Nov 2023 – Oct 2028 (5years)
  - Members: RIKEN, Softbank, U. Tokyo and Osaka Univ.

- **Missions**
  - Research and development of **quantum HPC hybrid system software** for the integration of quantum computers and supercomputers (HPC) are conducted.
  - Using the system software, a **quantum-supercomputer hybrid platform** is built with two types of on-premis quantum computers, IBM superconductive QPU and Quantinuum trapped -ion QPU, and supercomputers including Fugaku.
  - As well as demonstrating the advantage (and **"Utility"**) of **quantum HPC hybrid applications** against existing applications only by supercomputers, advanced internet technology will be developed to deploy the quantum HPC hybrid applications as **a service in the post-5G era**.

JHPC Quantum QC-HPC hybrid computing Platform



Supercomputer “Fugaku” at R-CCS

RIKEN Center for Computational Science (R-CCS)

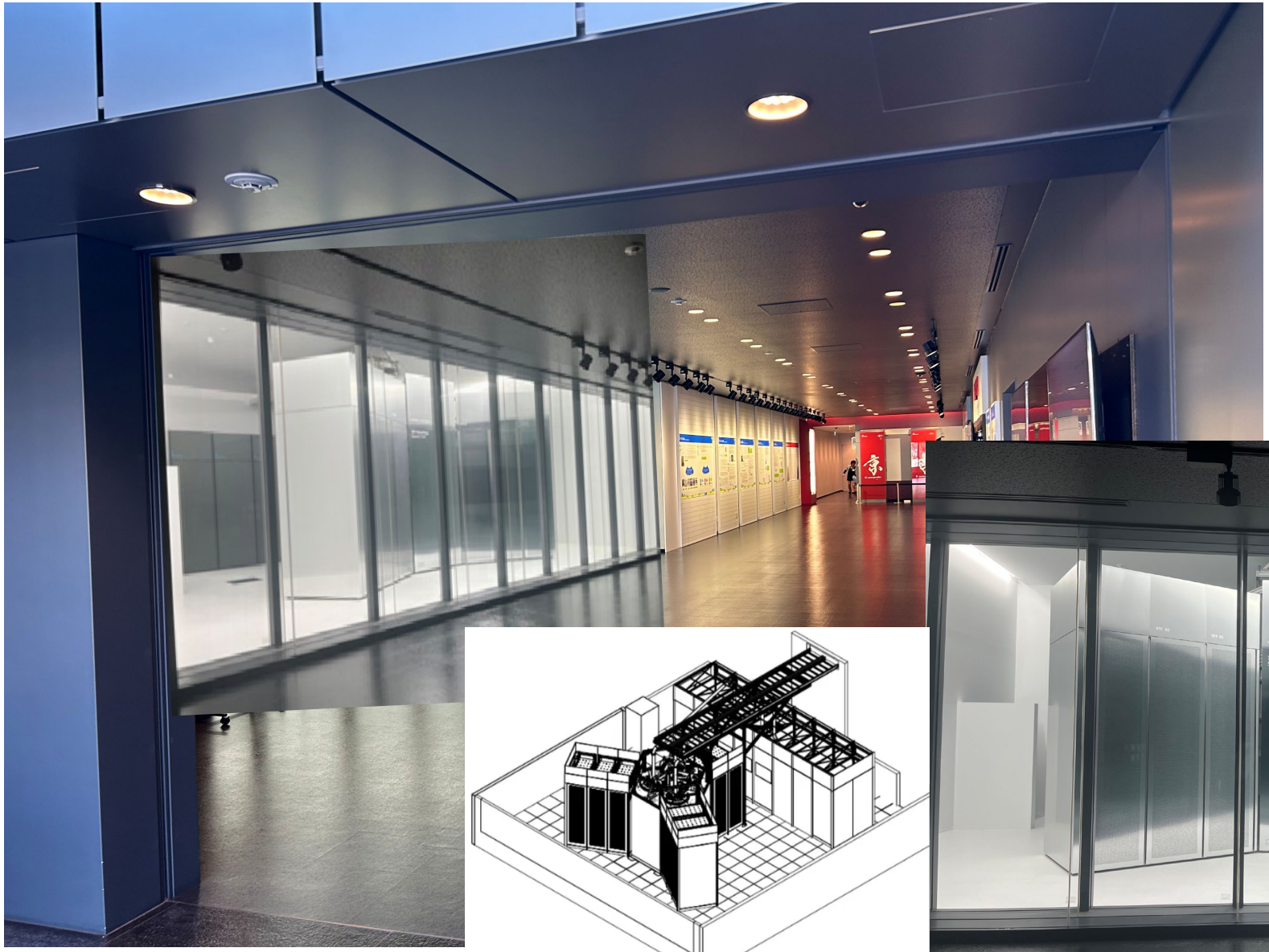
432 racks
158,976 general-purpose manycore processors Fujitsu A64FX, 7 Million Cores

Half exaflops in DP
1 Exaflops in SP!

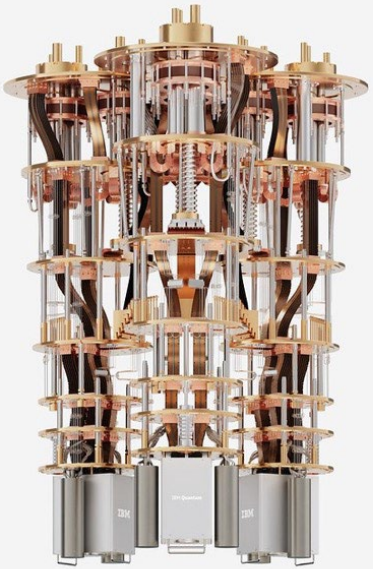
Very power-efficient system with 20MW power-consumption!

The Public Service has started from March, 2021

IBM_kobe System Two in R-CCS@Kobe



IBM kobe was installed in R-CCS in June!
Heron R2 QPU (156 qbits) in IBM system two.



System 2は、3つのQPUを収容できるが、本システムはHeron R2 1 QPUのみ

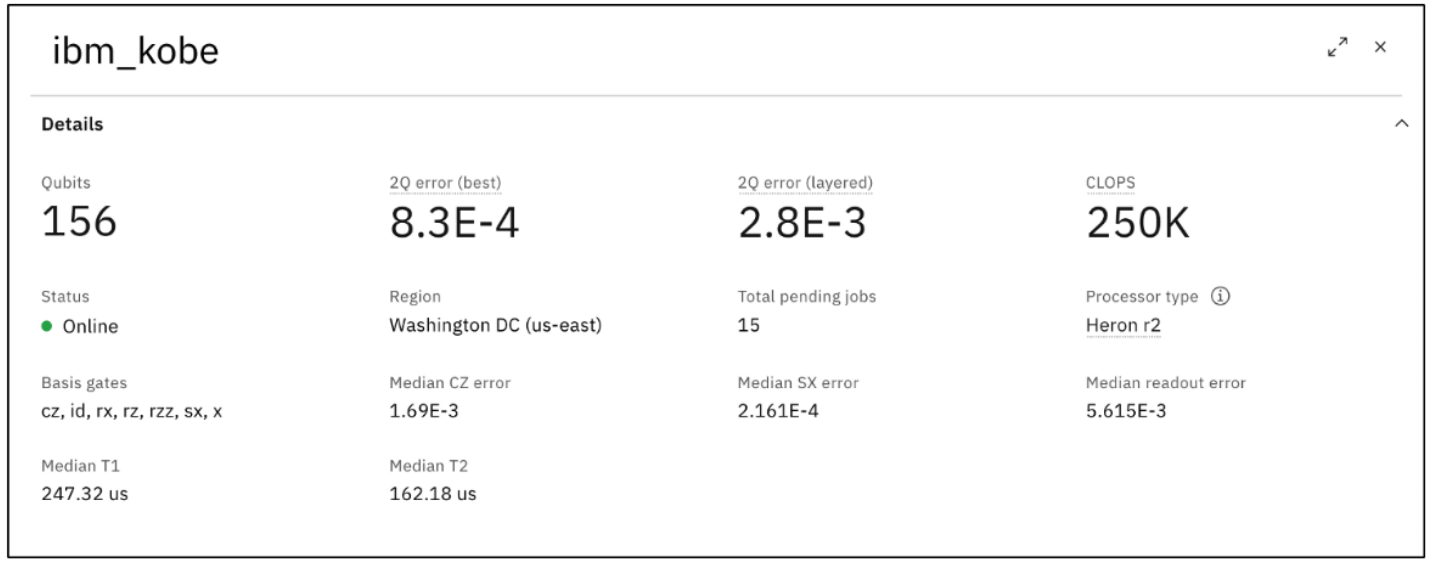
Timeline of IBM Q installation

- **Nov. 2023: JHPC-Quantum Project was launched.**
- **Contract with IBM for 5 years**
- **Timeline:**
  - Nov. 2023: contract
  - July 2024- Dec. 2024 (6 month): Site Preparation (walls, floors, etc.) and infrastructure work (electrical, cooling water, air conditioning, etc.) at the R-CCS installation site
  - Jan 2025-Apr 2025 (3month): delivery and installation
  - May 2025: installation and adjustment work completed
  - June 2025- : Full operation begins

- **First installation of IBM System Two outside of US.**

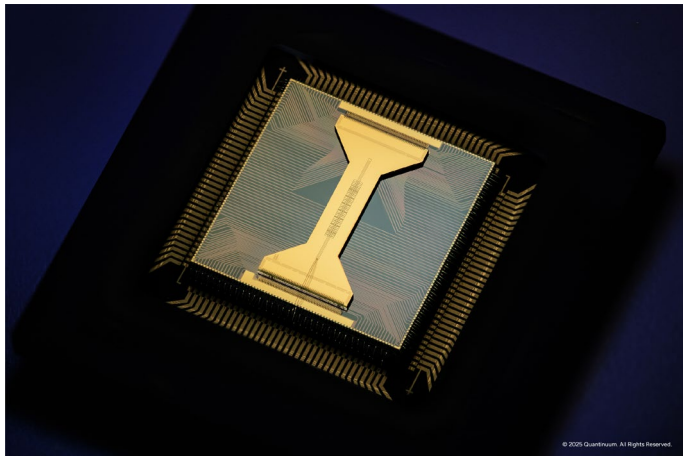
Performance of IBM_kobe

- **#qubit : 156 qbits in Heron R2**
- **TQ error: 8.3e-4 (best),**
  2.8e-3 (layered)
- **CLOPS: 250K**
- **#max depth circuit: 200-300**



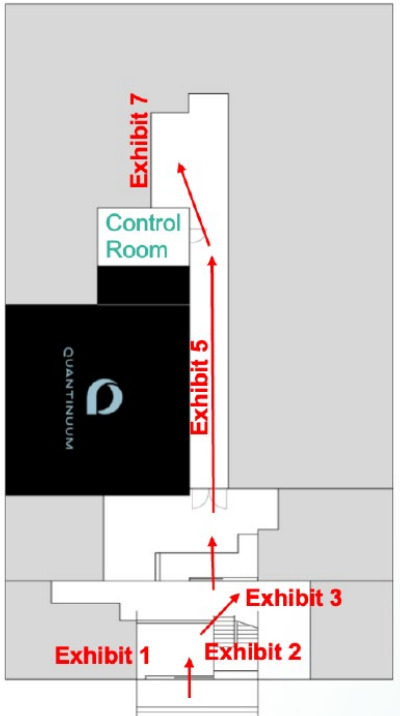
- **Power consumption**
  - 25-30 kW (Idilution refrigerator only)
  - + 10~15kW (control and servers)
- **Direct Access APIs**
- **Only Direct Access (IBM Quantum Cloud is shutdown at end of 2025)**

“Remei” Quantinuum Trapped-Ion Quantum Computer

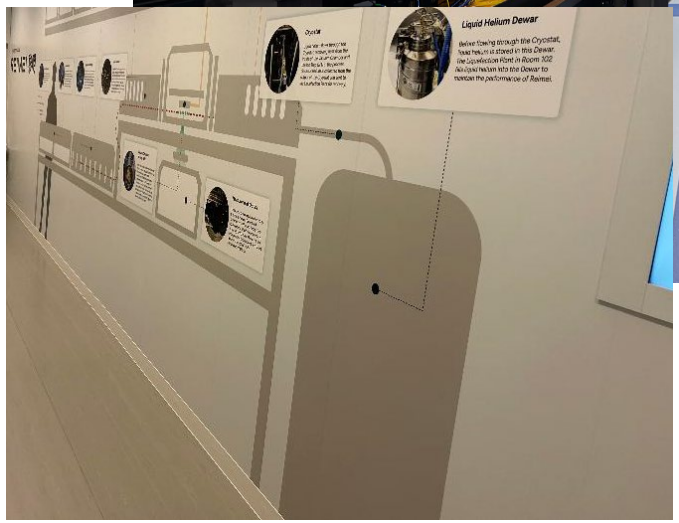


黎明

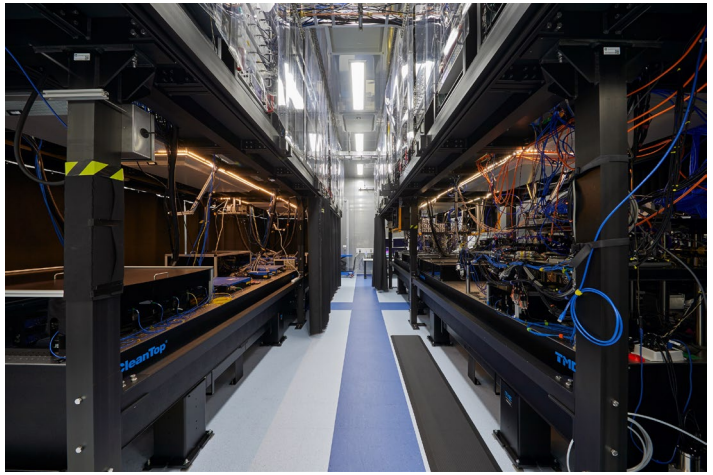
QUANTINUUM
REIMEI



Quantinuum Trapped-Ion Quantum Computer H1 (20 qubits) was installed in Wako Campus, Japan and is operated since Feb, 2025



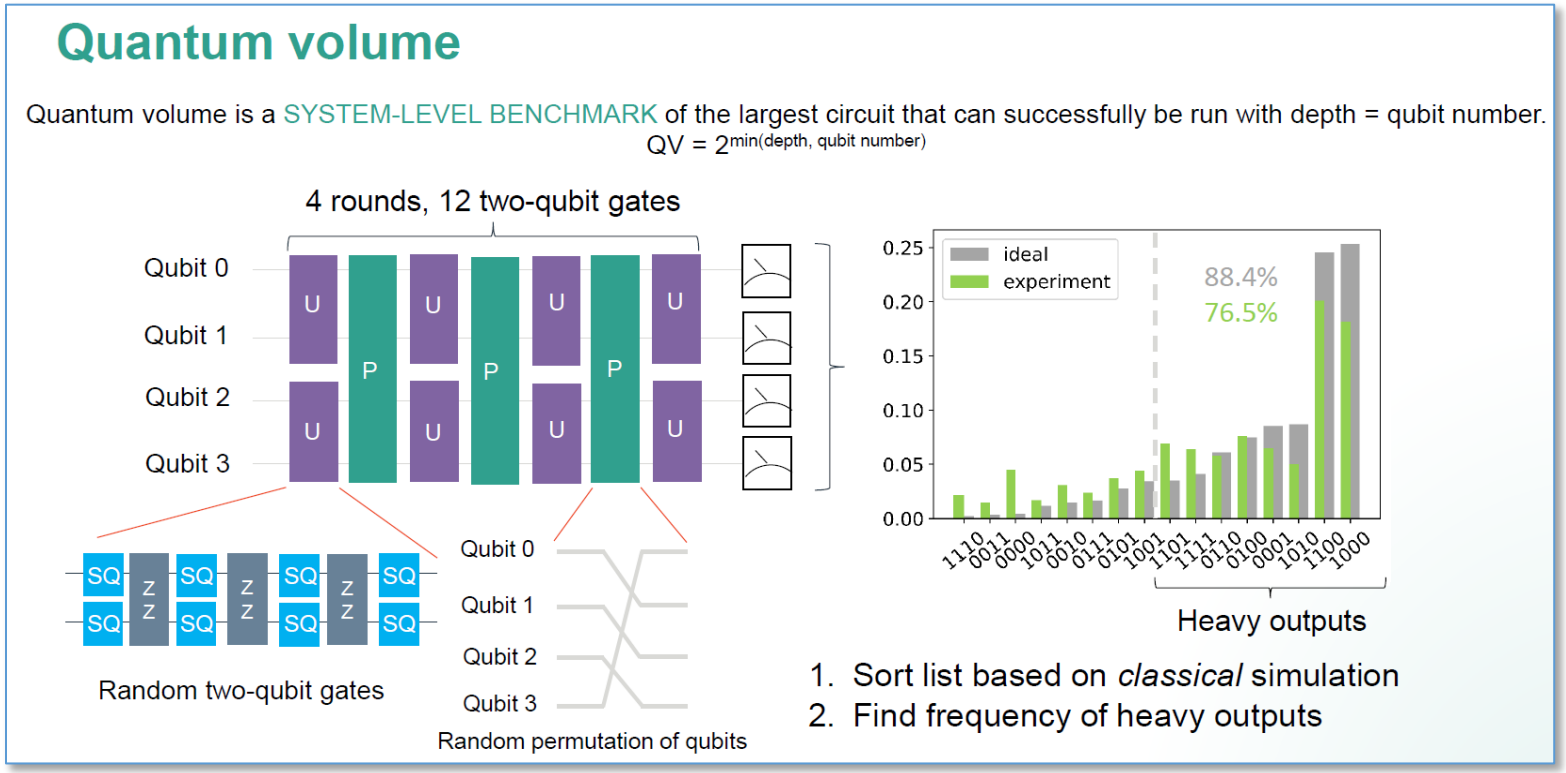
Timeline of Quantinuum installations



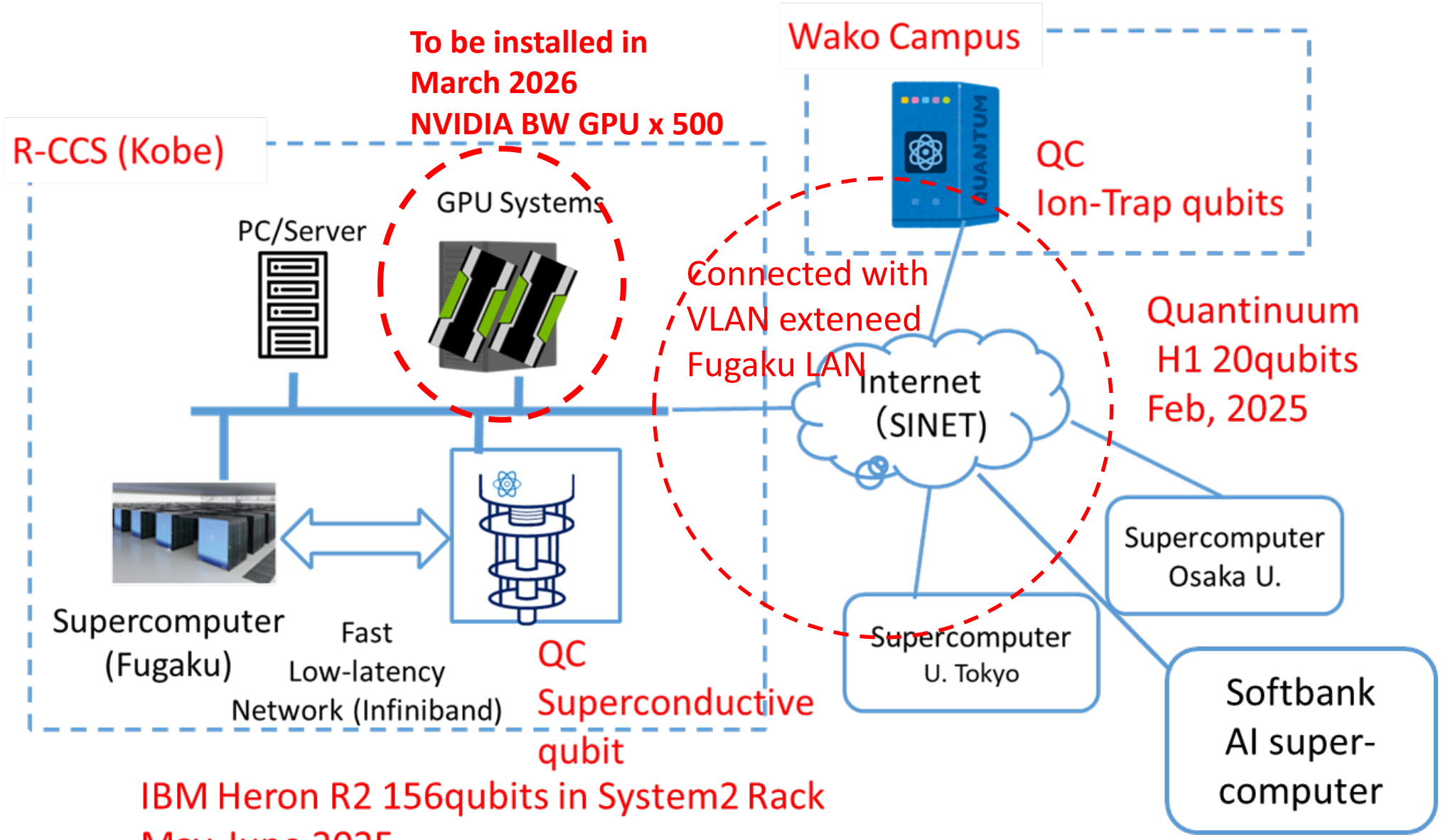
- **Nov. 2023: JHPC-Quantum Project was launched.**
- **Contract with Quantinuum for 5 years**
- **Quantinuum requested “clean-room” and Liquid helium plant for local installation (in Wako campus of RIKEN)**
- **Timeline:**
  - Phase1(Nov/2023-Apr/2024): Remote access to H1-2 and H1-2E (located in US)
  - Phase2(May/2024-Jan/2025): Remote access to H1-2 and Localization of H1-2 (disassemble, ship, rebuild, validate)
    - Packaging and shipment (3 month): Apr/2025-Jun/2025
    - Local installation (3 month): July/2025-Sep/2025
    - Validation and optimization: (4 month) Oct/2025-Jan/2026
  - Phase3(Feb/2025 -): Full operations of local H1-2, now REIMEI, and additional remote access to US
- **Full system successfully shipped to Japan**

“Reimei” Technical Highlights and performance

- **Met or exceeded all QSA (Quantum Service Agreement) performance requirements**
  - At least 20 qubits ⇒ Reimei has 20bits
  - SQ error 1.0E-04 (QSA) ⇒ 1.80E-05 (measured)
  - TQ error 3.0E-03 (QSA) ⇒ 1.22 e-03 (measured)
- **Demonstrated QV 2^{19}**
- **Power consumption**
  - 12 kW (“Reimei” only)
  - 100 kW (system)
- **Average of uptime > 90%**
- **Direct Access and HPC coordination (Tierkreis) APIs**
- **Both Direct Access and Nexus Cloud Access are available in parallel**



JHPC Quantum QC-HPC hybrid computing Platform

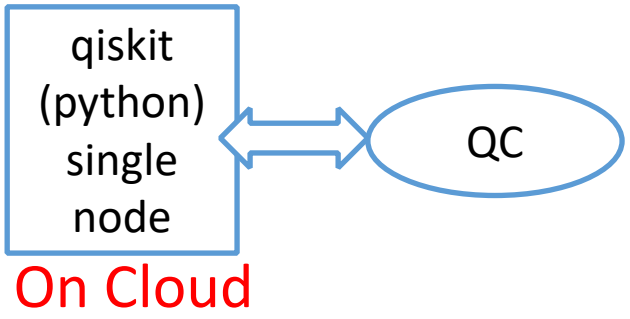


Value of on-premises Quantum Computers

- **System design for QC-HPC hybrid computing**
  - Support Tightly-coupled model by priority-based QC request scheduler
- **User management and authentication by local policy**
  - Running idp for JHPC-Quantum users

Programming Models for QC-HPC Hybrid Apps
How to combine QC and HPC

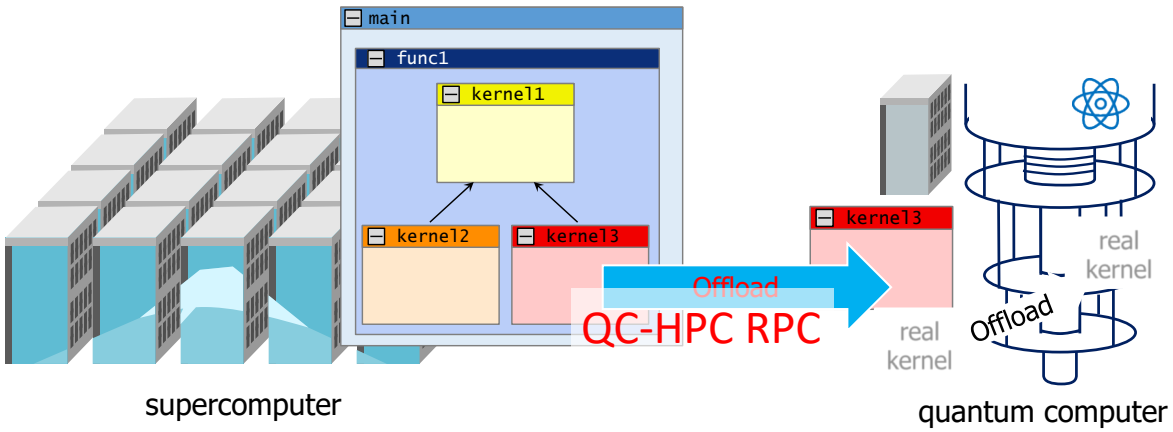
(0) Running Qiskit program on a single node as in “Cloud”

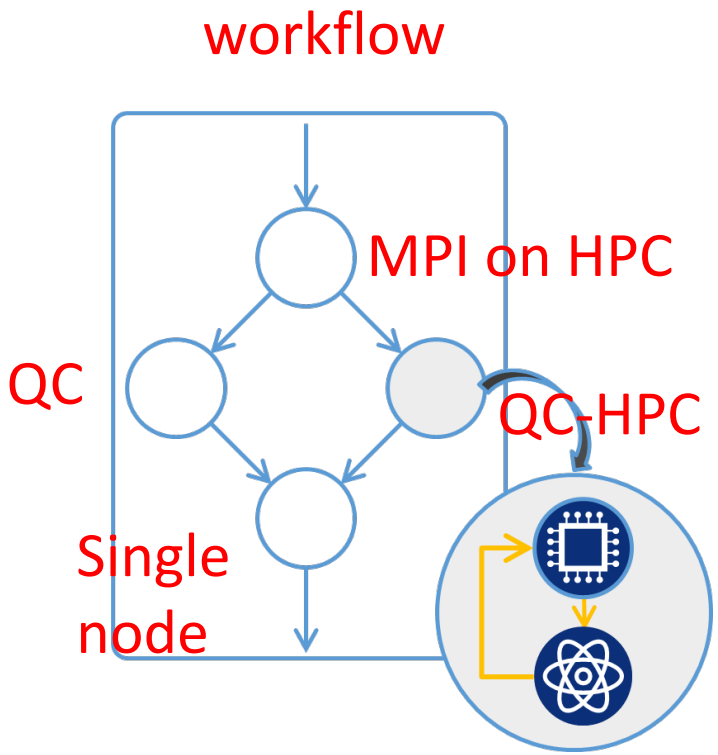


(1) Loosely-coupled independent programs of QC and HPC by workflow tools

(2) Tightly-coupled QC and HPC in one HPC program by offloading of QC computation using (asynchronous) RPC (remote procedure call)

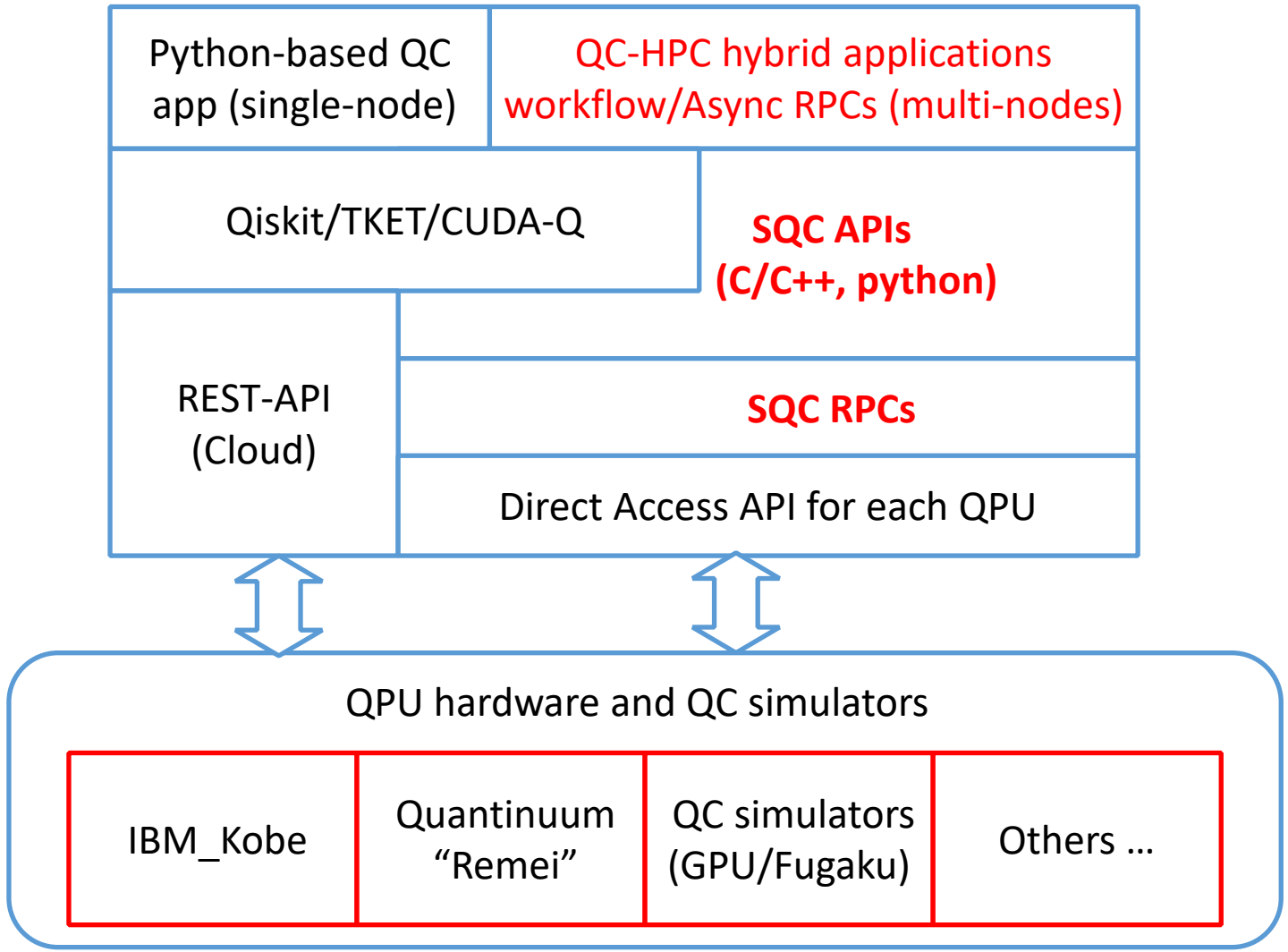
⇒ by priority-based scheduling



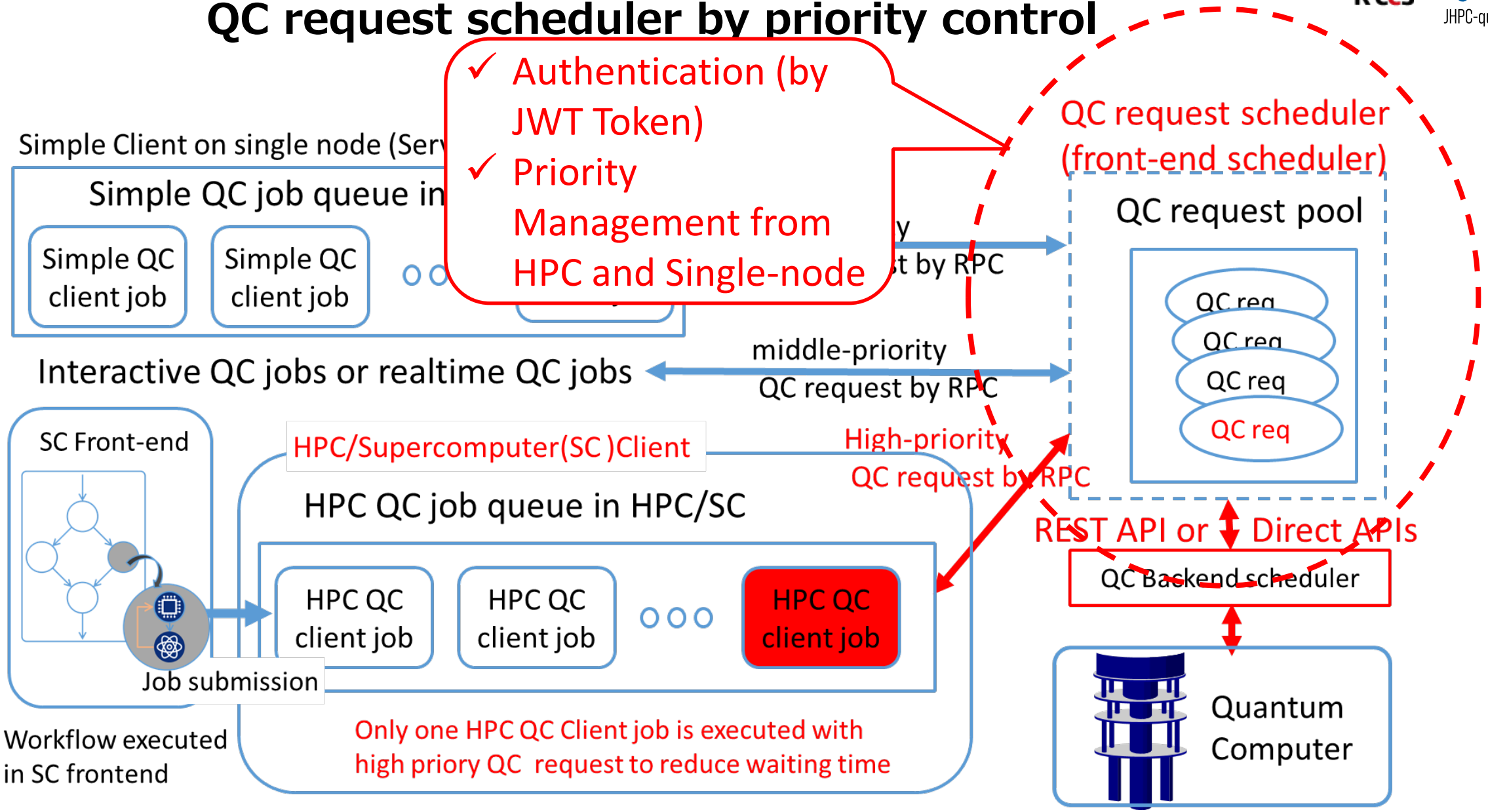


JHPC Quantum Software Stack

- **Two ways to access QC**
  - Our SQC APIs and RPC. The RPC uses direct access APIs provided by QPU venders
  - REST-APIs through vender clouds
- **Workflow tools**
  - Tierkreis (Quantinuum), Prefect, Xcrypt
- **QC software libraries**
  - JHPC Quantum QC software lib
  - Qunasys QURI SDK
  - Error mitigation
  - Error surpression

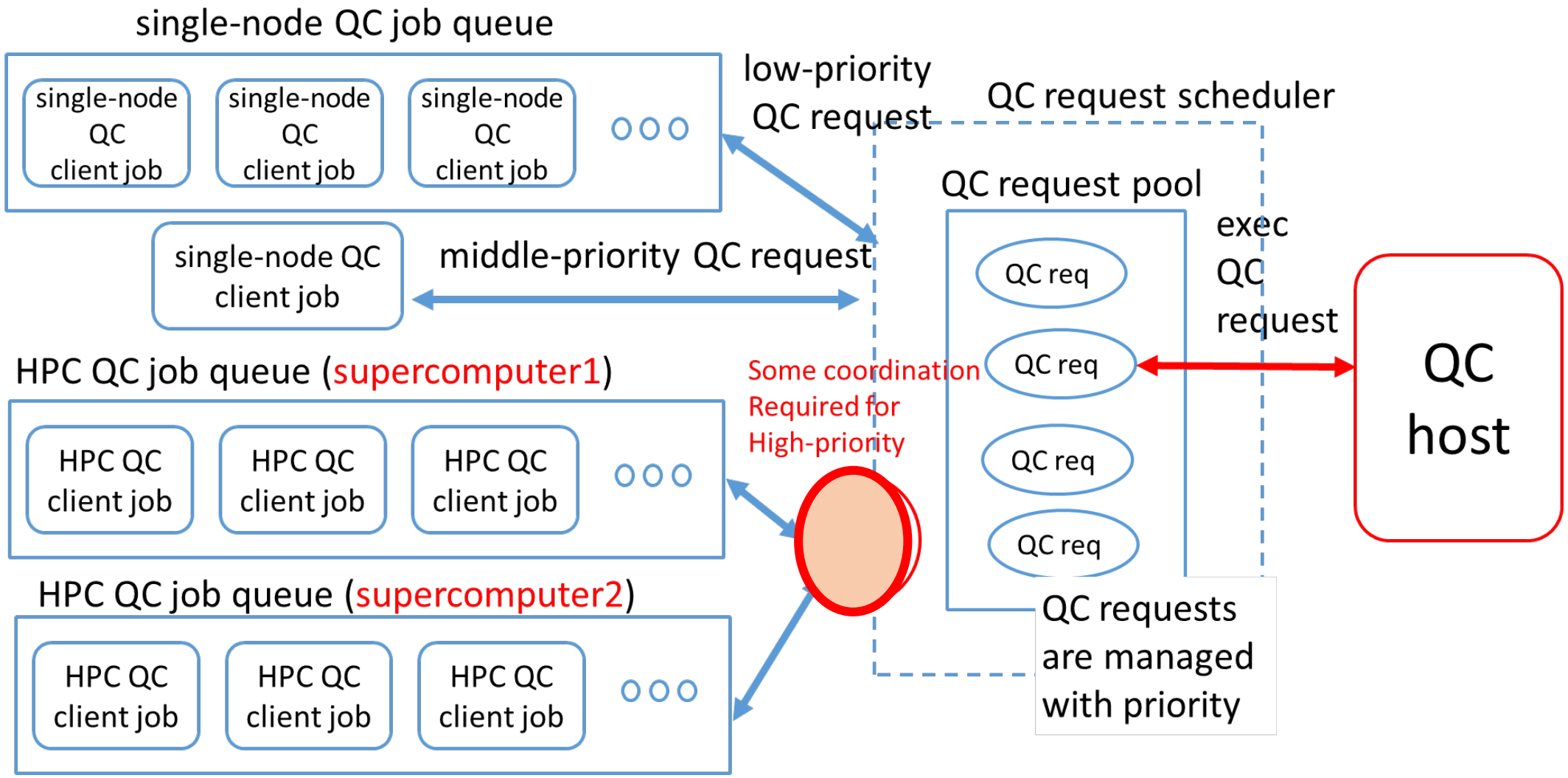


Coordinated scheduling with HPC scheduler and QC request scheduler by priority control



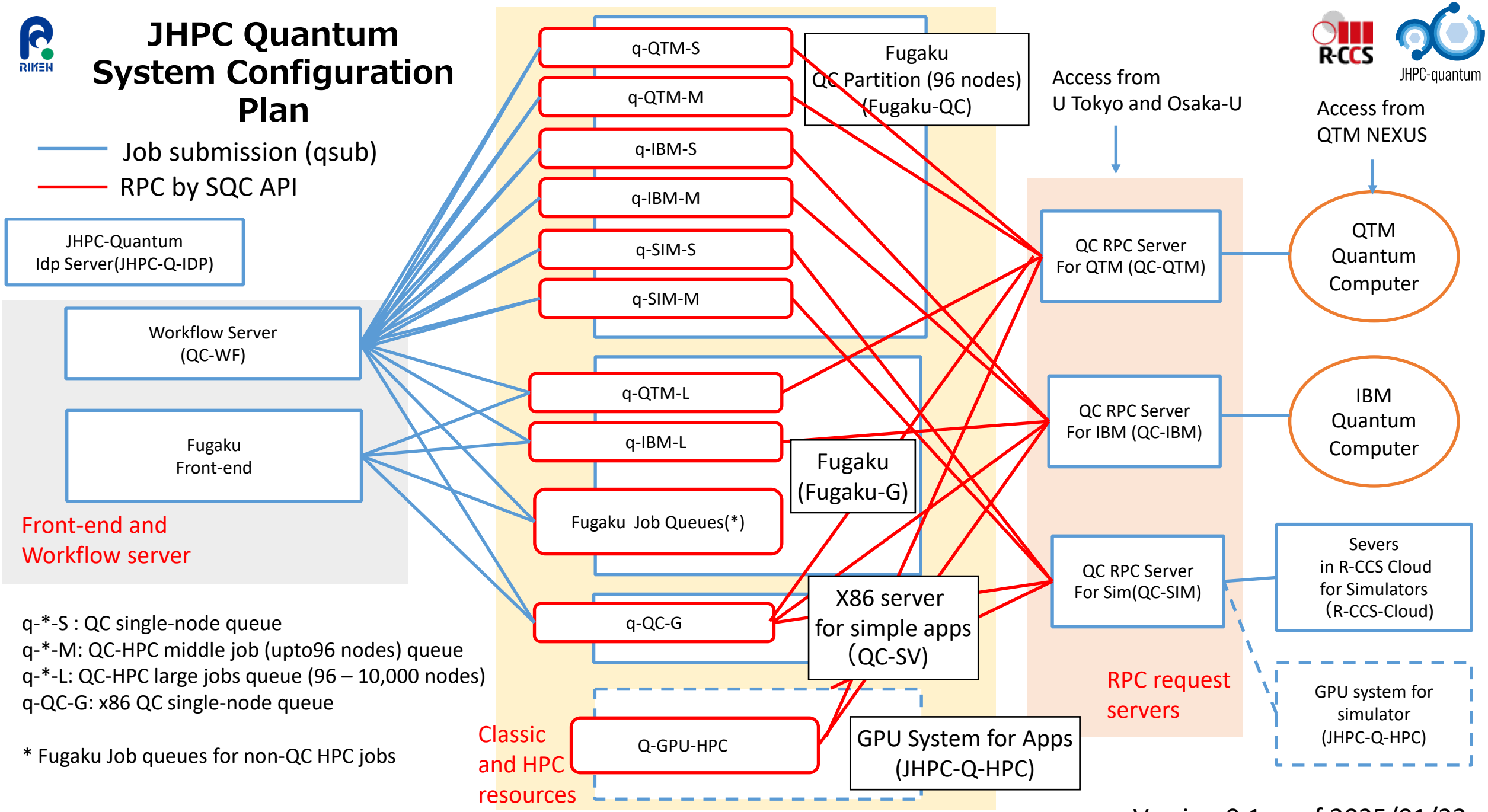
How to support multiple high-priority queue

- **Coordination mechanism required to restrict high-priority execution**



JHPC Quantum System Configuration Plan

Job submission (qsub)
RPC by SQC API



q-*-S : QC single-node queue
q-*-M: QC-HPC middle job (upto96 nodes) queue
q-*-L: QC-HPC large jobs queue (96 – 10,000 nodes)
q-QC-G: x86 QC single-node queue

* Fugaku Job queues for non-QC HPC jobs

Version 0.1 as of 2025/01/22

Value of on-premises Quantum Computers

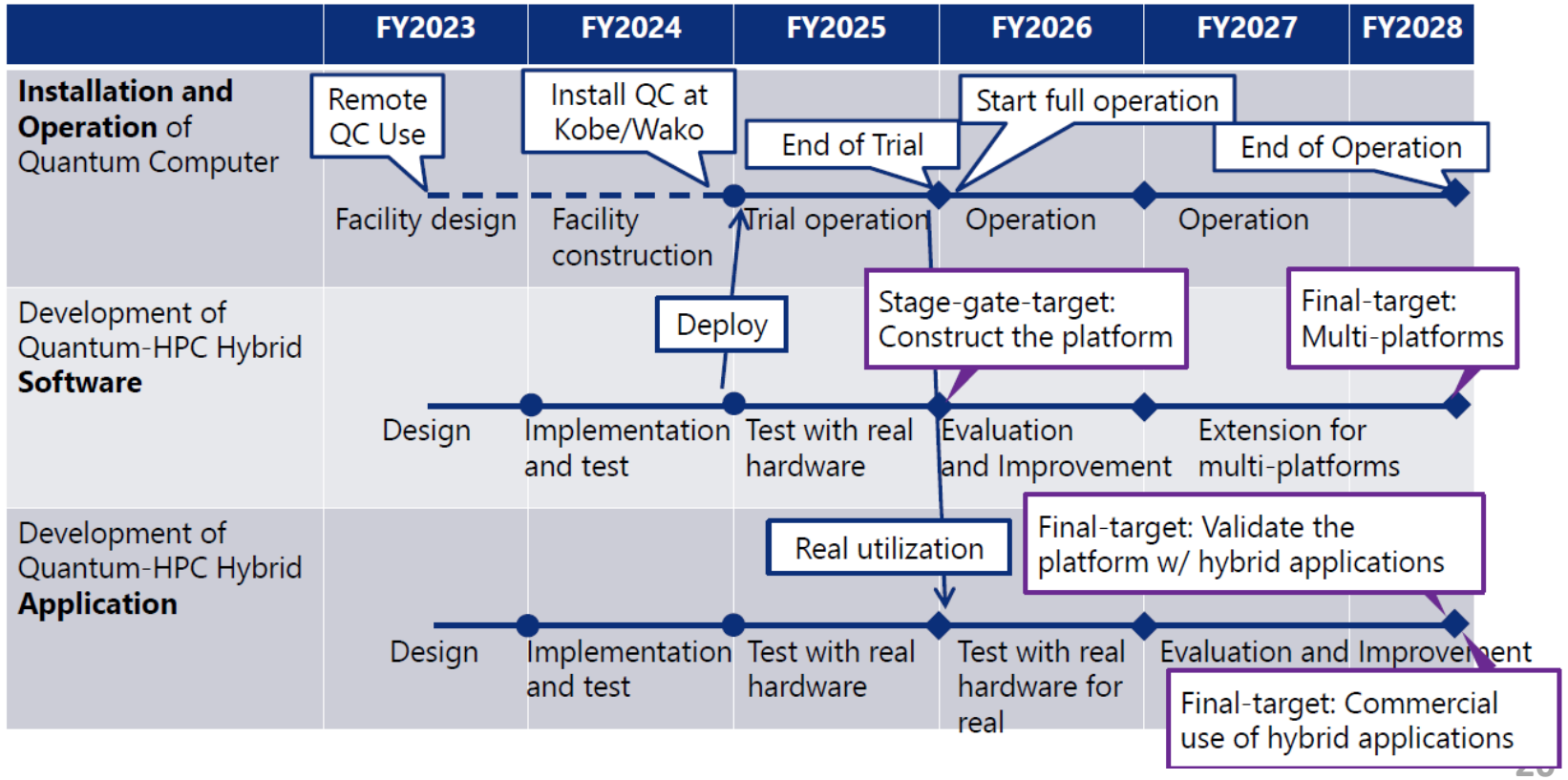
- **System design for QC-HPC hybrid computing**
  - Support Tightly-coupled model by priority-based QC request scheduler
- **User management and authentication by local policy**
  - Running idp for JHPC-Quantum users
- **Sovereign QC**
  - National strength and security
- **Sympathy and interest for Quantium technology**
  - Important for education and HR development in local community

JHPC quantum project roadmap

- **Our project, JHPC quantum, was accepted and started from Nov. 2023.**
- **Installation of QC hardware in 2Q 2025**
- **In 1st Q of 2026, operation of the quantum supercomputer hybrid platform will be started and used to demonstrate the effectiveness of quantum and HPC hybrid applications in the later half of our project.**

We started “test-user program” to invite external users who are interested in QC-HPC hybrid computing.

International collaboration is welcome



Thank you for your attention.

Q & A