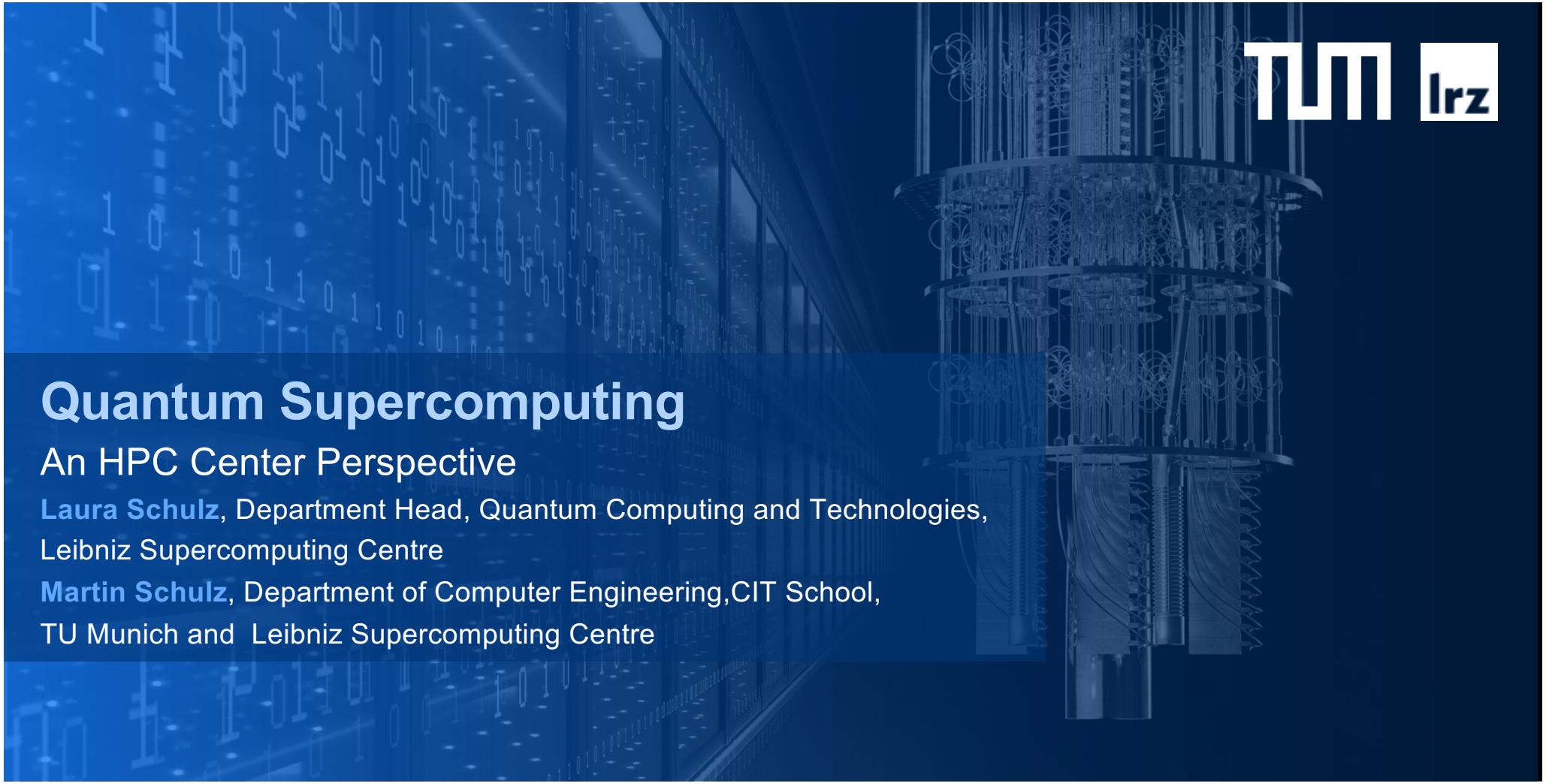


Quantum Supercomputing

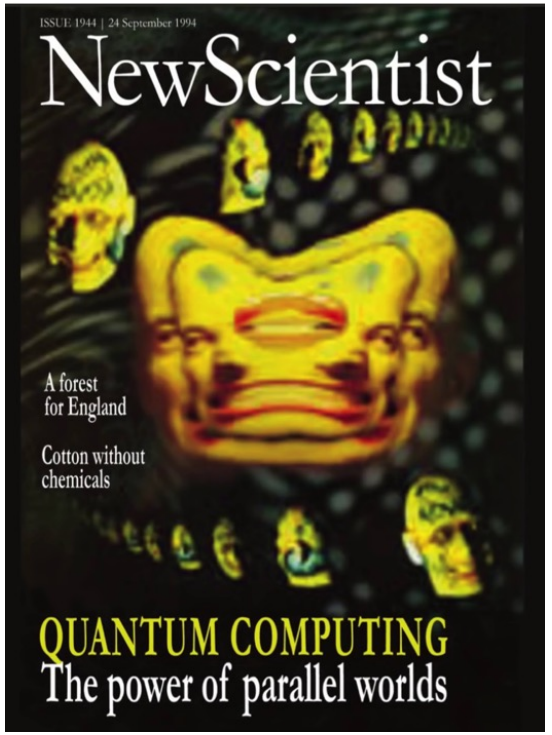
An HPC Center Perspective

Laura Schulz, Department Head, Quantum Computing and Technologies,
Leibniz Supercomputing Centre
Martin Schulz, Department of Computer Engineering,CIT School,
TU Munich and Leibniz Supercomputing Centre

“New” Technology

2023

2014

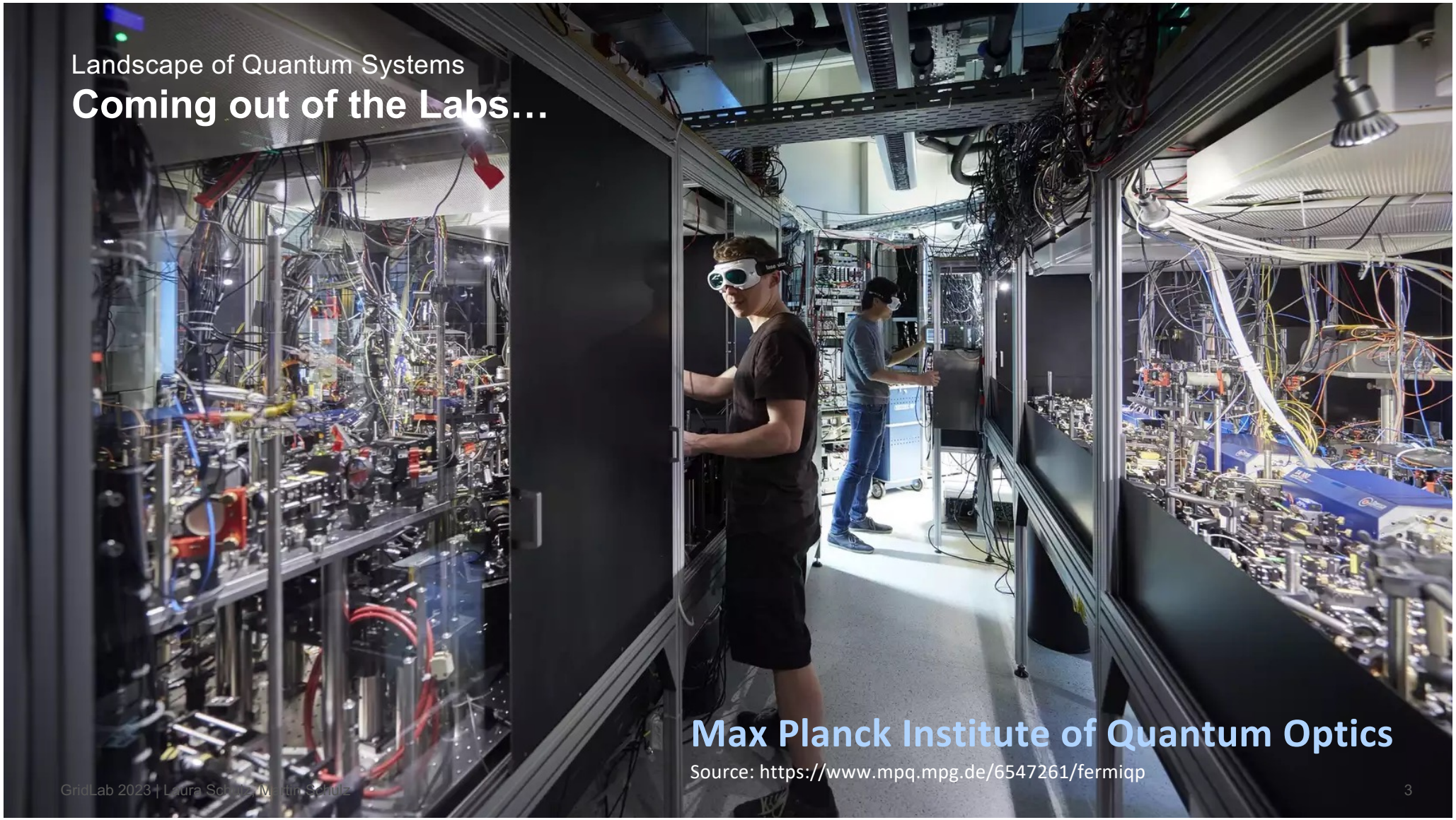


1994

https://time.com/magazine/south-pacific/6252834/february-13th-2023-vol-201-no-5-international/
https://content.time.com/time/subscriber/article/0,33009,2164806,00.html
http://opentranscripts.org/transcript/towards-quantum-computer/

Landscape of Quantum Systems

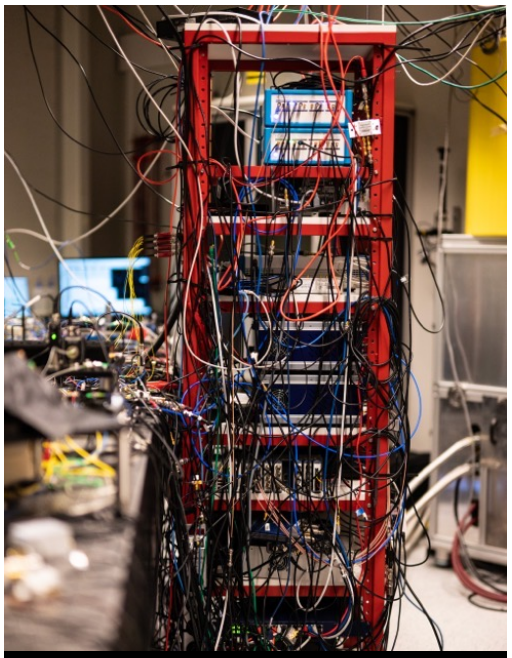
Coming out of the Labs…



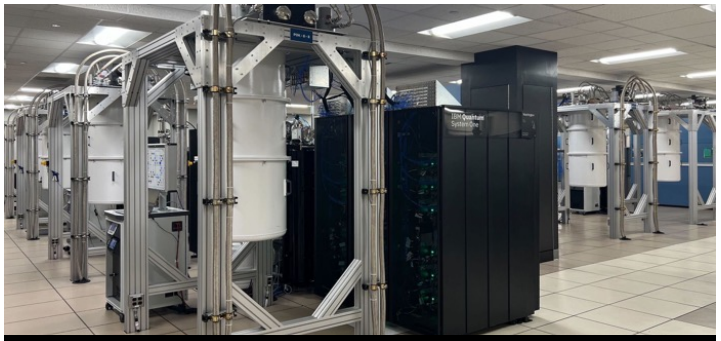
Max Planck Institute of Quantum Optics

Source: https://www.mpq.mpg.de/6547261/fermiqp

Different development stages: From Lab to Compute Floor



“Oh sure, we have the system in a 19” rack.”
work in progress…



Typical dilution fridge with control electronics rack

HPC blade form factor

More commercially ”production-ready” designs

Familiar HPC Form Factor and Operational Parameters

Source: https://physicsworld.com/a/the-diamond-quantum%E2%80%AFrevolution/

Different types of qubits, different characteristics and challenges

		Pros	Cons
Superconducting	Synthetic	High gate speeds and fidelities. Can leverage standard lithographic processes. Among first modalities so has a head start	Requires cryogenic cooling. Short coherence times. Microwave interconnect frequencies still not well understood
Trapped Ions	Natural	Extremely high gate fidelities and long coherence times. Extreme cryogenic cooling not required. Ions are perfect and consistent.	Slow gate times / operations are low connectivity between qubits. Lasers hard to align and scale. Ultra-high vacuum required. Ion charges may restrict scalability.
Photonics	Natural	Extremely fast gate speeds and promising fidelities. No cryogenics or vacuums required. Small overall footprint. Can leverage existing CMOS fabs.	Noise from photon loss. Each program requires its own chip. Photons don't naturally interact so 2Q gate challenges.
Neutral Atoms	Natural	Long coherence times. Atoms are perfect and consistent. Strong connectivity more than 2Q. External cryogenetics not required.	Requires ultra-high vacuums. Laser scaling is challenging.
Silicon Spin / Quantum Dots	Synthetic	Leverages existing semiconductor technology. Strong gate fidelities and speeds.	Requires cryogenics. Only a few entangled gates to date with low coherence time. Interference/cross talk
Nitrogen-vacancy in diamonds	Natural	Limited decoherence; room temperature; electron spin is easy to manipulate; many commodity laser components.	Diamonds not as easily produced as silicon – harder to etch. Scalability very low currently.

Source: https://physicsworld.com/a/the-diamond-quantum%E2%80%AFrevolution/

Quantum computers will not replace HPC.

Quantum *accelerators* are HPC.

Why HPCQC?

Quantum
Computing
=
High-Performance
Computing

New compute capability that adds to the supercomputing portfolio and ability to achieve breakthrough discovery.

Quantum Computing as Accelerator for HPC

For HPC: Promising accelerator technology to scale past Moore's Law

- Similar to other accelerators, on-node (like GPUs, FPGAs) or disaggregated (like AI HW), but still on transistor/CMOS technology
- Radically new computational paradigm if successful
- Targeted at specific workloads
- Intended for fine-grained kernels within larger applications or workloads

For QC: Quantum Computing requires HPC to scale

- Growing computational need for control of systems with growing number of qubits.
- Data staging and pre- and post-processing (trivial now, will be a topic with scale)
- Tight interactions needed for variational algorithms
- Complex compilation and runtime environment with high computational demands

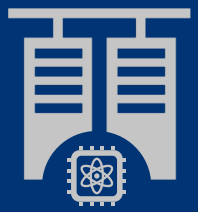
Consequences: HPC and QC as a single HPCQC system

An HPC Center's Role

QC Hardened

Facilitate quantum systems' viability and robustness in data centers

Quantum-HPC Enabled



Develop single-source SW stack for optimized acceleration and workflow

User Focused

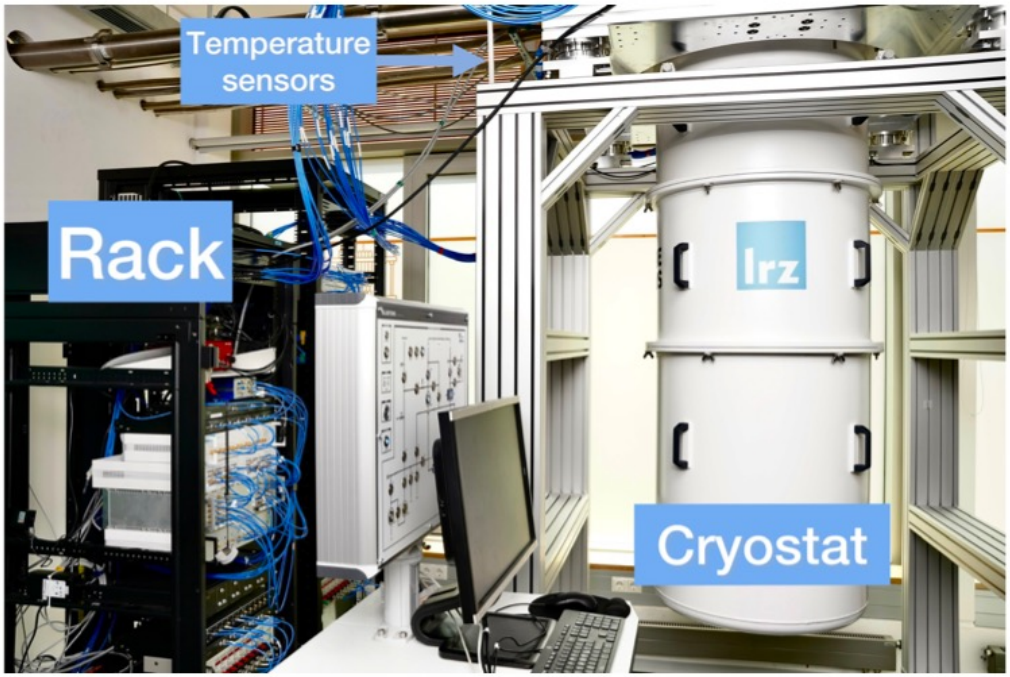
Make easy as possible for users:

familiar experience for HPC users

familiar experience for QC users

- Infrastructure
- Hardware
- Software
- Applications
- Culture

Integration into HPC Center Telemetry / Montoring



HPC Center Monitoring

System and Infrastructure Health
Application Performance

Inclusion of QC

From Cryostat to Control Electronics
IoT Infrastructure needed
Plus: Key metrics like fidelity

Operational Data Analytics

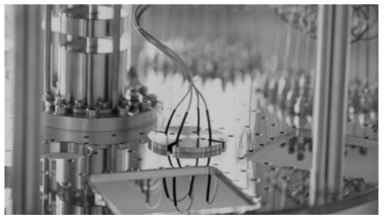
Towards predictive / hands-off maintenance

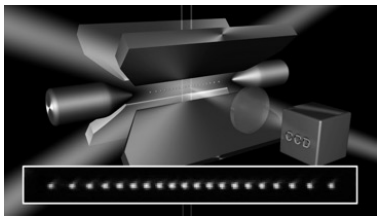
Future State & Requirements

Wide User Communities

Comprehensive Software Stack for Accelerators

integrated into HPC Environments accessible from HPC codes

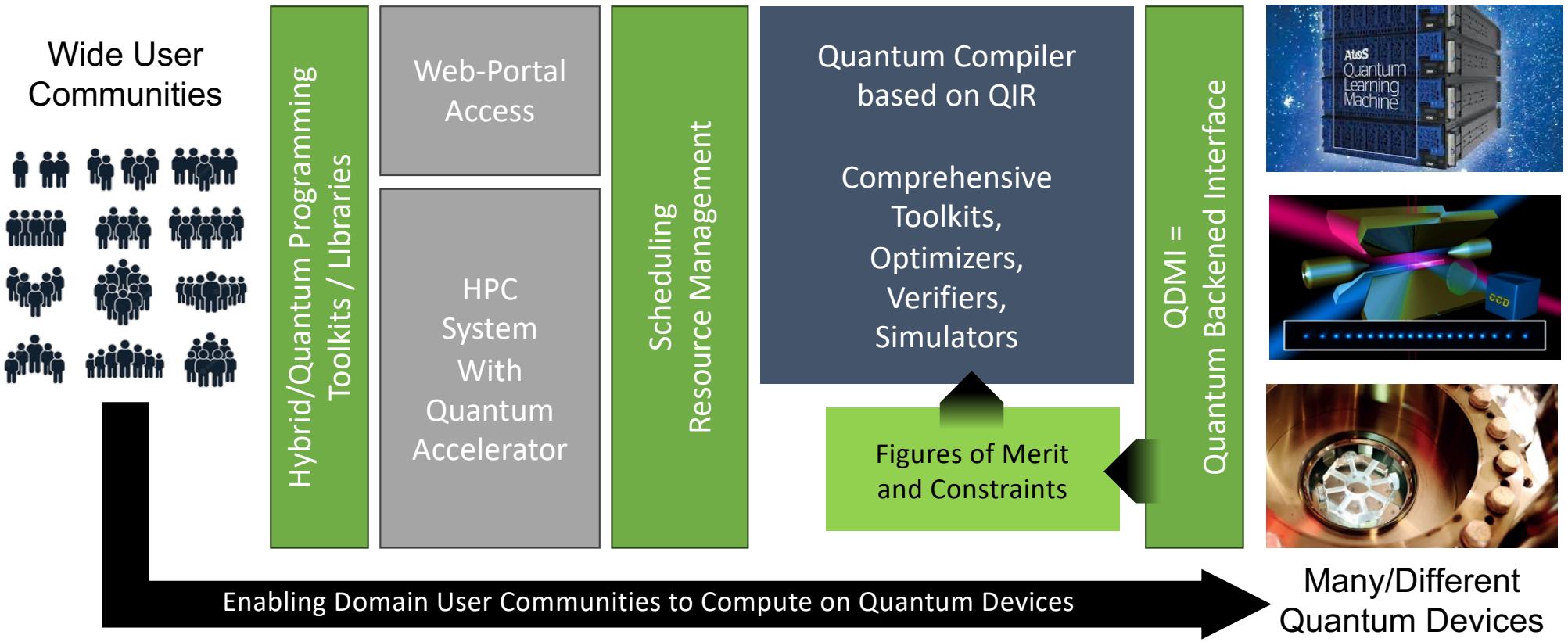




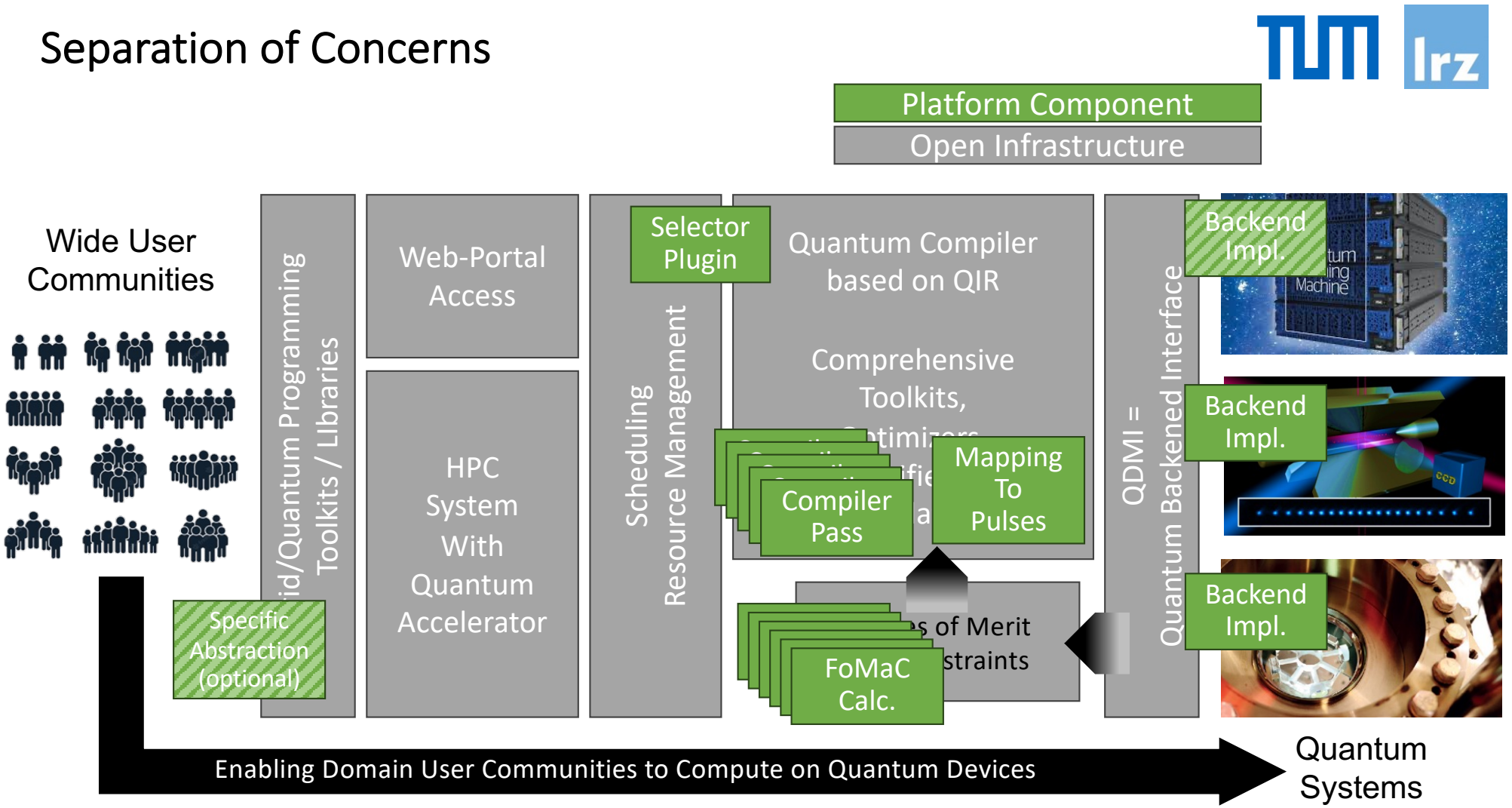
Quantum Devices

Munich Quantum Software Stack

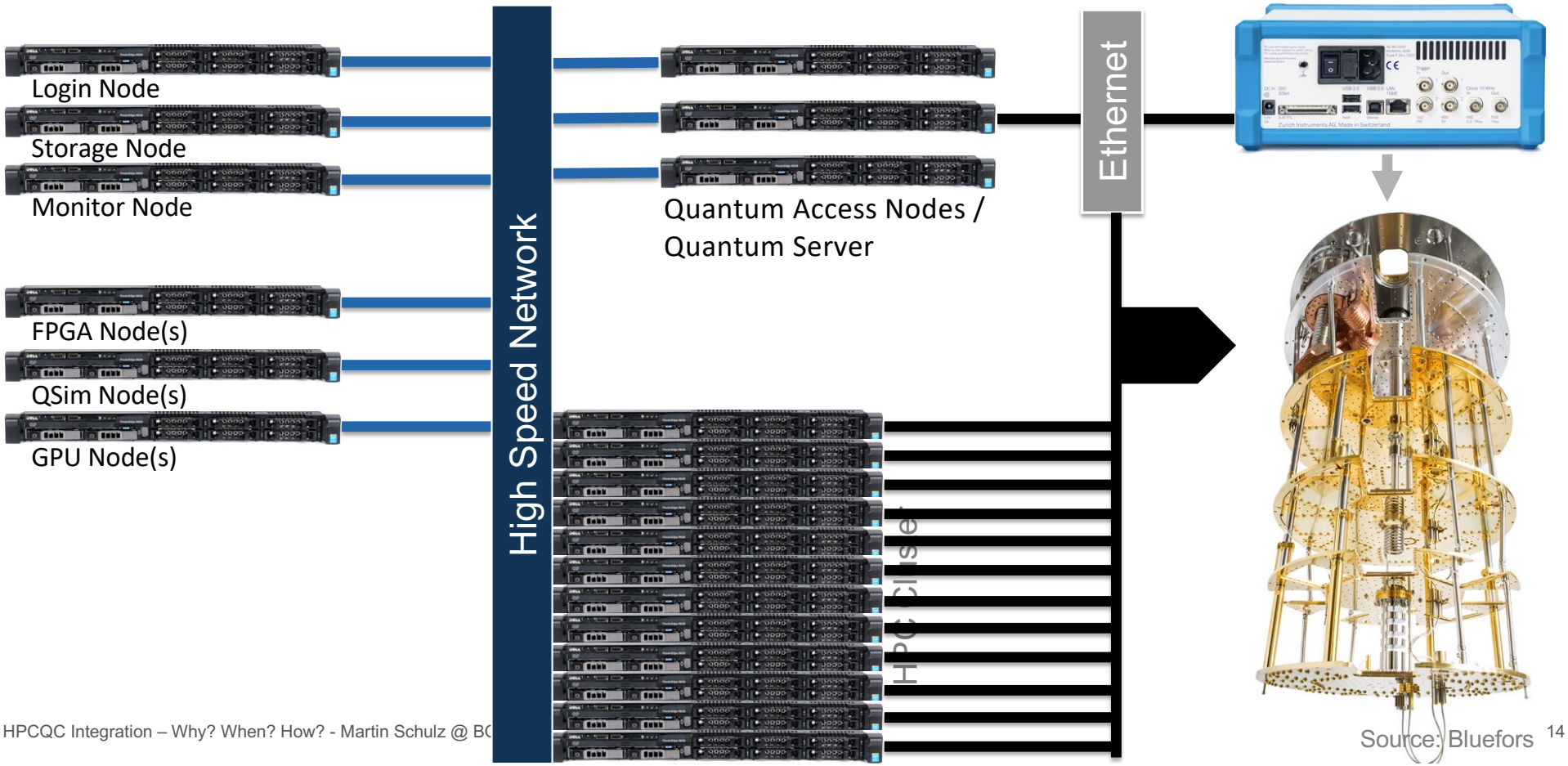
- Forming the Bridge between Application Users and Novel Platforms



Separation of Concerns



Wolpertinger: HPCQC Testbed for R&D



Source: Bluefors

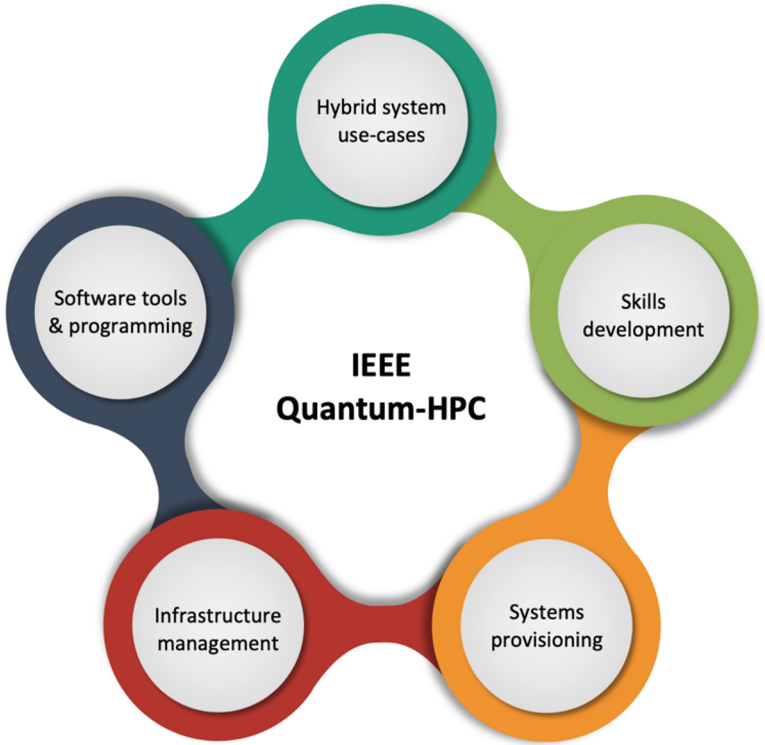
IEEE QUANTUM

Quantum-HPC Working Group

Building a global community for sustained, structured engagements

Developing community-driven best practices for deploying, operating and using hybrid HPC-QCS systems, tools and applications

- Launched at IEEE QCE23 (September 2023)
- SC23 BOF Session: Tue, Nov 14, 2023, 17:15 - 18:45 (MST) Rm 605



ICHEC Irish Centre for High-End Computing

Los Alamos NATIONAL LABORATORY

OAK RIDGE National Laboratory

Technische Universität München

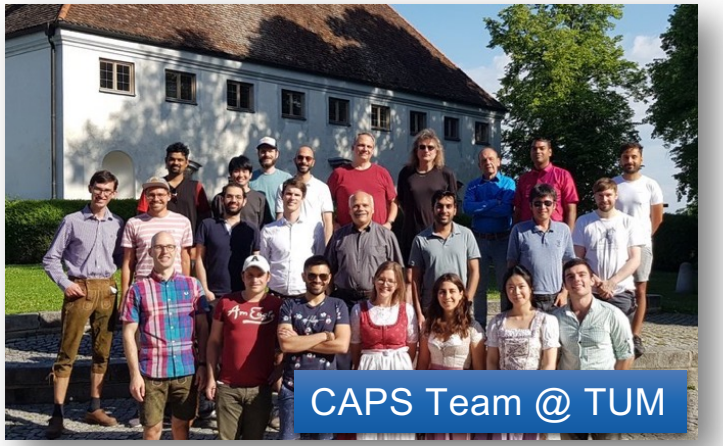
Leibniz Supercomputing Centre of the Bavarian Academy of Sciences and Humanities

Read more at quantum.ieee.org/working-groups

or grab the QR code

Acknowledgements

It takes a team, or rather many teams!



CAPS Team @ TUM

QCT Team @ LRZ

From the MQV Review Meeting 2022

Munich Quantum Valley

TUM

lrz

Bayerisches Staatsministerium für Wissenschaft und Kunst

Federal Ministry of Education and Research

Federal Ministry for Economic Affairs and Climate Action

EuroHPC Joint Undertaking

European Commission

QC@LR HPCQC