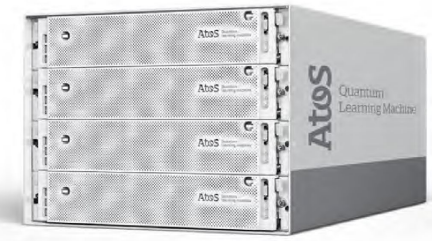
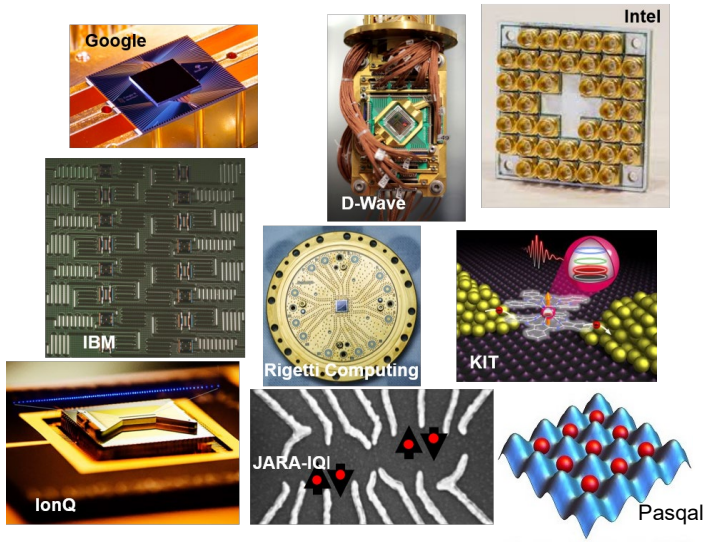


State of the Art: the promises and limitations of Hybrid Qomputing

Workshop: Europe is on its way towards "Hybrid Qomputing"

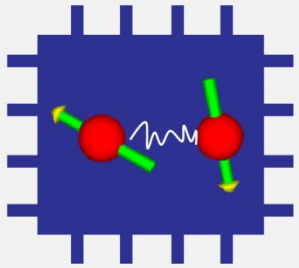
Forum Teratec 2021 | June 22, 2021 | KRISTEL MICHIELSEN

Quantum Technology Readiness Levels



QTRL

Quantum Technology Readiness Levels describing the maturity of Quantum Computing Technology



QTRL9	QCs (QAs) exceed power of classical computers
QTRL8	Scalable version of QC (QA) completed and qualified in test
QTRL7	Prototype QC (QA) built solving small but user-relevant problems
QTRL6	Components integrated in small quantum processor w/ error correction
QTRL5	Components integrated in small quantum processor w/o error correction
QTRL4	Multi-qubit system fabricated; classical devices for qubit manipulation developed
QTRL3	Imperfect physical qubits fabricated
QTRL2	Applications / technologically relevant algorithms formulated
QTRL1	Theoretical framework for quantum computation (annealing) formulated

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(http://www.fz-juelich.de/ias/jsc/EN/Research/ModellingSimulation/QIP/QTRL/_node.html)

Quantum Technology Readiness Levels

QTRL

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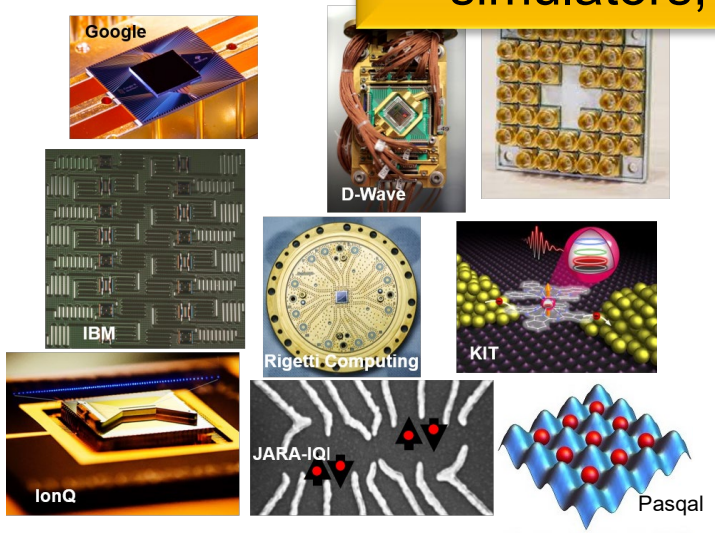
Huge challenge and opportunity: Practical quantum computing

→ Development of **prototype applications and use cases** for quantum simulators, quantum computers and quantum annealers



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(http://www.fz-juelich.de/ias/jsc/EN/Research/ModellingSimulation/QIP/QTRL/_node.html)

High performance & Quantum Computers

linked, to solve problems optimally

High Performance Computers

HPC simulations of quantum computing / annealing devices

Quantum Computers & Annealers

Understanding – Design – Benchmarking

(Hybrid) simulations for applications

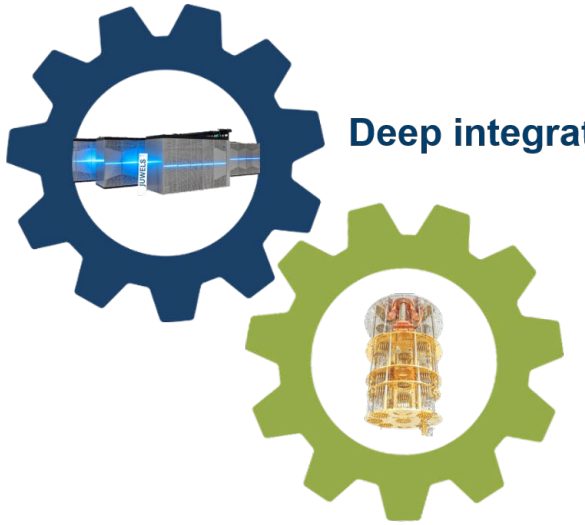
Hybrid quantum-classical computing systems

for the realization of the full potential of quantum computing

- **Hybrid quantum-classical algorithms**
  - Variational Quantum Eigensolver – **VQE**: quantum chemistry
  - Quantum Approximate Optimization Algorithm – **QAOA**: optimization
  - Quantum Support Vector Machine – **qSVM**: classification and clustering

Proper benchmarking & implementation on real devices

- **Hybrid quantum-classical hardware**



Deep integration

Latencies & execution times

Quantum Approximate Optimization Algorithm

Jülich Universal Quantum Computer Simulator – JUQCS

- Variational quantum algorithm (**hybrid** algorithm)
- Relies on iteratively applying a series of parametrized unitary transformations to a quantum register, measuring its resulting state and evaluating the **energy expectation value**
  - Number of iterations $p \geq 1$
- A **classical optimization algorithm** is used to optimize the parameters β and γ of the unitary transformations

GPUs of JUWELS Booster for execution quantum part → QPUs

CPUs of JUWELS Booster for execution classical part

De Raedt et al., CPC **176**, 121 (2007)

De Raedt et al., CPC **237**, 47 (2019)

Simplified tail assignment problem

40 qubits

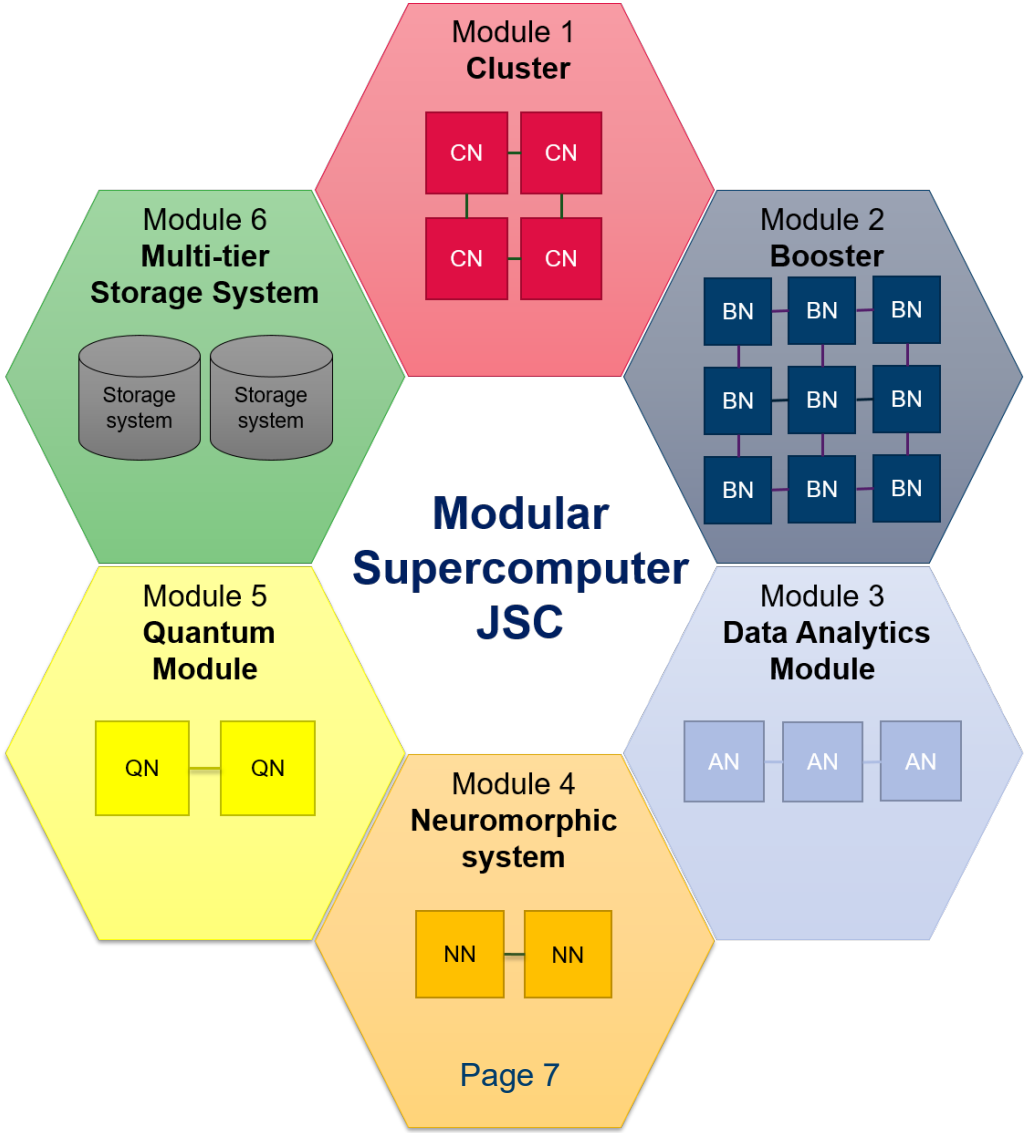
Willsch et al, Quant. Inf. Proc. 19:197 (2020)

Willsch et al, arXiv:2104.03293

https://www.youtube.com/watch?v=zqRcT62cEsE

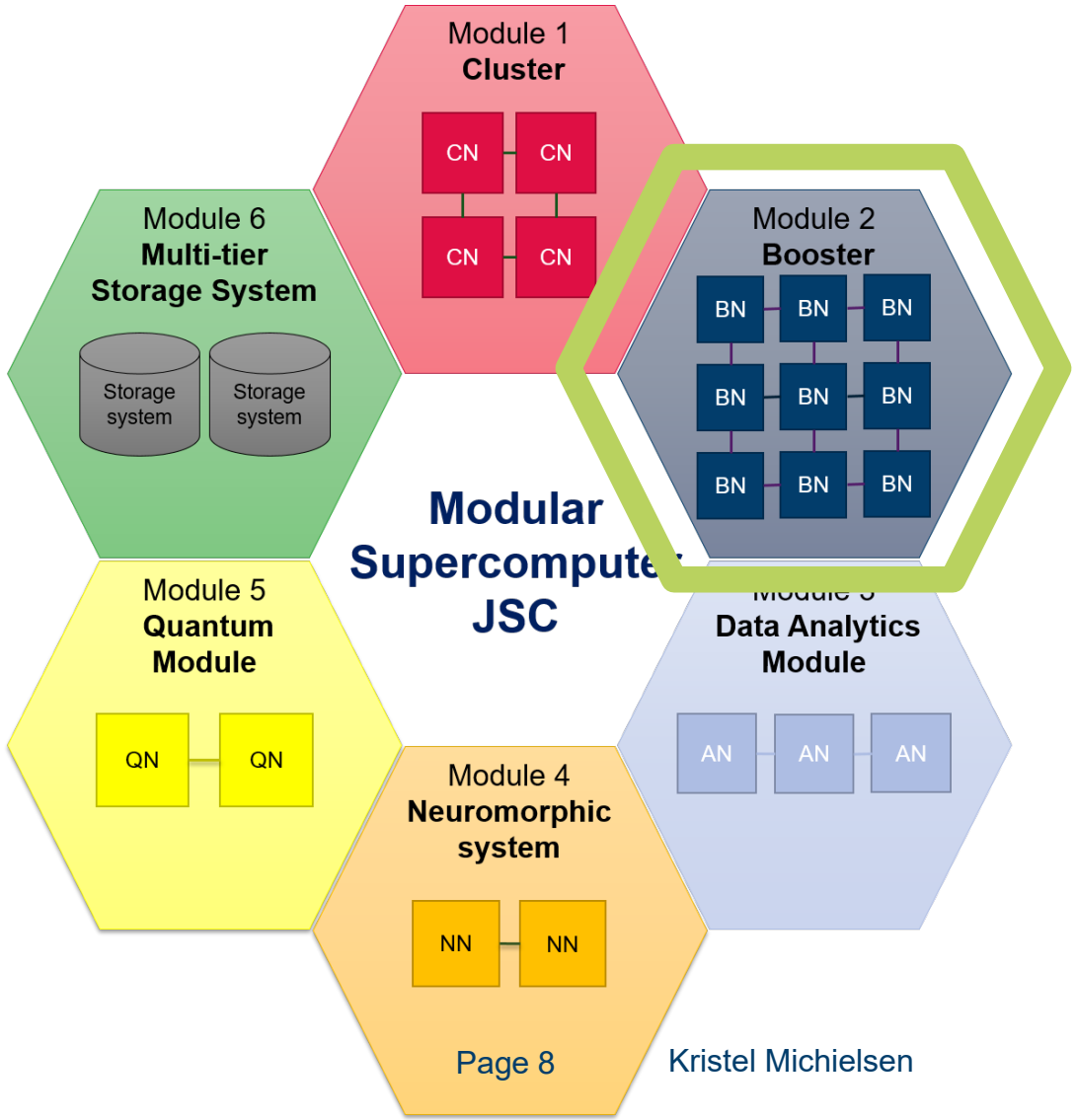
Modular Supercomputer Architecture

Jülich Supercomputing Centre



Modular Supercomputer Architecture

Jülich Supercomputing Centre

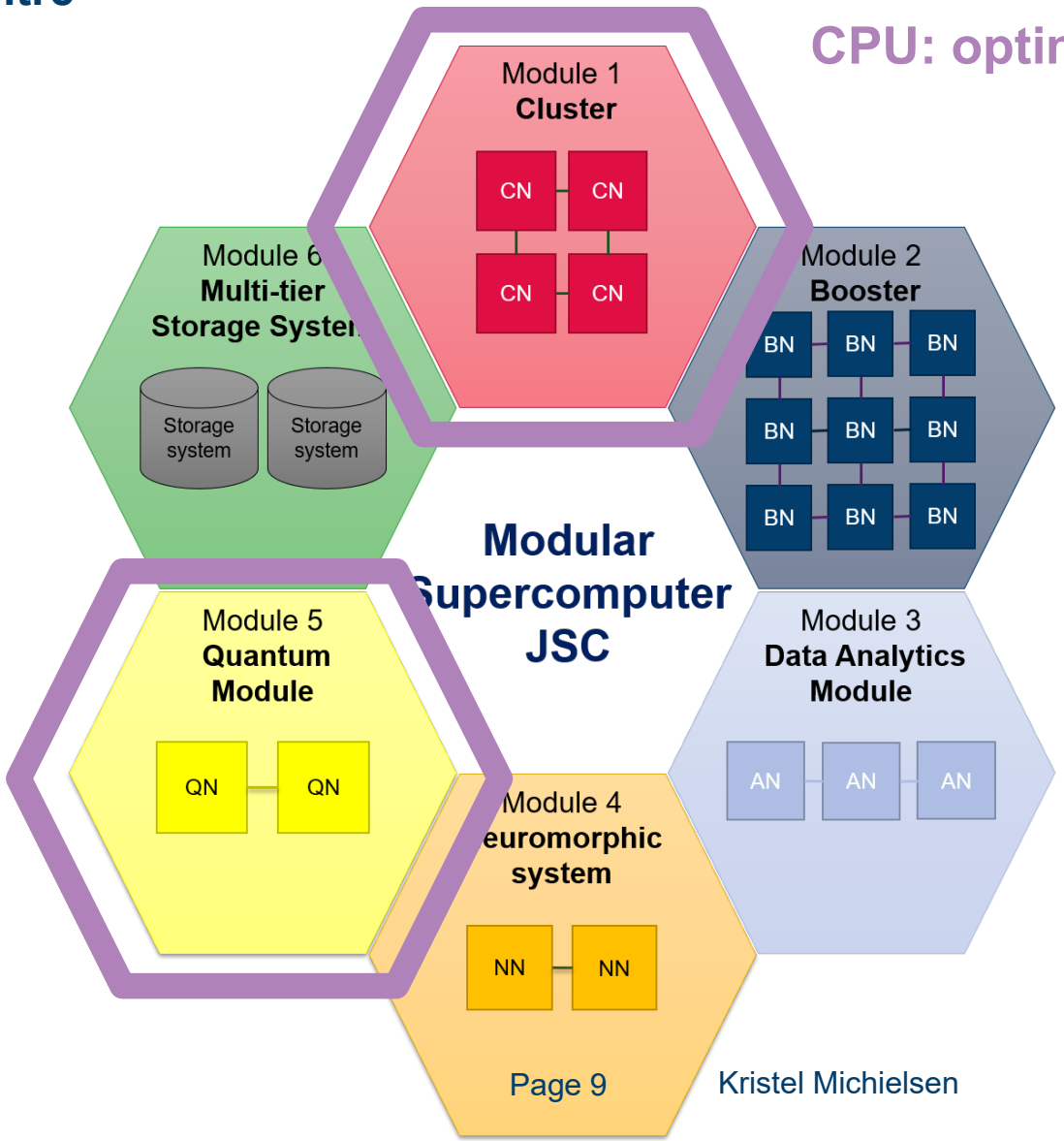


CPU: optimization
GPU: quantum circuit

Modular Supercomputer Architecture

Jülich Supercomputing Centre

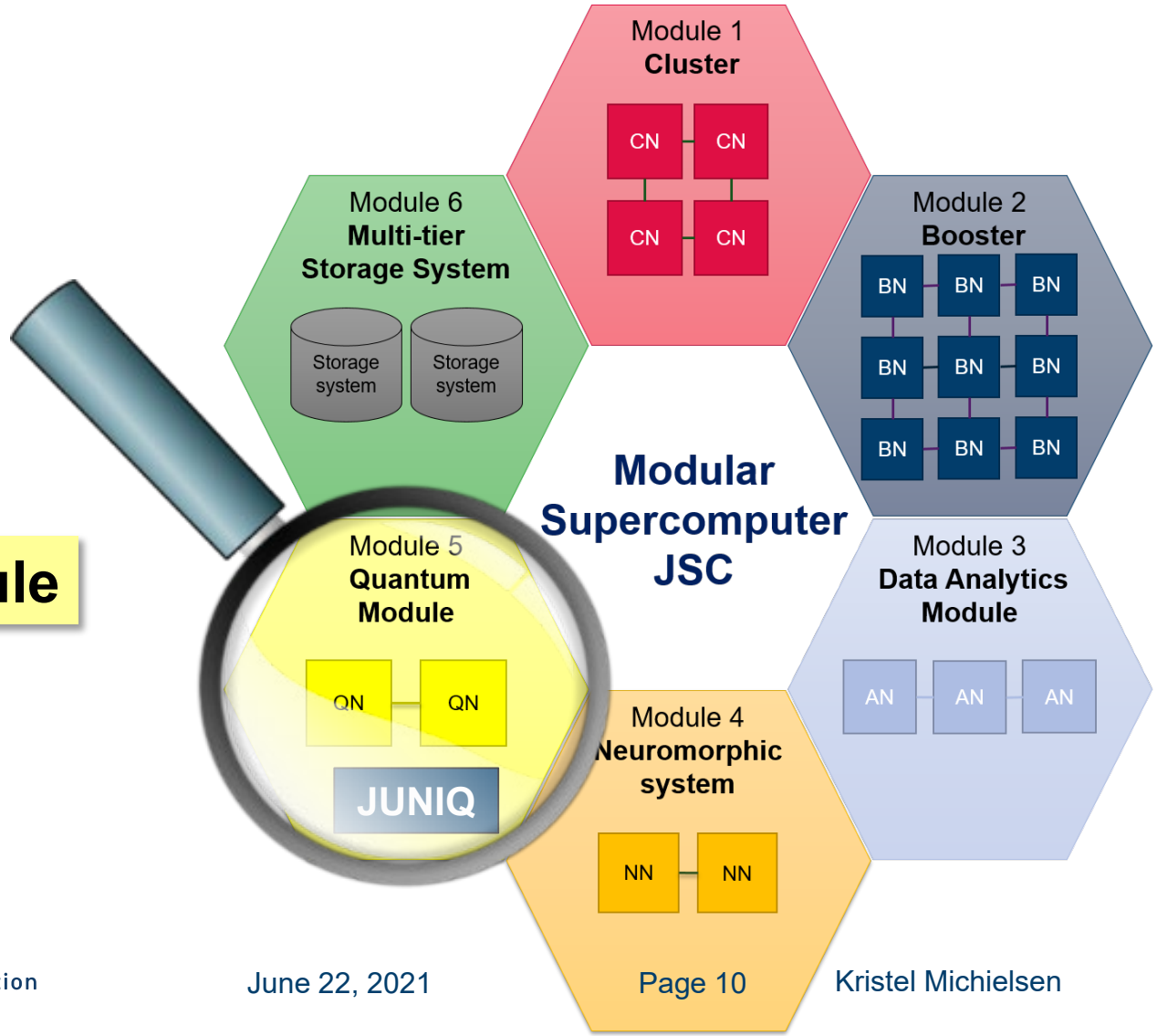
CPU: optimization



QPU: quantum circuit

JUNIQ - Jülich UNified Infrastructure for Quantum computing

A European quantum computer user facility at the Jülich Supercomputing Centre

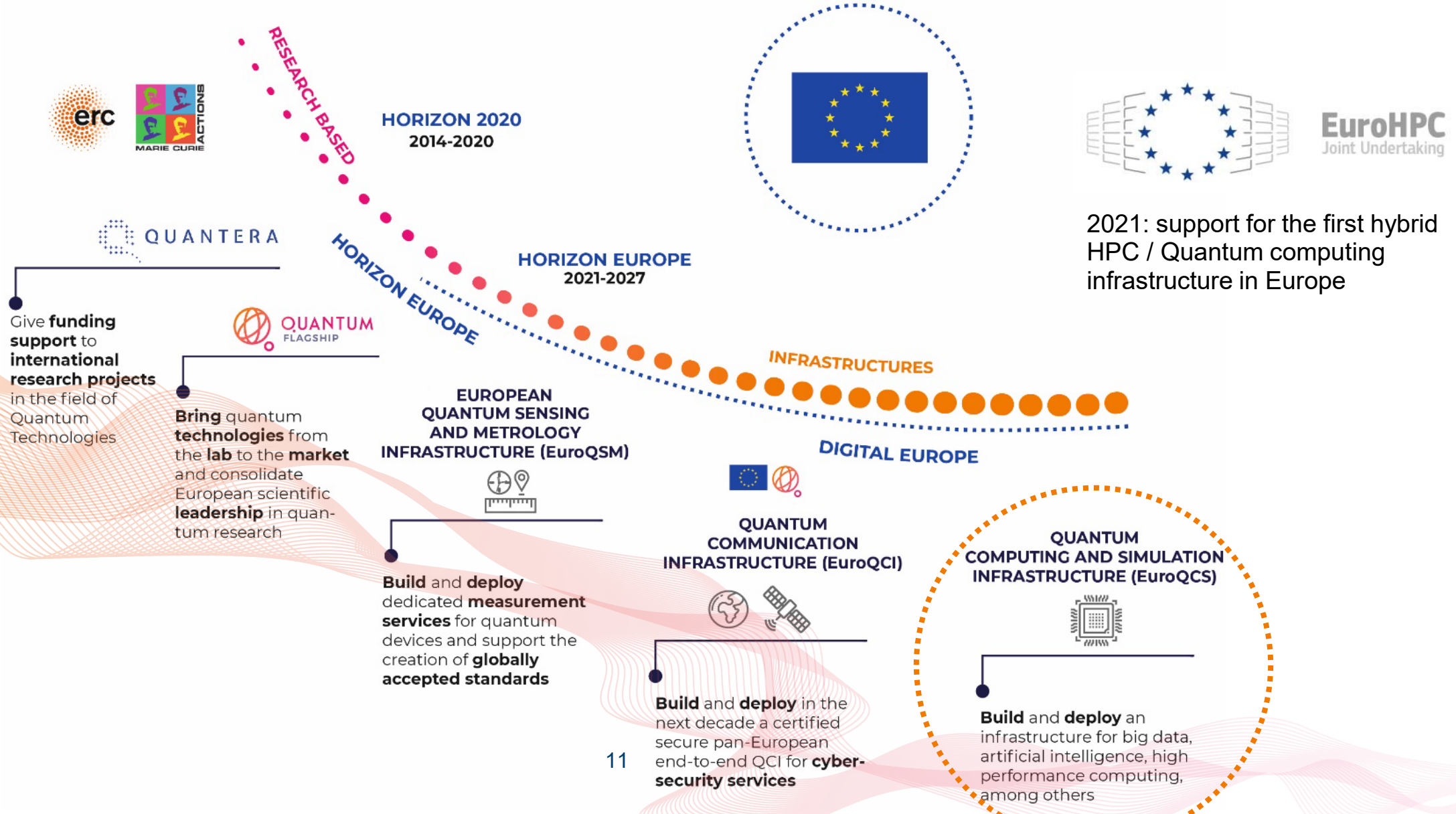


Quantum Module

Plan: Seamless QC-HPC integration

Perspective:
Quantum-Classical
Hybrid Computing Models

FROM VISION TO REALITY – THE EU'S COMMITMENT



EuroHPC Joint Undertaking

2021: support for the first hybrid HPC / Quantum computing infrastructure in Europe

High Performance Computer and Quantum Simulator hybrid

EuroHPC Joint Undertaking

2021: support for the first hybrid HPC/Quantum computing infrastructure in Europe

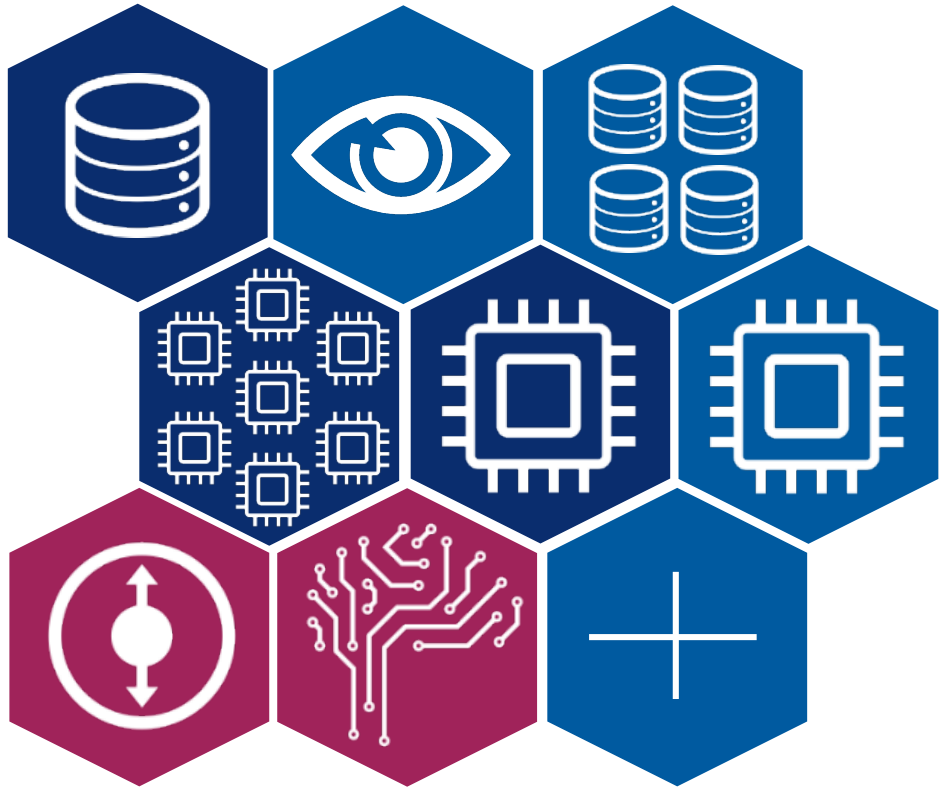
JUNIQ - Jülich UNified Infrastructure for Quantum computing

1. QC user facility for science and industry
2. Installation, operation and provision of QCs
3. Unified portal for access to QC emulators and to QC devices at different levels of technological maturity (QC-PaaS)
4. Development of algorithms and prototype applications
5. Services, training and user support
6. Modular quantum-HPC hybrid computing

Future: Modular Exascale Supercomputer

- Unique world-leading instrument for high-end simulation, large-scale AI and data science, for scientific and industrial research in Germany and Europe

- Optional: integration of future computing technology (quantum, neuromorphic)



Quantum booster

Neuromorphic computing

Hybrid usage of High performance & Quantum Computers

High Performance Computers

Quantum Computers & Annealers

Succesful development of quantum computing applications