MQSS
Munich Quantum Software Stack

From HPC to HPCQC: Software Foundations for Hybrid Classical–Quantum Computing

Martin Schulz, Technical University of Munich

HPCSE, Karolinka, Czechia, May 21st 2026

MUNICH QUANTUM VALLEY
MQV

The Munich Quantum Valley initiative develops quantum computation and quantum technologies in Bavaria.

Superconducting. Ion. Neutral Atom. Quantum-HPC.

BAdW Bayerische Akademie der Wissenschaften · DLR · FAU Friedrich-Alexander-Universität Erlangen-Nürnberg · Fraunhofer · LMU Ludwig-Maximilians-Universität München · Max Planck Gesellschaft · Technische Universität München

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Mission of MQV

The primary goal of the Munich Quantum Valley initiative is **developing and operating competitive quantum computers** in close cooperation with strong industry partners and visionary start-ups and making them available for a broad range of applications.

It links **universities, research institutions and industry**, and fosters research and industrialization of **quantum technologies** throughout **Bavaria**.

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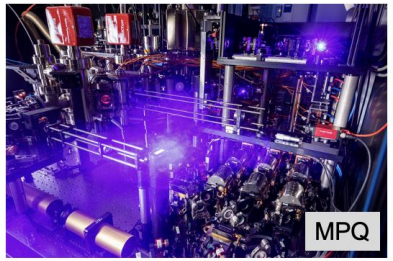
Full Stack Quantum Computing

Towards a Sustainable Eco-System

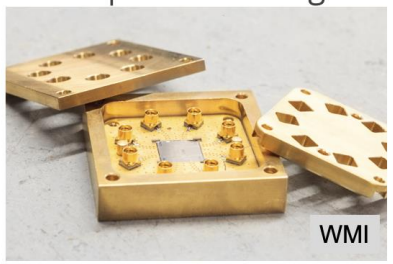
Munich Quantum Valley

Neutral Atoms



planqc
creating quantum computers atom by atom

Superconducting



Peak Quantum

IQM

Software Stack

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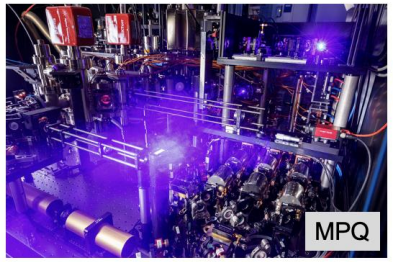

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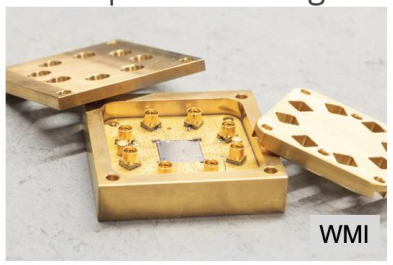

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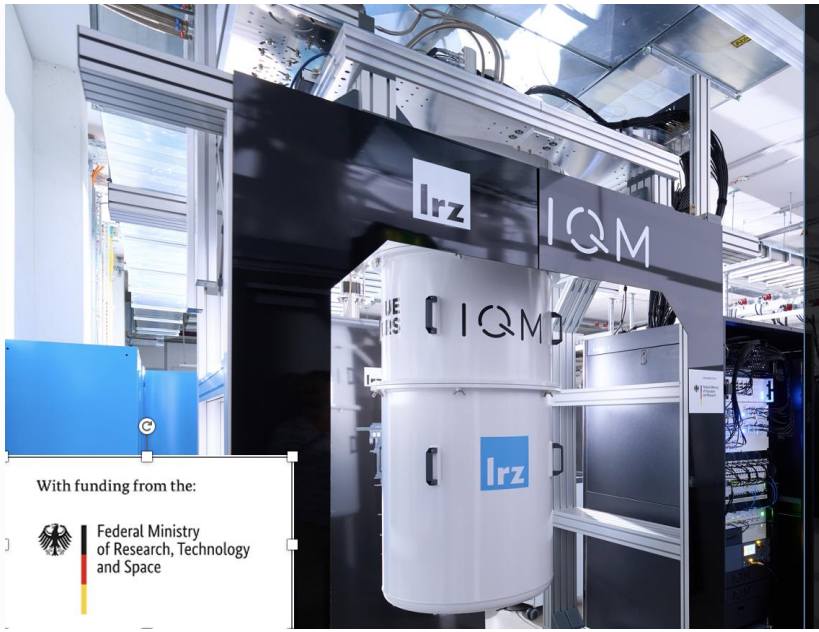

With funding from the:
Federal Ministry of Research, Technology and Space

Deployments & Access

By MQV / Context of MQV

Research Prototypes at WMI/MPG

Data Center integrated
- On premise at LRZ
- Tight connection
- Superconducting (IQM)
- Ion-Trap (AQT)
- Neutral Atoms (planQC)

Quantum Pathway Program
- Easy industry access
- Incl. cloud collaborations

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EuroHPC's Euro-Q-Exa, hosted at LRZ

Leibniz-Rechenzentrum
der Bayerischen Akademie der Wissenschaften

EURO-Q-EXA

PRACTICAL, SCALABLE AND RELIABLE EUROPEAN
QUANTUM-ACCELERATED EXASCALE-CLASS COMPUTING

SPONSORED BY THE

EuroHPC Joint Undertaking

Federal Ministry of Education and Research

Bayerisches Staatsministerium für Wissenschaft und Kunst

- Two-stage system delivery, all superconducting
  - 53 qubit in 2025
  - 100-150 qubit in 2026
- Academic and industrial use
- Inauguration: Spring 2026

Progressively tighter HPCQC integration and demands on vendor

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Federal Ministry
of Education
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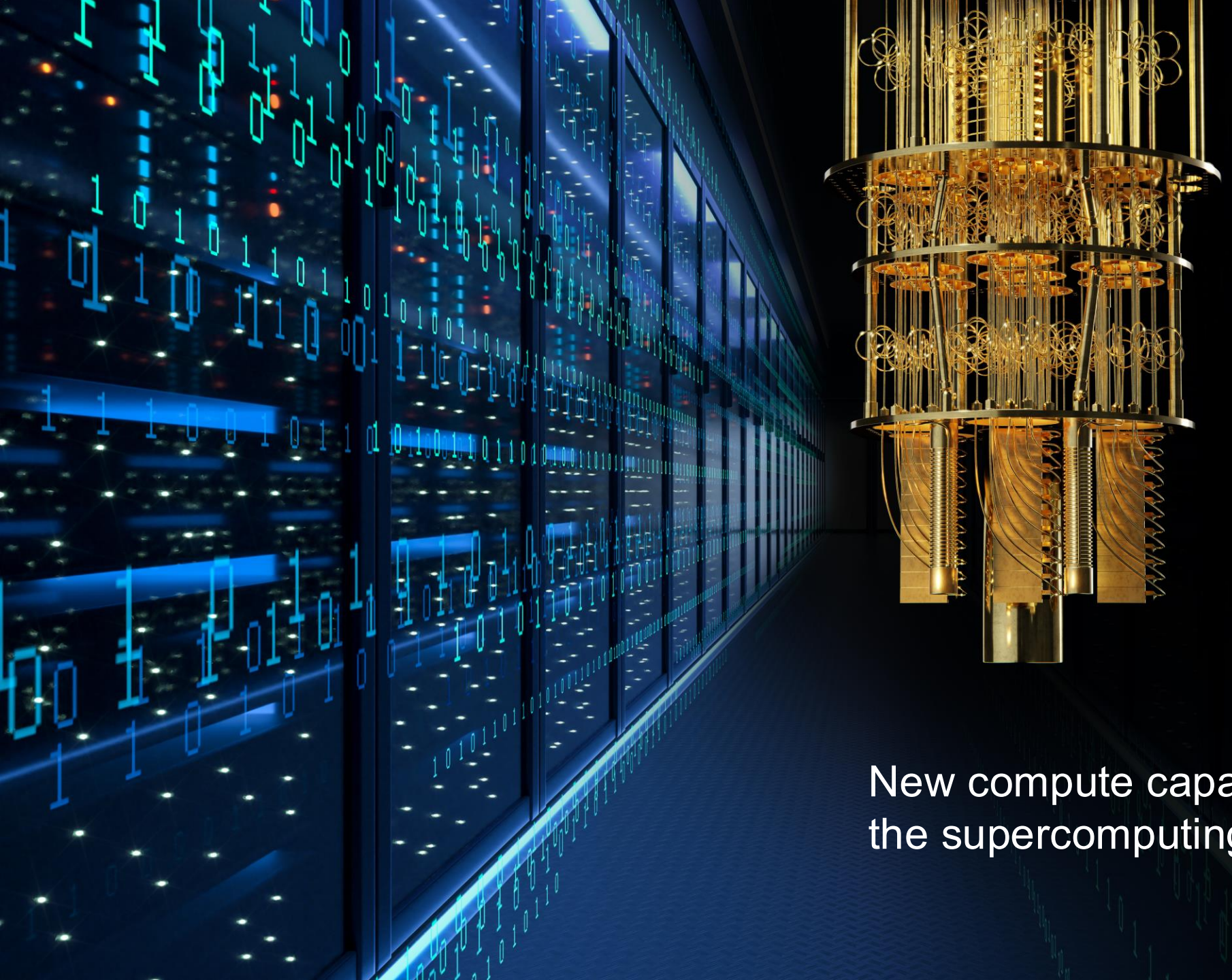
Quantum computers will not replace HPC.

Quantum *accelerators* are HPC.



Why HPC-QC?

Quantum Computing
=
High-Performance Computing

New compute capability that adds to the supercomputing portfolio.

Strategy: Quantum Computing as Accelerator for HPC

Usage as accelerator for HPC workloads

- Intended for fine-grained kernels within larger applications or workloads
  - Targeted towards very specific workloads and kernels
  - Tight interactions needed for variational algorithms
- Similar to other accelerators, on-node (like GPUs, FPGAs) or dissaggregated (like AI HW)

Quantum Computing as a stand-alone system not viable at growing scales

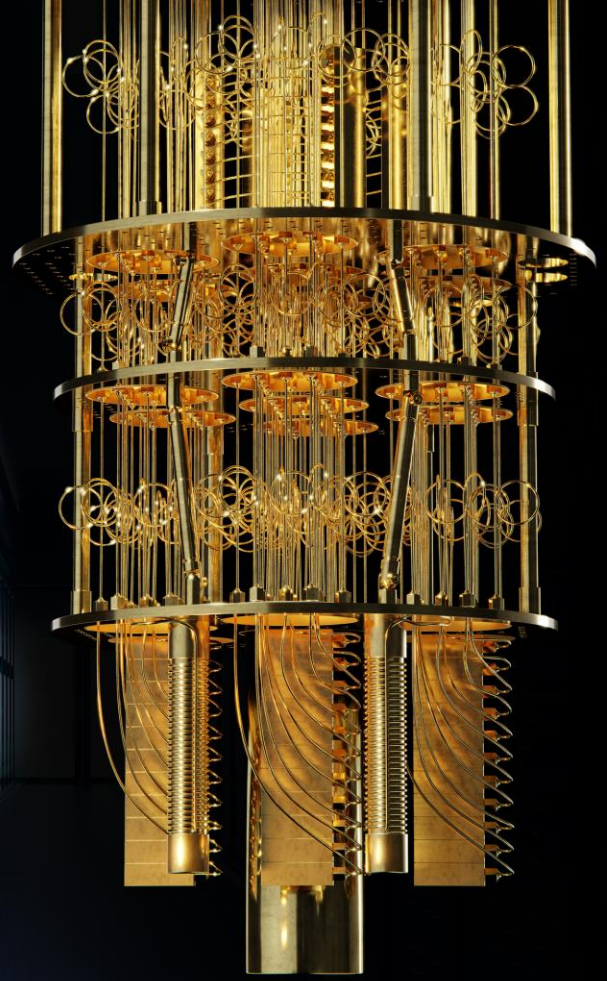
- Complex control systems, especially when moving to FT-QC systems
- Data staging and post-processing
- Complex compilation and runtime environment with high demands need HPC

Consequences: HPC and QC as a single HPCQC system

- Requires tools and models to extract application components relevant for acceleration
- Requires easy access for HPC community to QC programming (or library usage)
- Requires integration into a single programming environment / software stack
- Requires unified user access/management/experience
- Requires close hardware integration (single system) for latencies and management

Challenges

- Hardware Integration of the QC control system



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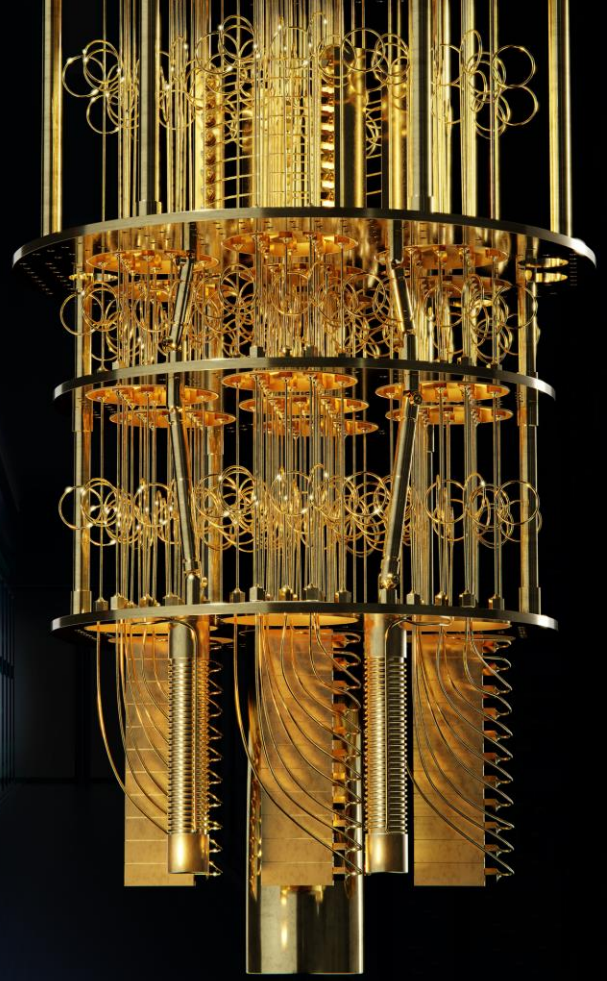
Challenges

- Hardware Integration of the QC control system
- Building a Hybrid HPCQC Software Stack



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Where we are / recently have been …

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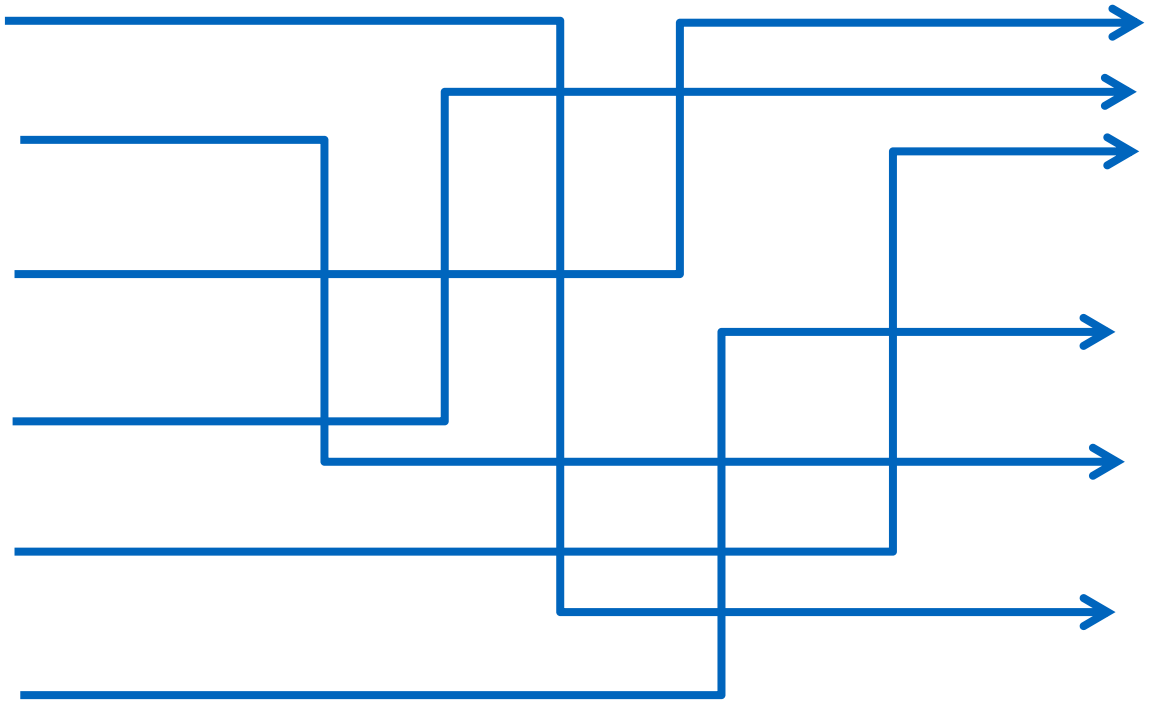
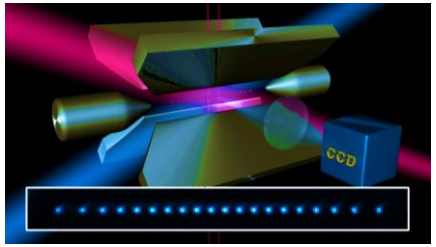
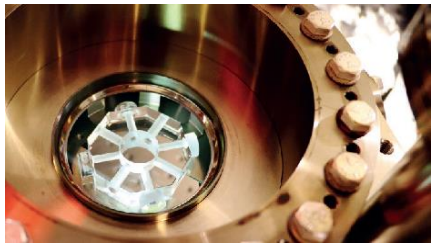
Munich Quantum Software Stack

Physics Experts



Quantum Devices





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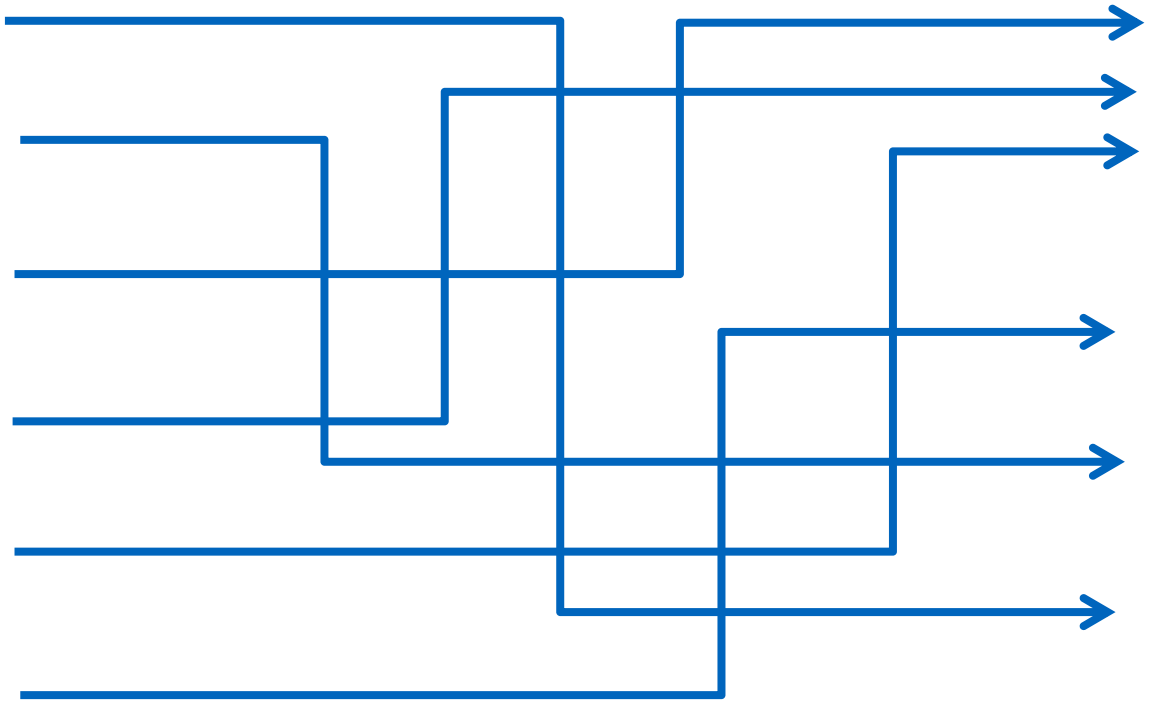
Domain Experts



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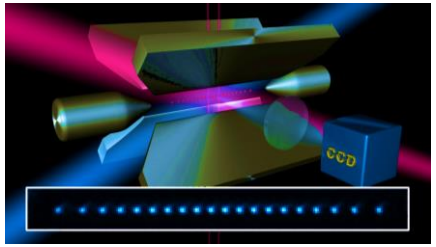

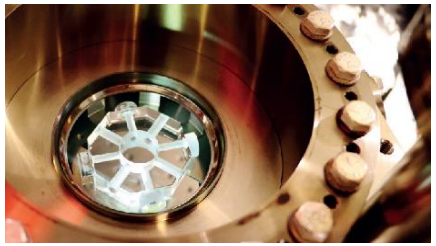

… and where we need to go

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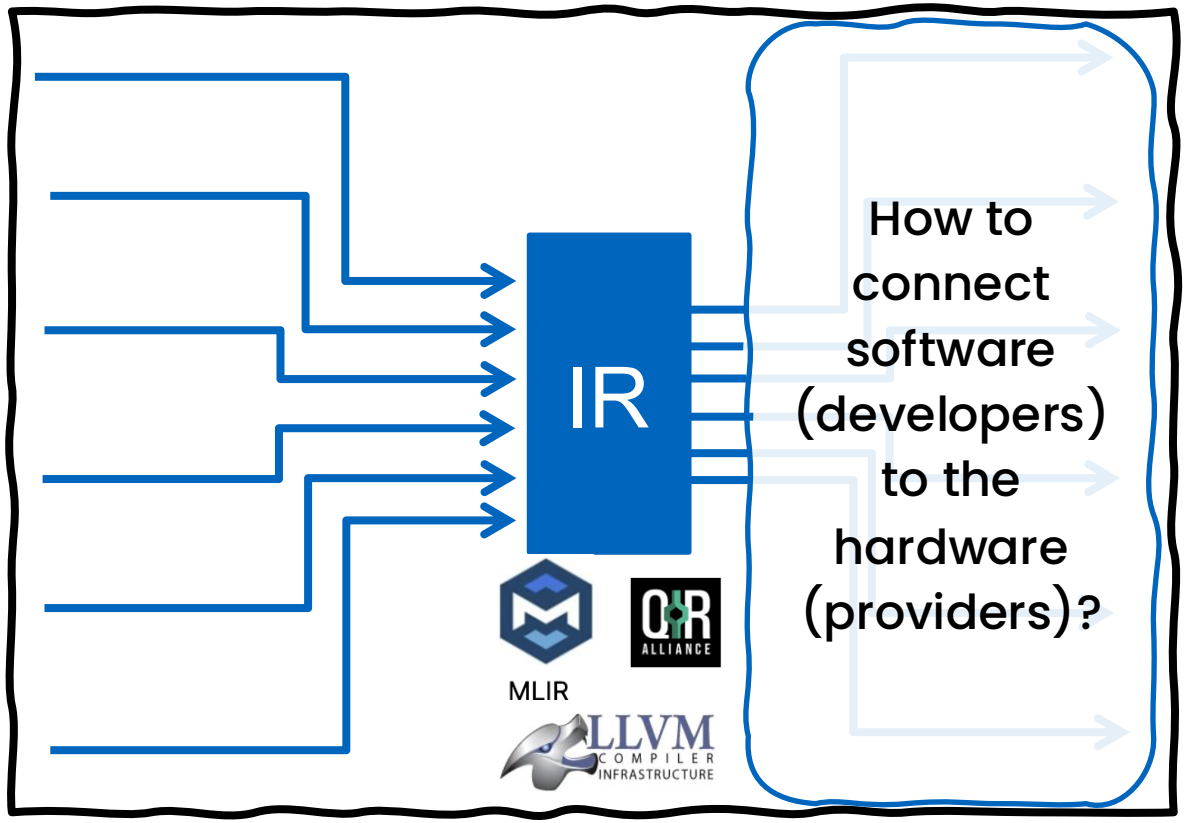
Domain Experts

Munich Quantum Software Stack (MQSS)



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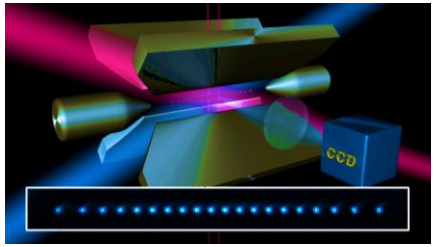

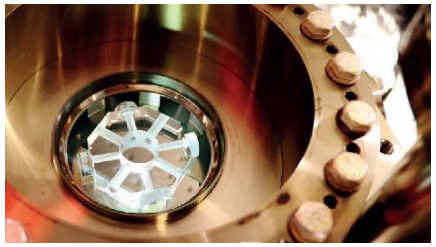

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Munich Quantum Software Stack (MQSS)

How to support potential users of quantum computers?

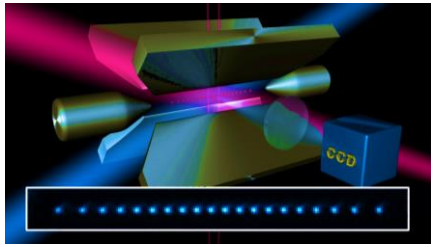
IR

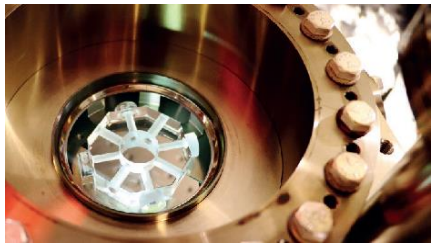
MLIR

LLVM COMPILER INFRASTRUCTURE

How to connect software (developers) to the hardware (providers)?

Quantum Devices





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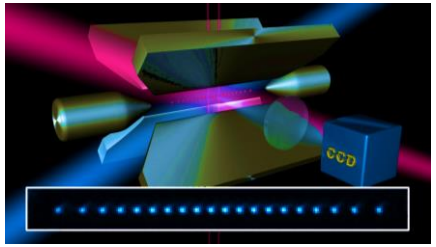
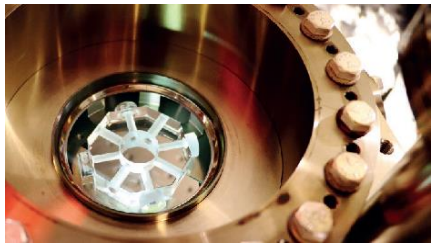
MLIR

How to connect software (developers) to the hardware (providers)?

How to connect to/integrate with existing compute & HPC to enable quantum acceleration?

Quantum Devices





MQSS Requirements

MQSS
Munich Quantum Software Stack

Support a wide range of QC modalities

- Find common abstraction among modalities
- Query properties from concrete systems where needed

Support a wide range of programming models and abstractions

- Decouple programming model from support stack, compiler and back-end
- Enable models from existing Python/Scripting models to high-performance approaches

Support HPCQC integration

- Integrate QC into the existing HPC ecosystem as a specialized accelerator
- Hybrid programming abstractions building on HPC models and languages

Support efficient resource utilization

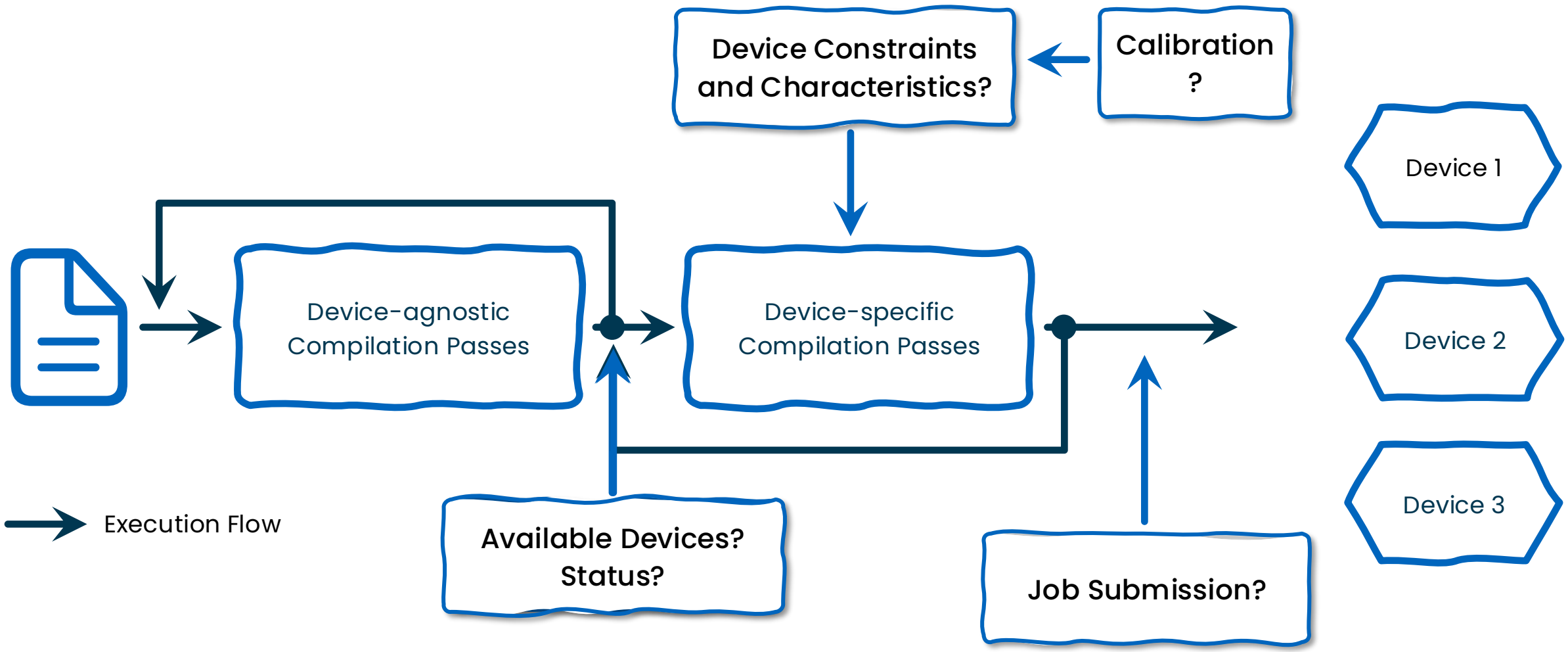
- Efficient, hierarchical scheduling combined with resource and runtime predictions
- Optimize quantum compilation and optimization on modern hardware

Support easy system management

- Comprehensive monitoring and Online Data Analytics
- Easy user and system management through configurable, modern portal interface

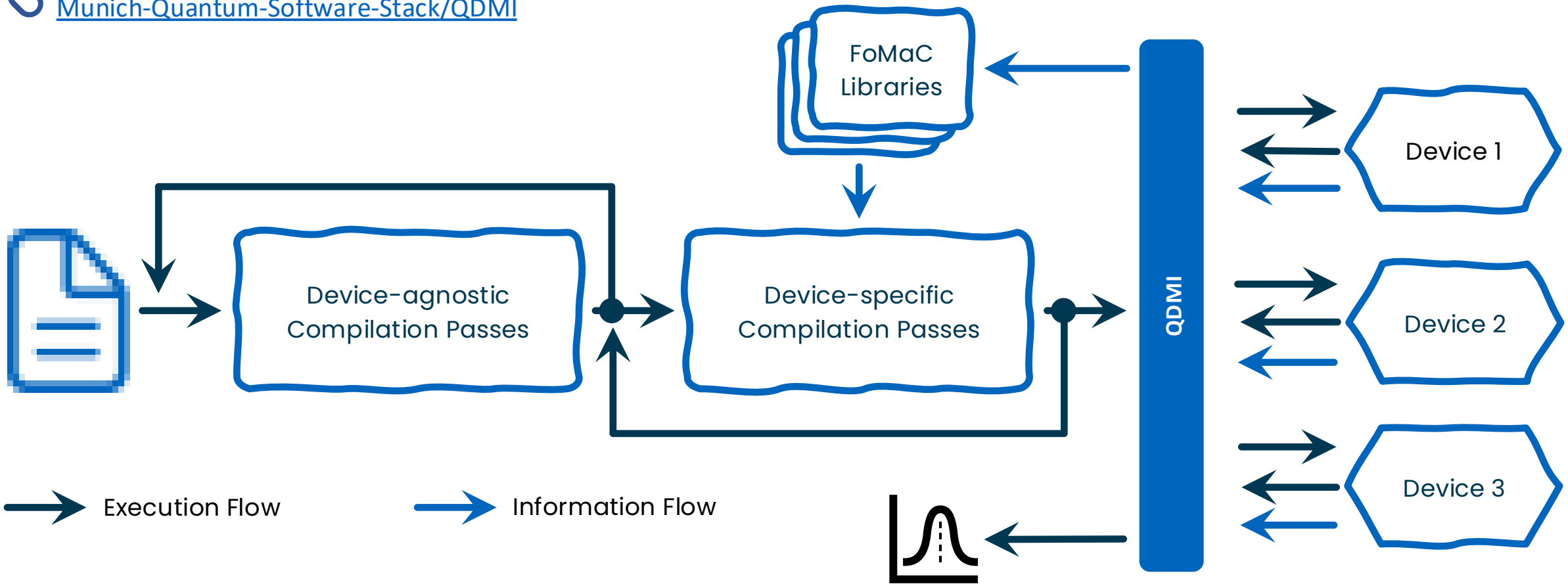
Support internal and external users and installations

Design of the runtime core, the compiler



Design of the runtime core, the compiler

Github.com/
Munich-Quantum-Software-Stack/QDMI



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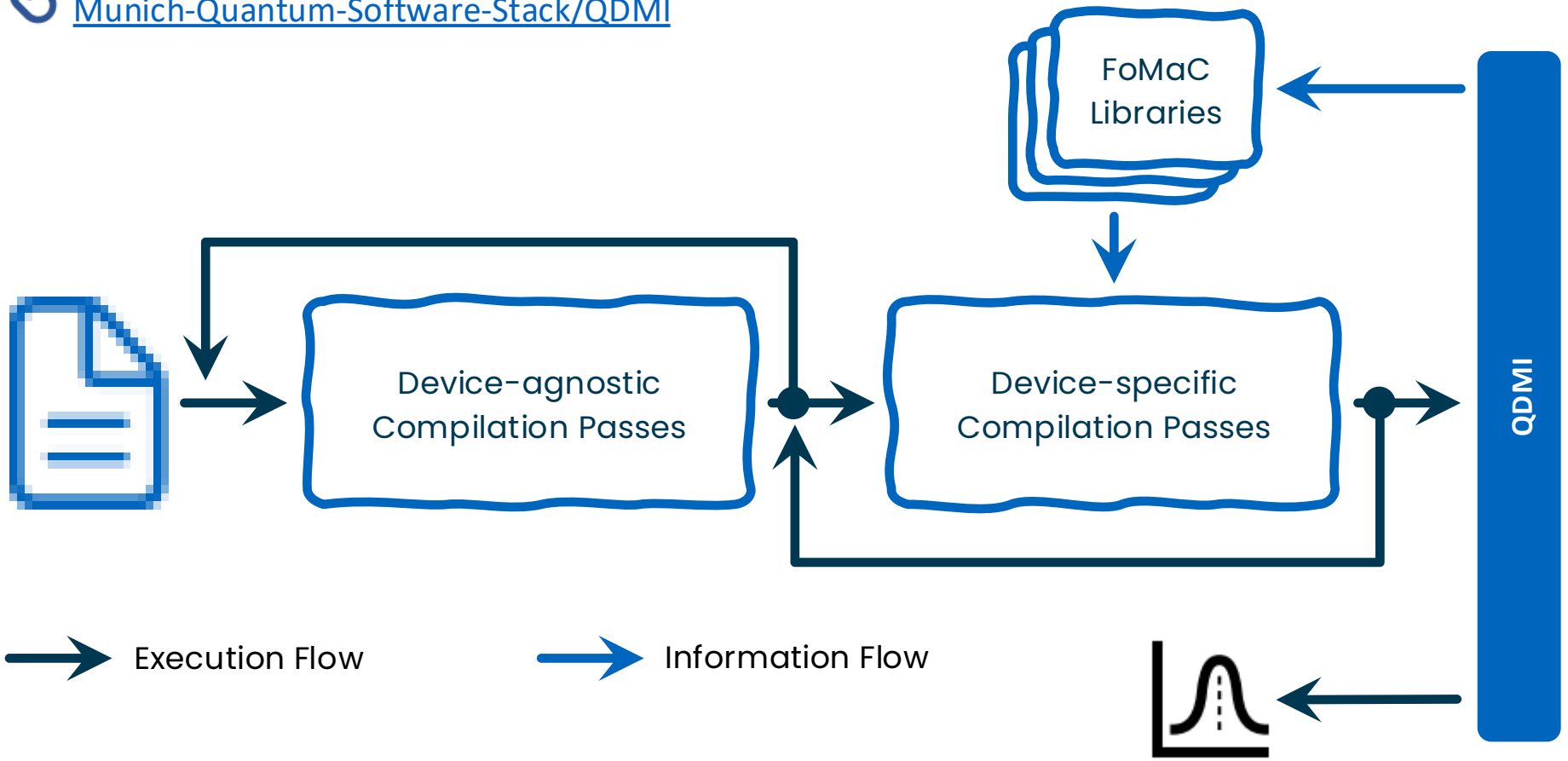

MQV System Back-ends

- WMI / K1
- MPQ / K3
- PlanQC
- PeakQ
- AQT Ion Trap
- DAQC
- Q-Exa
- Euro-Q-Exa
- MQV Simulators
- HPC Q-Simulators
- Eviden Qaptiva
- Cloud Backends
- Commercial QCs
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- EuroHPC QCs

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Integration of a Wide Range of Backends

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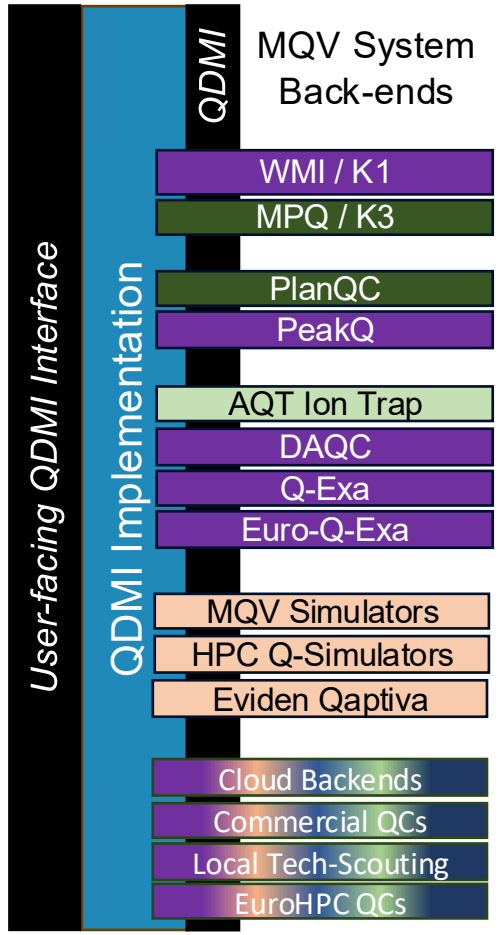

MQSS Core:

Back-End

Interfaces /APIs

Plugins by Modality

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QDMI is Available Open Source

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QDMI: Quantum Device Management Interface

- Manage job execution
- Various levels of abstraction

Enables information retrieval

- Static device properties
- Pre-analysis of results
- Live system status
- Environmental sensor data

QDMI is already being leveraged by Academic and Industry Leaders

WMI · AQT · IQM · planqc · DLR · lrz

Compatibility to QDMI

EVIDEN · parityqc · aws

TRY ME!

README · Apache-2.0 license

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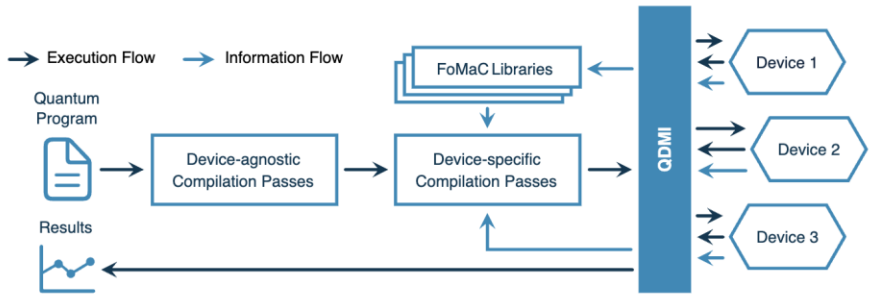
QDMI — Quantum Device Management Interface

DOCUMENTATION

The Quantum Device Management Interface (QDMI) is one of the core components of the Munich Quantum Software Stack (MQSS)—a sophisticated software stack to connect end users to the wide range of possible quantum devices. It enables the submission to and the control of gate-based quantum systems and enables software tools to automatically retrieve and adapt to changing physical characteristics and constraints of different platforms. QDMI strives to connect the software and hardware developers, mediating between their competing interests, bridging between technologies, and eventually providing corresponding figures of merits and constraints to be considered. QDMI is therefore the method of choice for integrating new platforms into the MQSS and for software tools to query information from these platforms. QDMI is provided as a collection of C header files to allow fast integration into an HPC environment.



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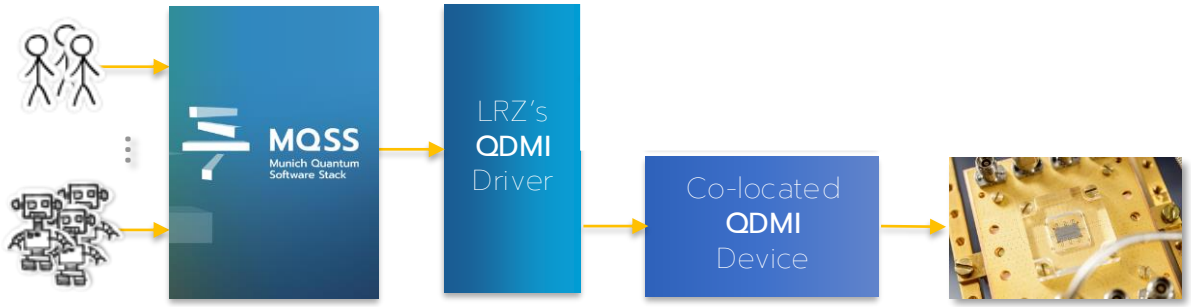
Remote Connection via QDMI



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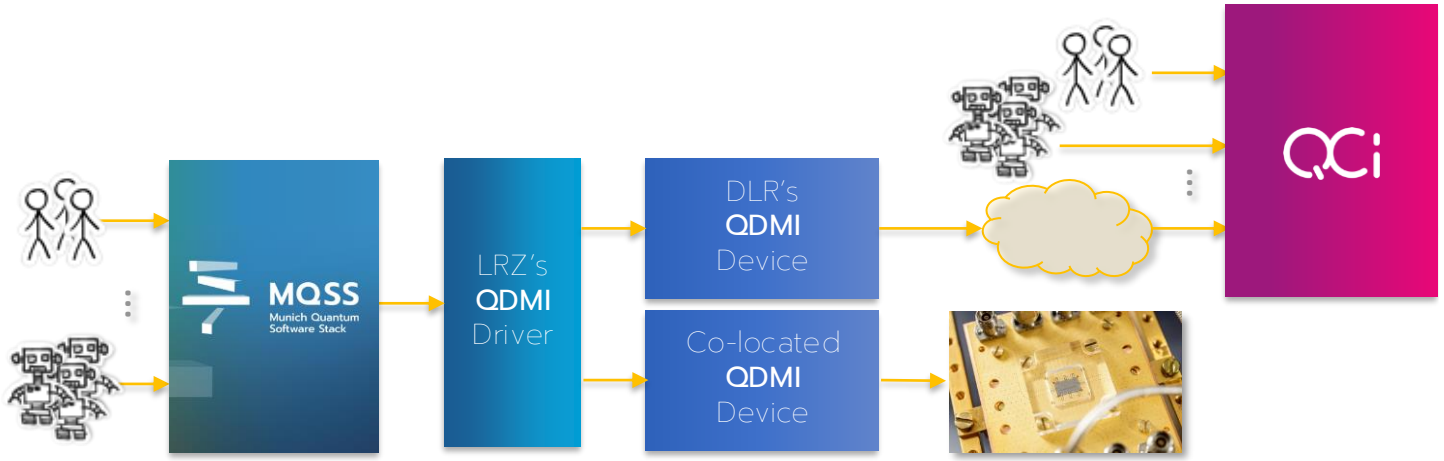

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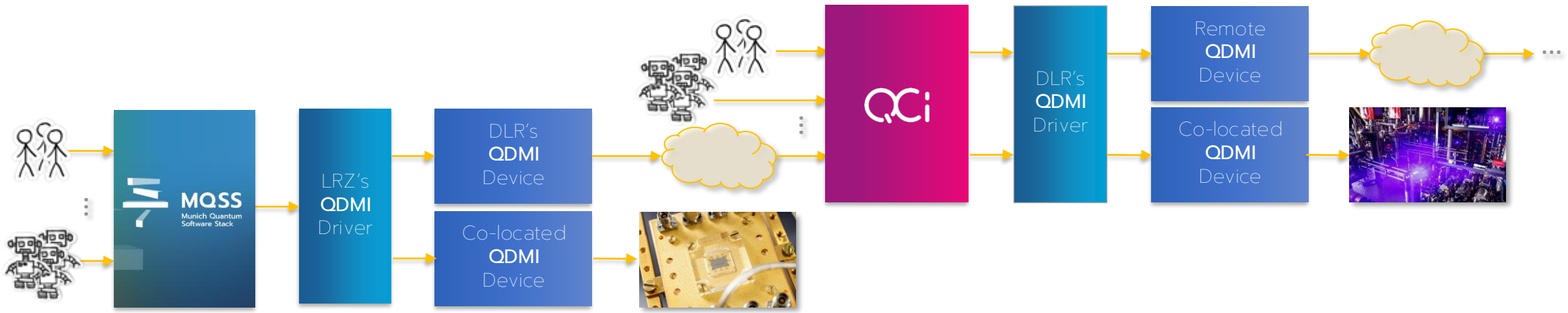

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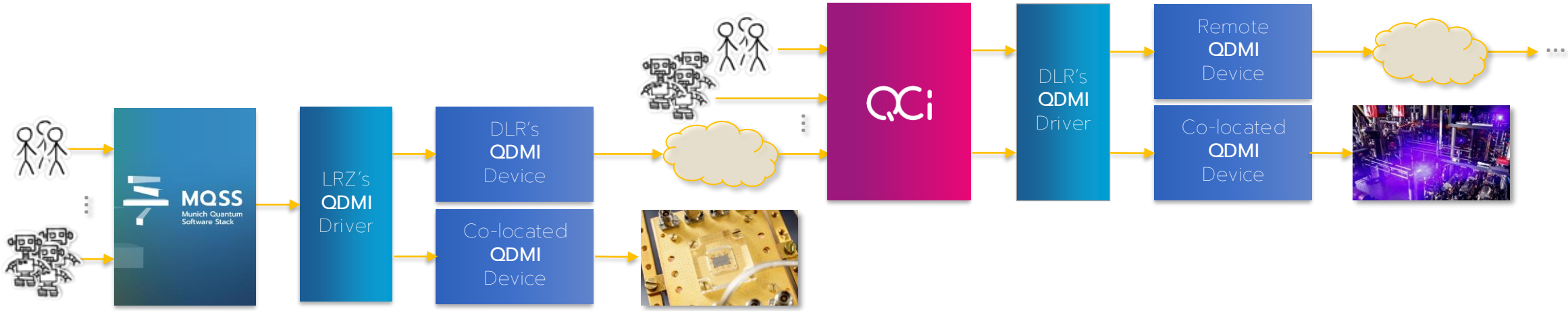

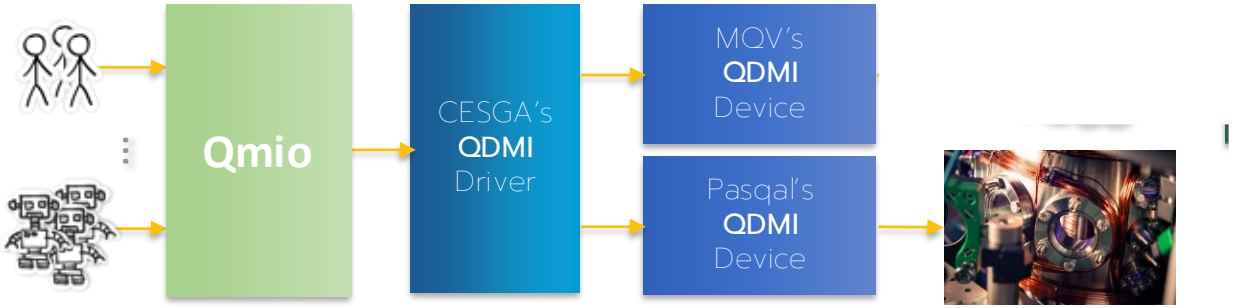

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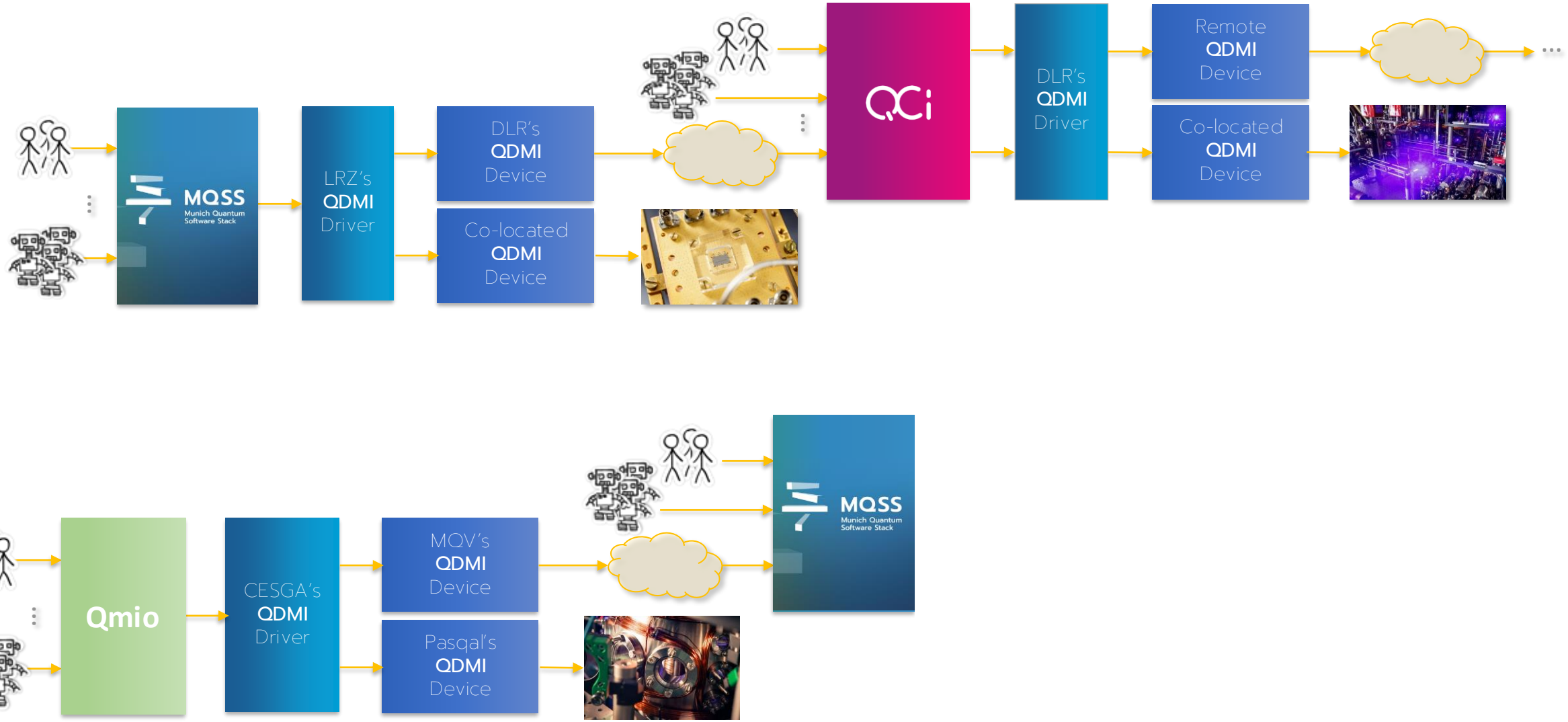

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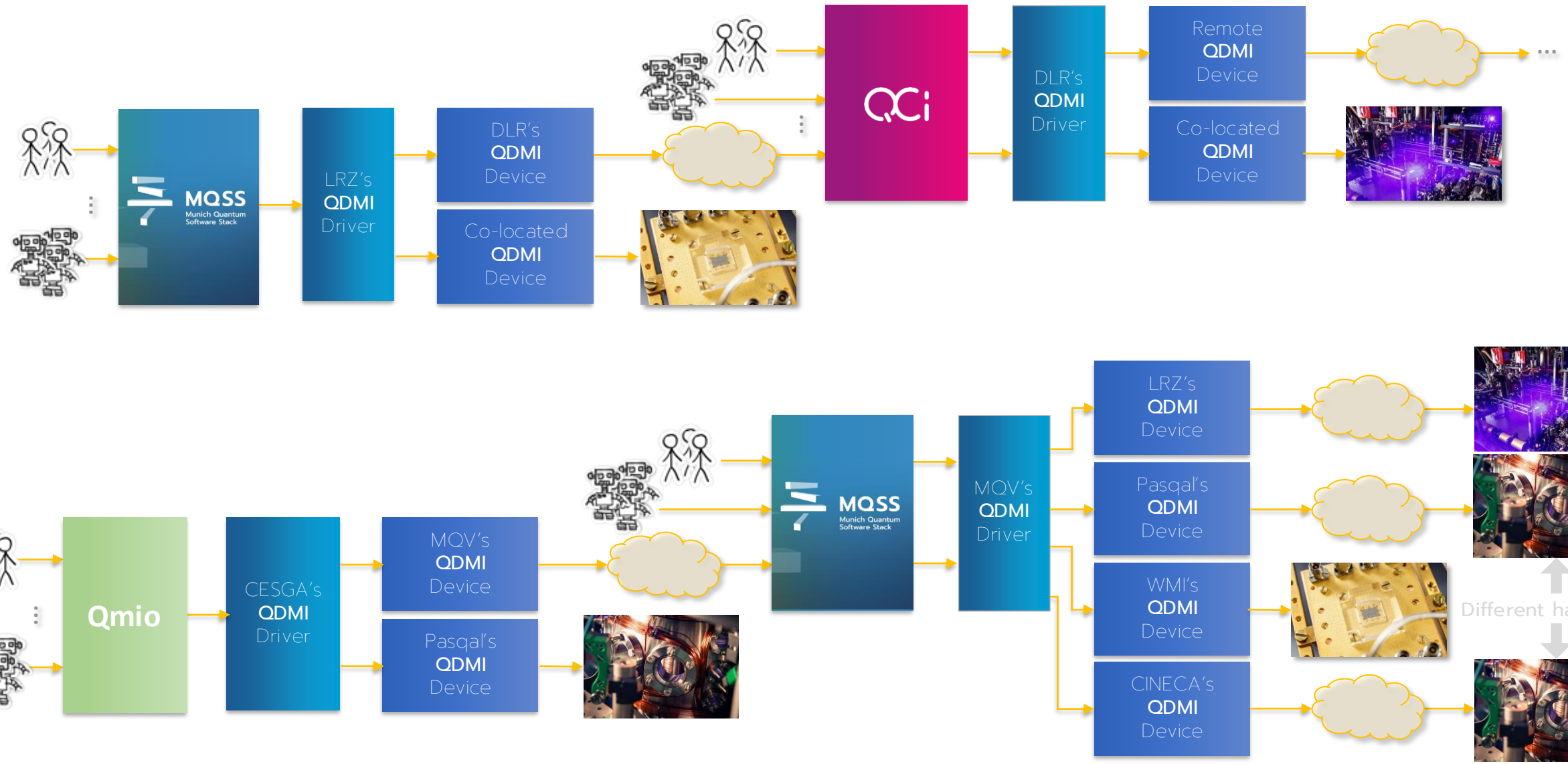
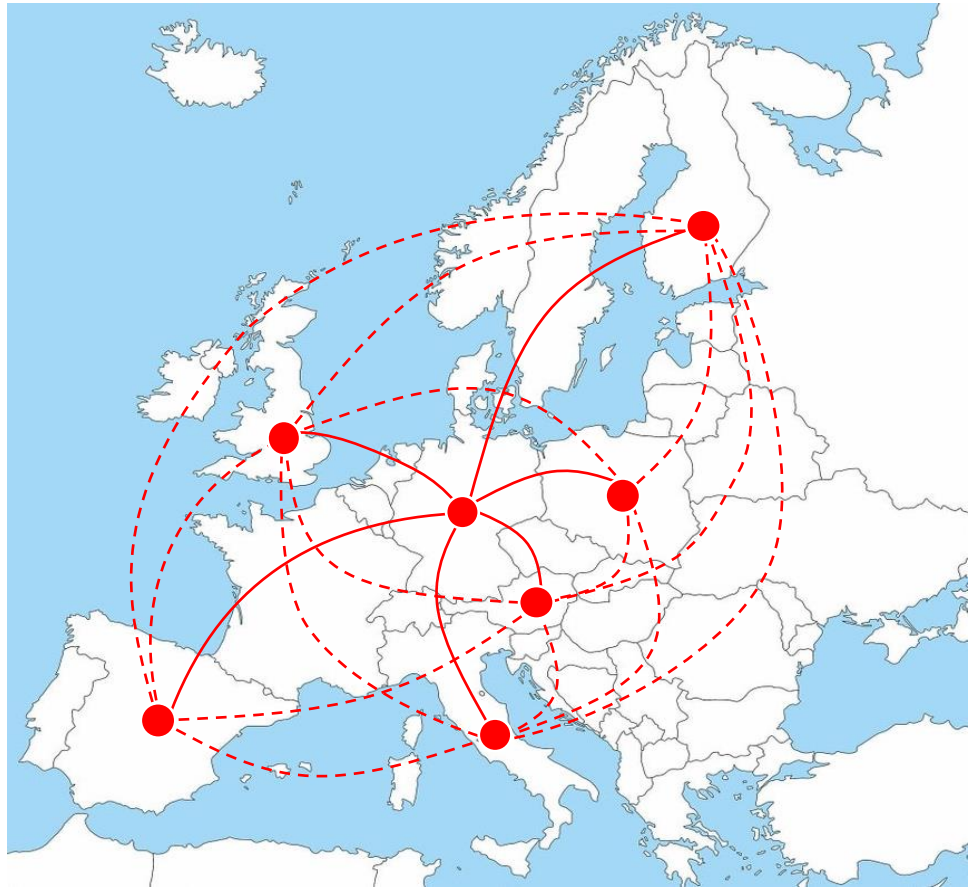
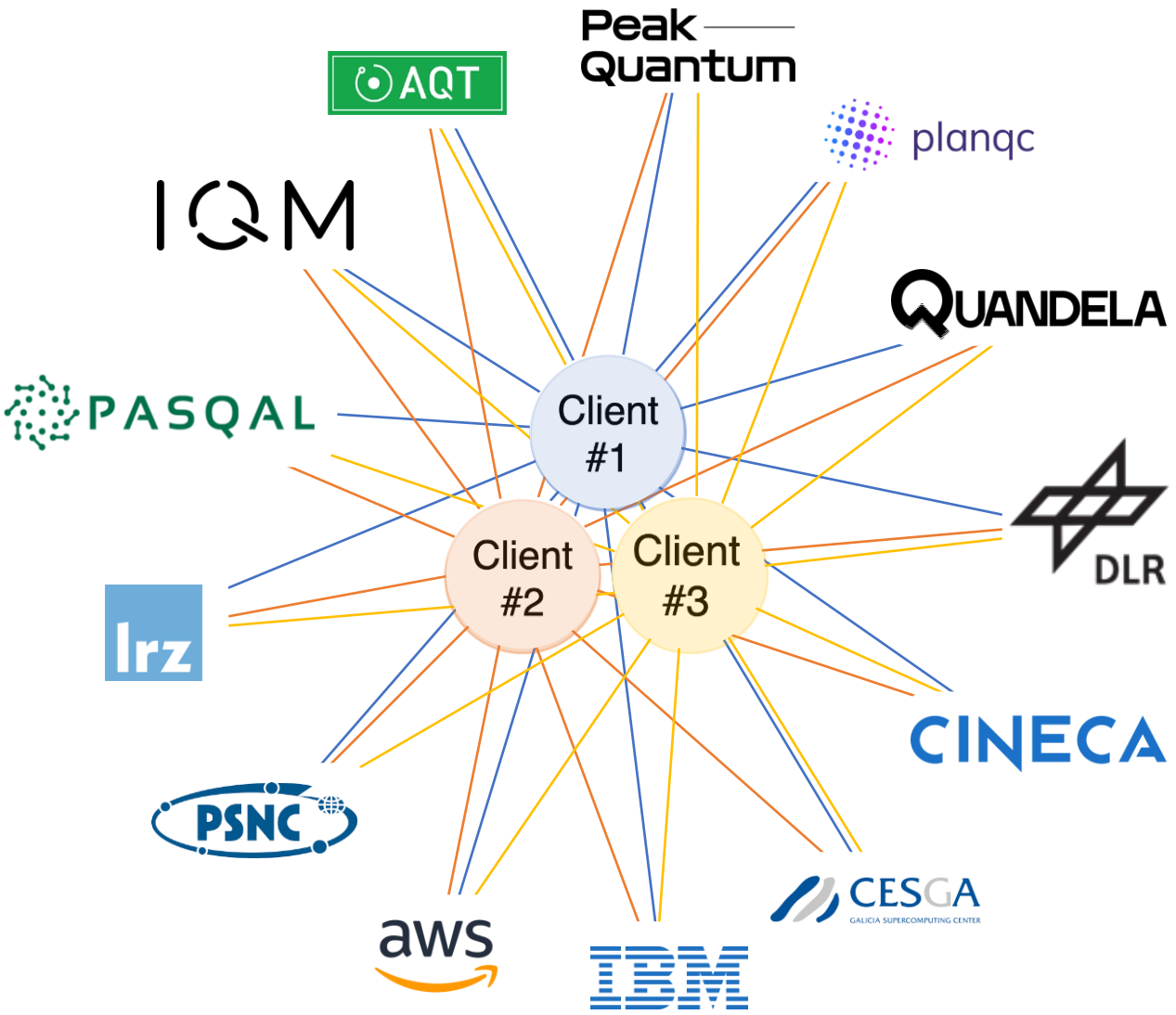


Integration Options via QDMI





MQV's Quantum Pathway Program

MQSS
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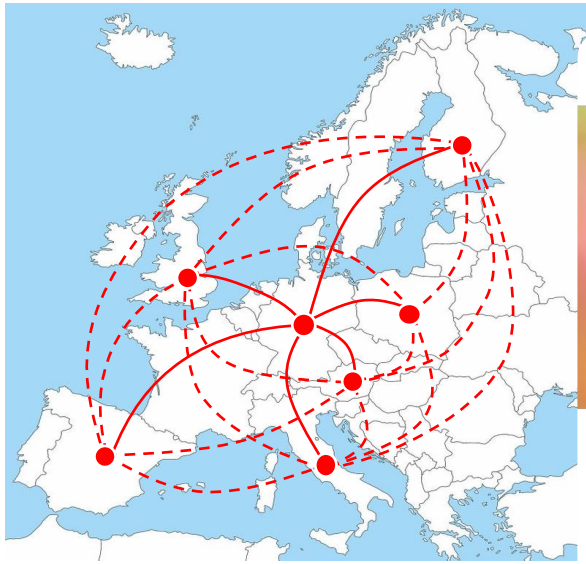
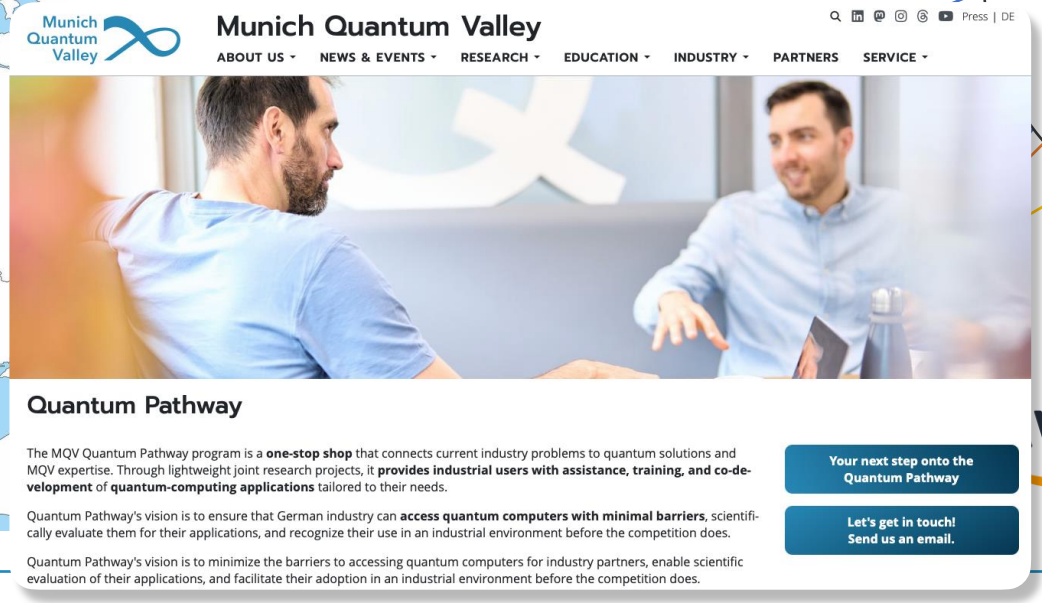
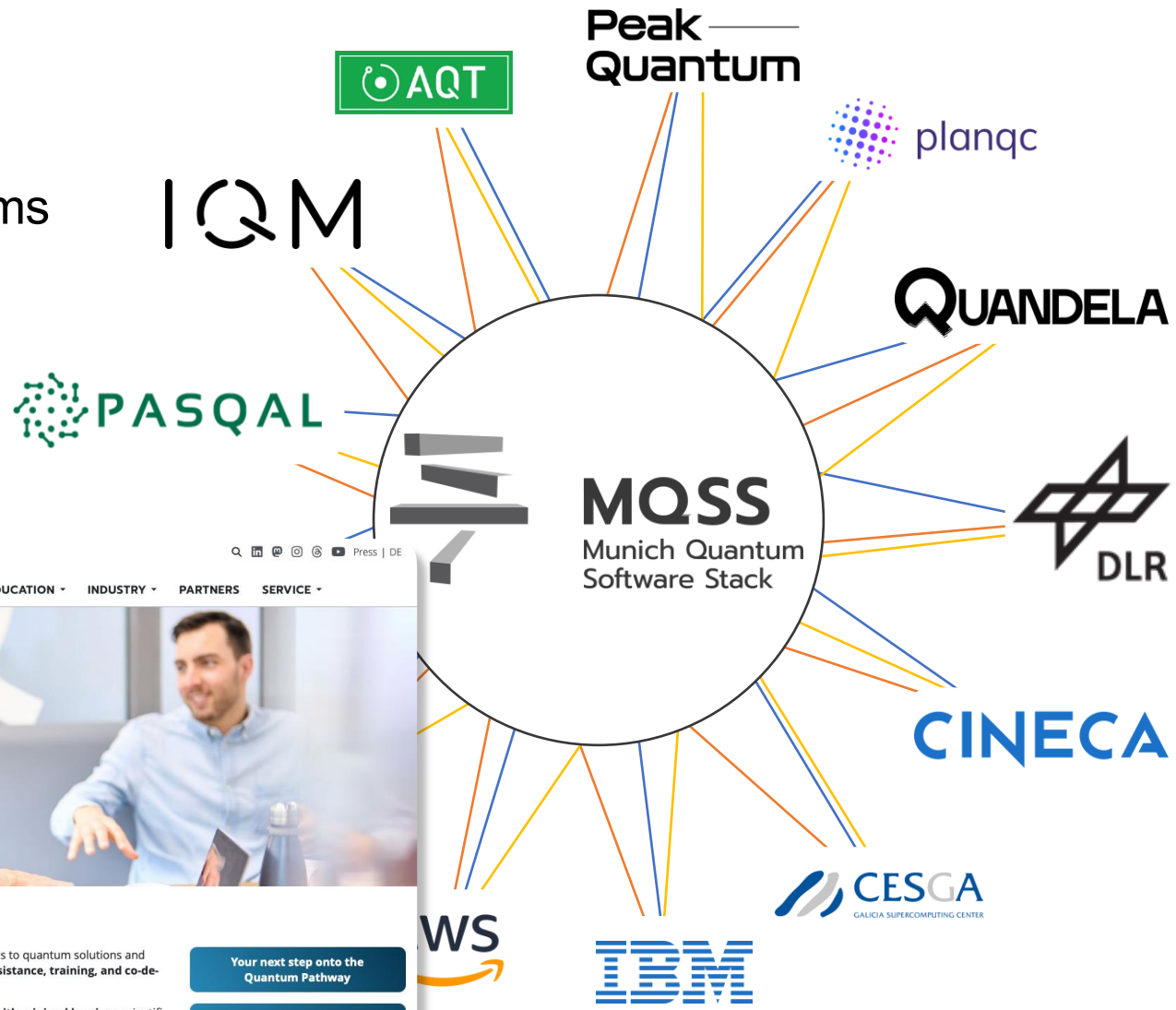
Easy Access for Industry

- Quantum integration across partners
  - Open for more partner sites
- Common interface for heterogeneous systems
- Consulting and support
- Integration into Centers of Excellence
- QDMI Network as the driver







Integration of a Wide Range of Backends

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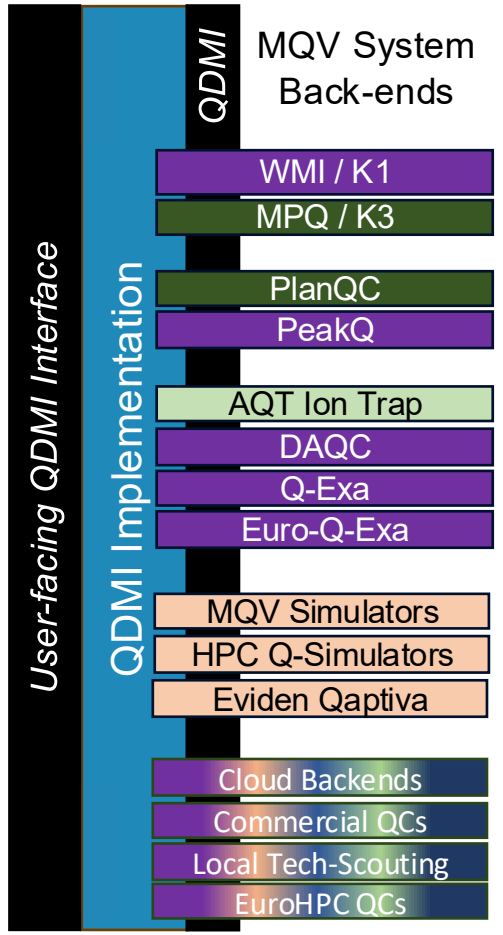
Domain Experts



MQSS Core:

Back-End

Interfaces /APIs

Plugins by Modality

MUNICH QUANTUM VALLEY MQV

MQSS Architecture

MQSS
Munich Quantum Software Stack

System Administrators

Domain Experts

Mngmt.

User and System Management
(Authentication, Configuration, Quotas, Operations)

Telemetry/ODA &
System Configuration

User-facing QDMI Interface

QDMI Implementation

QDMI

MQV System Back-ends

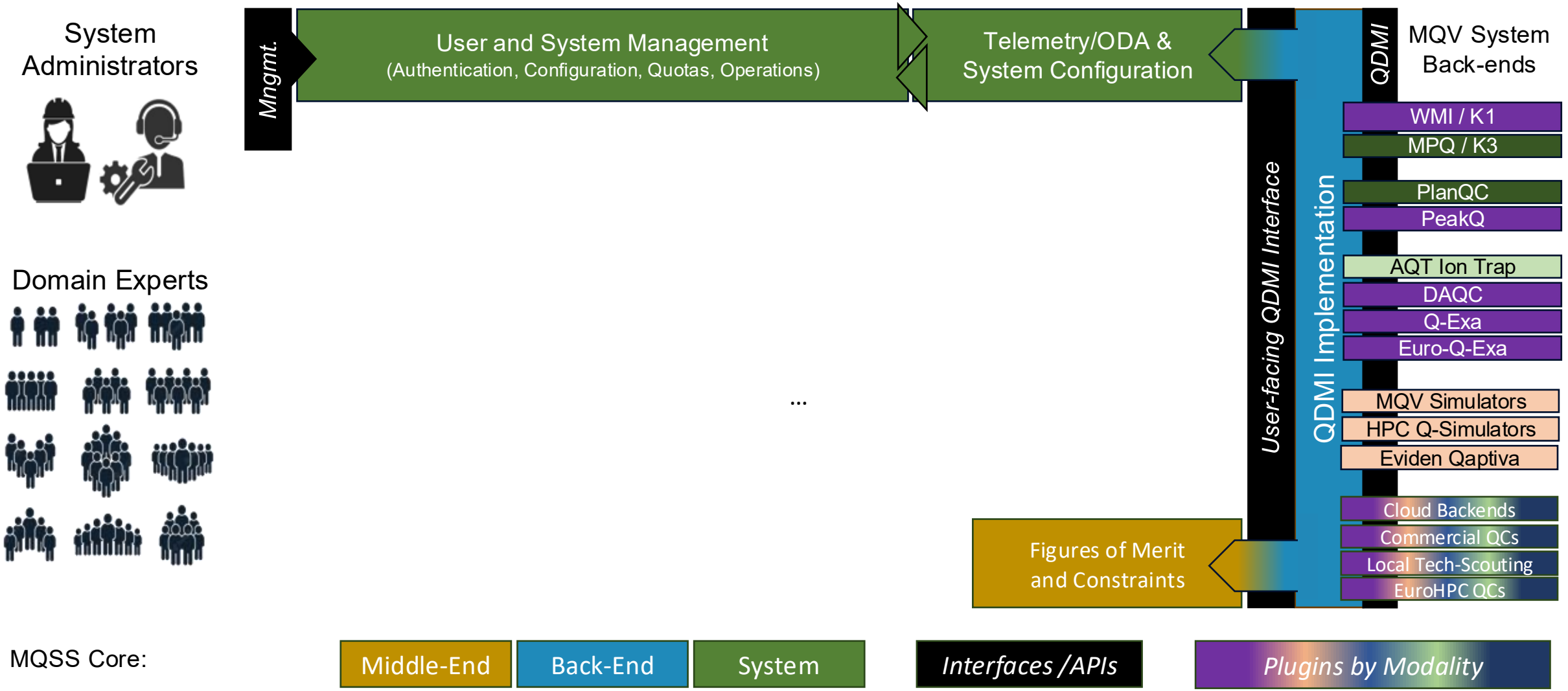
- WMI / K1
- MPQ / K3
- PlanQC
- PeakQ
- AQT Ion Trap
- DAQC
- Q-Exa
- Euro-Q-Exa
- MQV Simulators
- HPC Q-Simulators
- Eviden Qaptiva
- Cloud Backends
- Commercial QCs
- Local Tech-Scouting
- EuroHPC QCs

MQSS Core:

Back-End | System | *Interfaces /APIs* | *Plugins by Modality*

MUNICH QUANTUM VALLEY MQV

MQSS Architecture



Extracting Topology Information with Sys-Sage

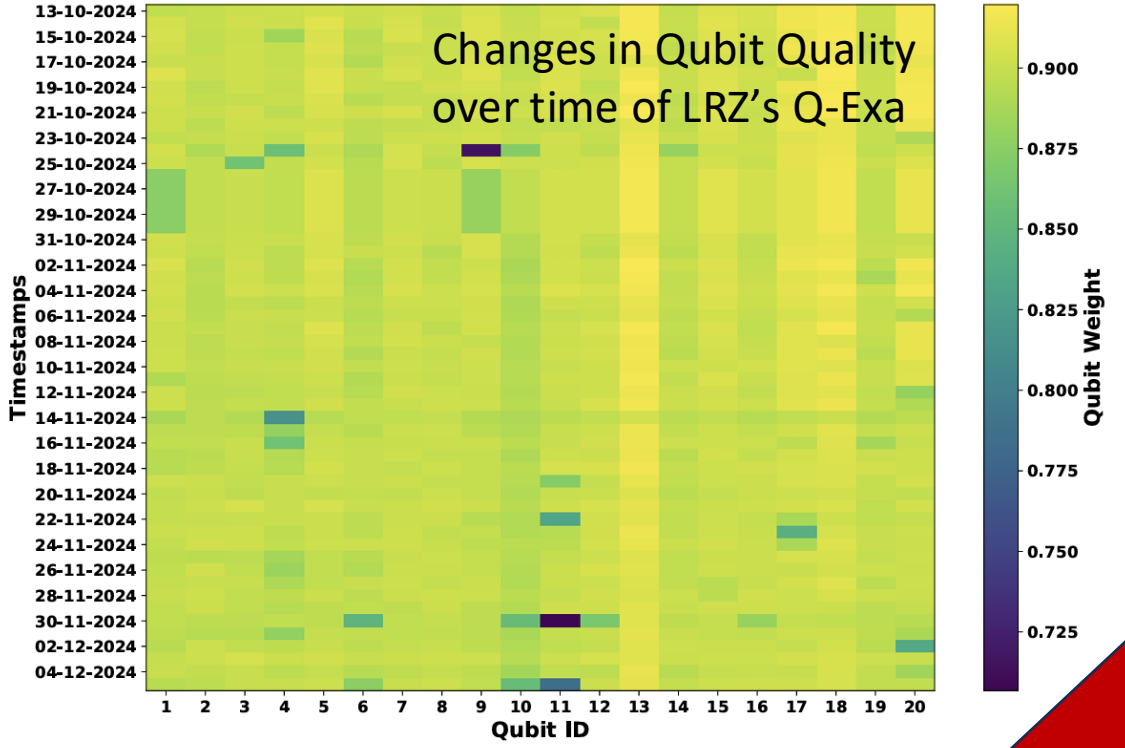
MQSS
Munich Quantum Software Stack

Topology data critical for both HPC and QC

- Sys-sage tracks dynamic topology data for HPC systems and applications
- Crucial for optimizations and mapping of applications to systems

Why not extend to Quantum Topologies?

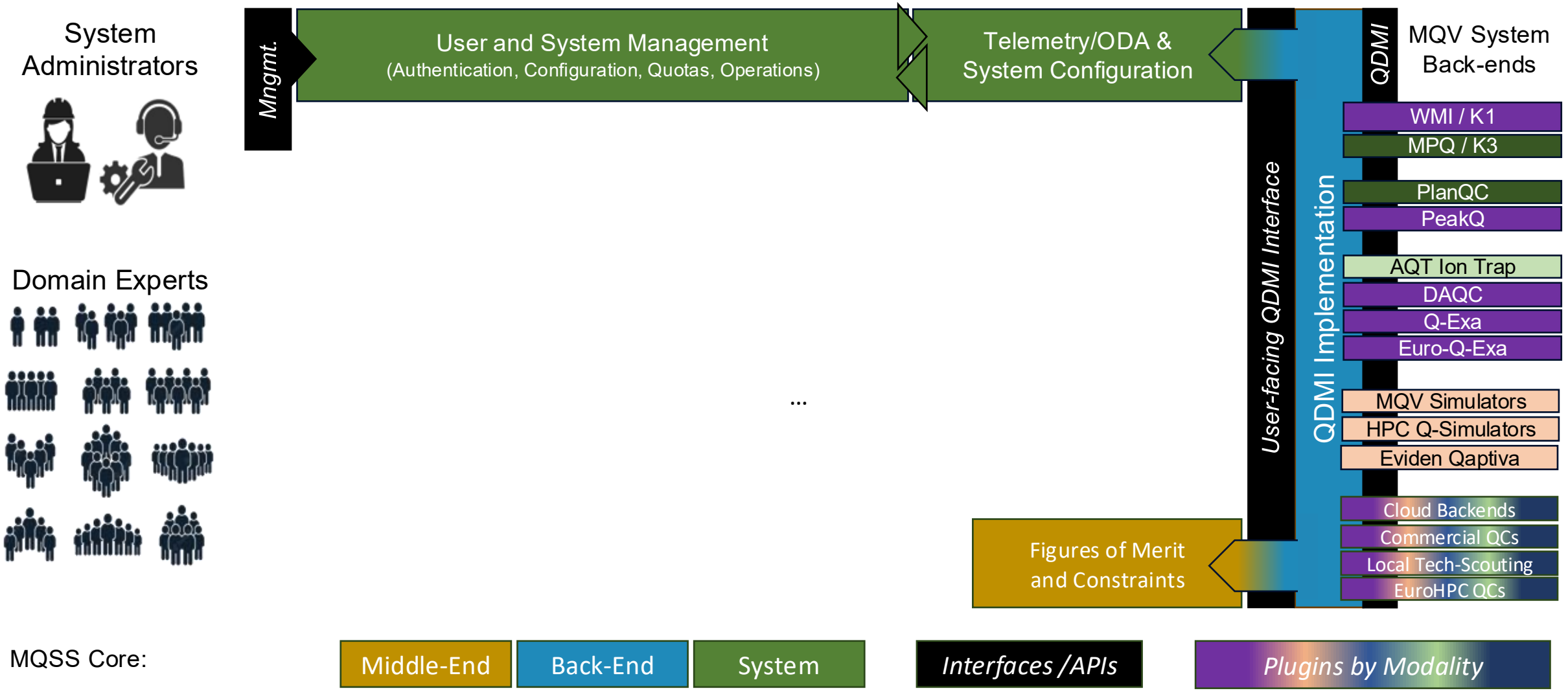
- Track qubit topologies (static property)
- Track qubit quality (dynamic property)
- Map both data into shared data structures



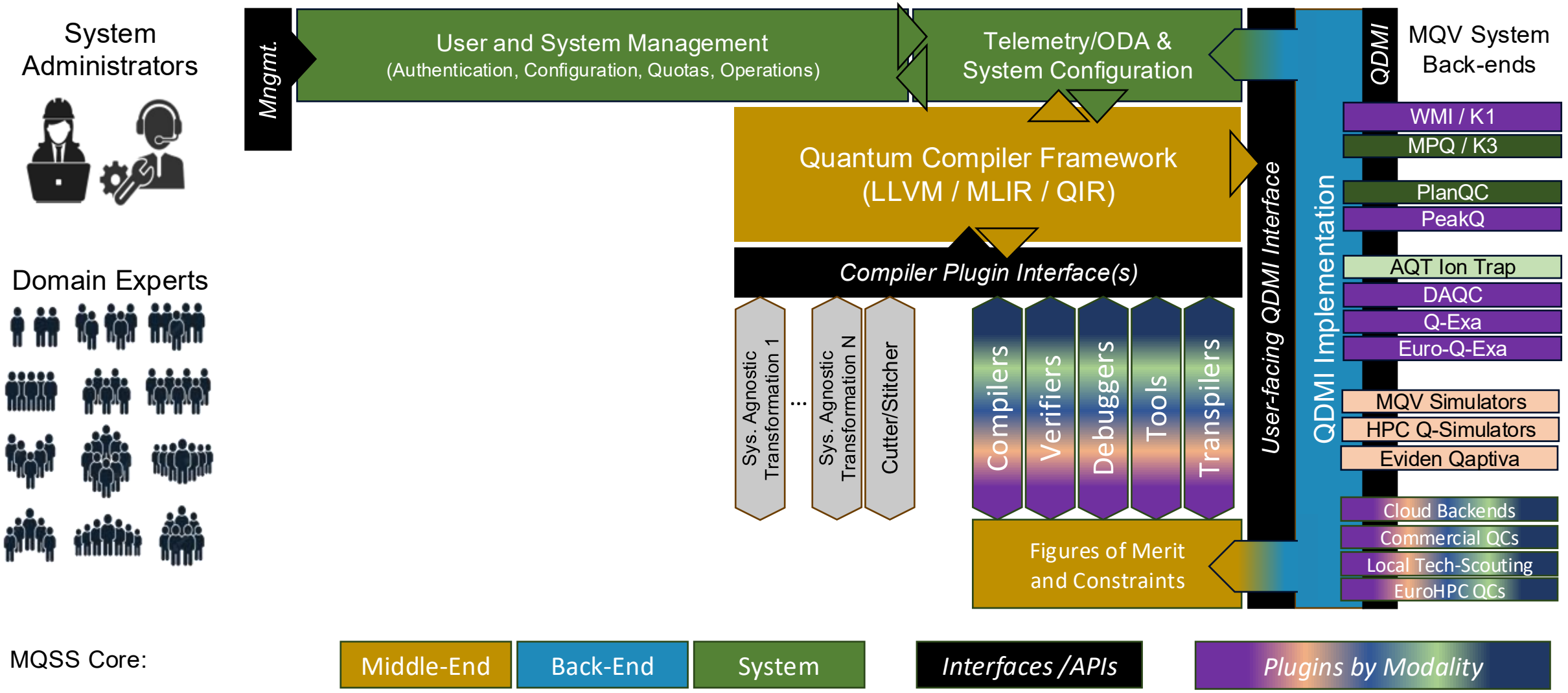
Towards a Unified Architectural Representation in HPCQC: Extending sys-sage for Quantum Technologies
Mishra, Vanecek, Echavarria, Deng, Mete, Schulz, Schulz @ ISC 2025, Hamburg

HANS MEUER AWARD WINNER 2025 best paper @ ISC25

MQSS Architecture



MQSS Architecture



MQSS Components Catalog

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Front-End

QPI: Hybrid Programming from C/C++
- LRZ/LS & TUM/MS: Ercüment Kaya

FPQA Compiler for Max3SAT problems
- TUM/PB: Oğuzcan Kırmemiş

qTPU: Large circuits as tensor networks
- TUM/PB: Nathaniel Tornow

ISV Job execution for Spin Hamiltonians
- LRZ/LS: Burak Mete and Tobias Bauer

MQT QECC: EC quantum circuit preparation
- TUM/RW: Lucas Berent

Parallel circuit extraction from ZX Diagrams
- LMU/DK: Karl Führlinger

GA4QCD: Application-specific synthesis
- LMU/CLP: Leo Sünkel

qcd-gym: Circuit builder/optimizer using RL
- LMU/CLP: Philipp Altmann

Middle-End

MQT Predictor: Predict suitable back-ends
- TUM/RW: Nils Quetschlich

MILQ: Assigning circuits backends
- TUM/CM: Philipp Seitz and Manuel Geiger

AI-based compiler path selection
- LRZ/LS & TUM/MS: Aleksandra Świerkowska

MQT QMAP: Topology mapping of circuits
- TUM/RW: Lukas Burgholzer

MQT QCEC: Tool for equivalence checking
- TUM/RW: Lukas Burgholzer

MQT Qudits: Compilation for multistate Qbits
- TUM/RW: Kevin Mato

Quantum constant propagation
- TUM/HS: Yanbin Chen

Mid-Circuit measurement reduction
- TUM/HS: Innocenzo Fulginiti

Back-End

Hardware backend development with partners
- LRZ/LS: Jorge Echavarria

FoMaCs via Sys-Sage tool library
- TUM/MS: Stepan Vanecek

Unified Quantum Platform (UQP)
- TUM/MS: Amr Elsharkawy

Quantum Control Processor (QCP) and ISA
- TUM/MS: Xiaorang Guo

Simulator: MQT DDSIM
- TUM/RW: Lukas Burgholzer

Simulator: Tensor networks
- TUM/CM: M. Geiher and Q. Huang

Simulator: Parallel Clifford+T
- LMU/DK: Florian Kroetz

Simulator: Back-ends for HPC simulators
- LRZ/LS: Marco De Pascale

System

Munich Quantum Portal (MQP) and plugins
- LRZ/LS: Marco De Pascale

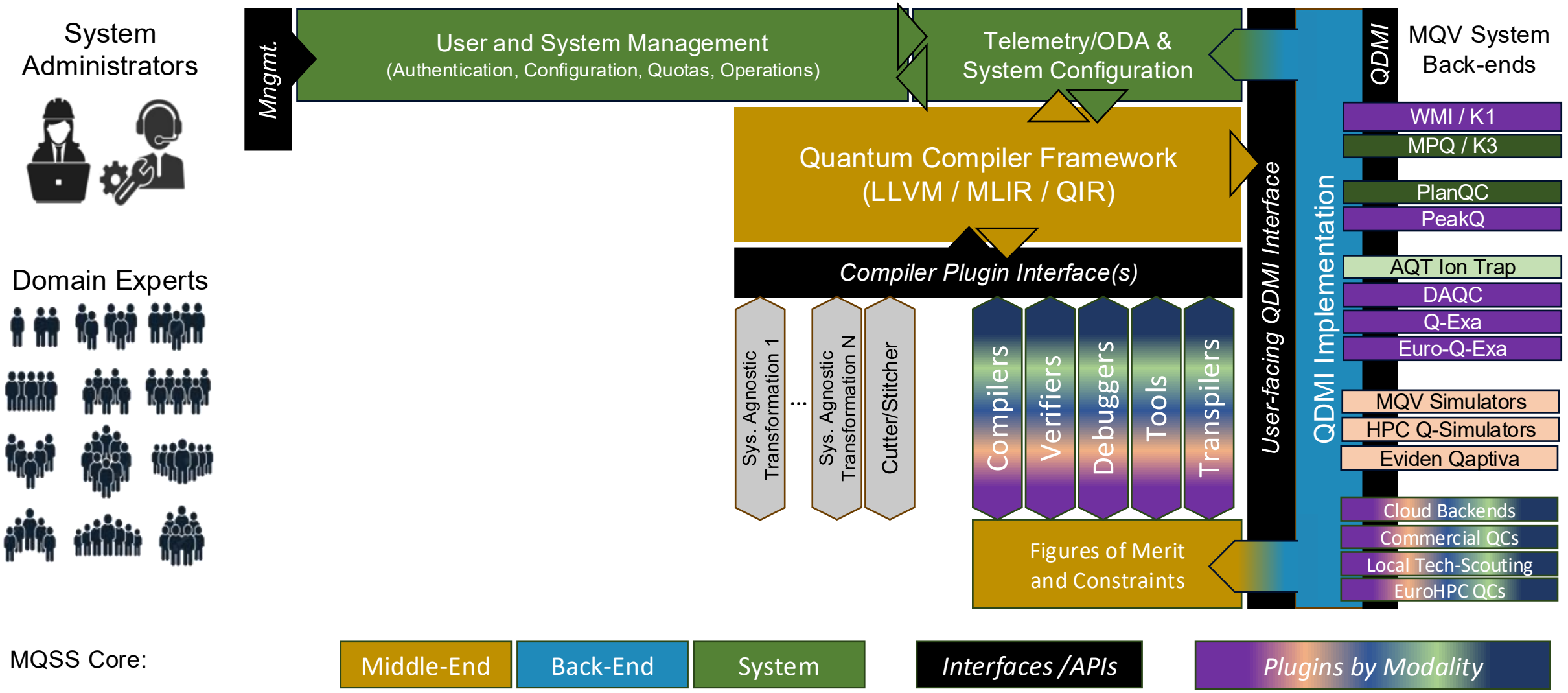
Resource prediction and circuit scheduler
- LRZ/LS: Minh Chung

IoT Environment / ODA / Digital Twins
- LRZ/LS & TUM/MS: H. Ahmed and Y. Gambo

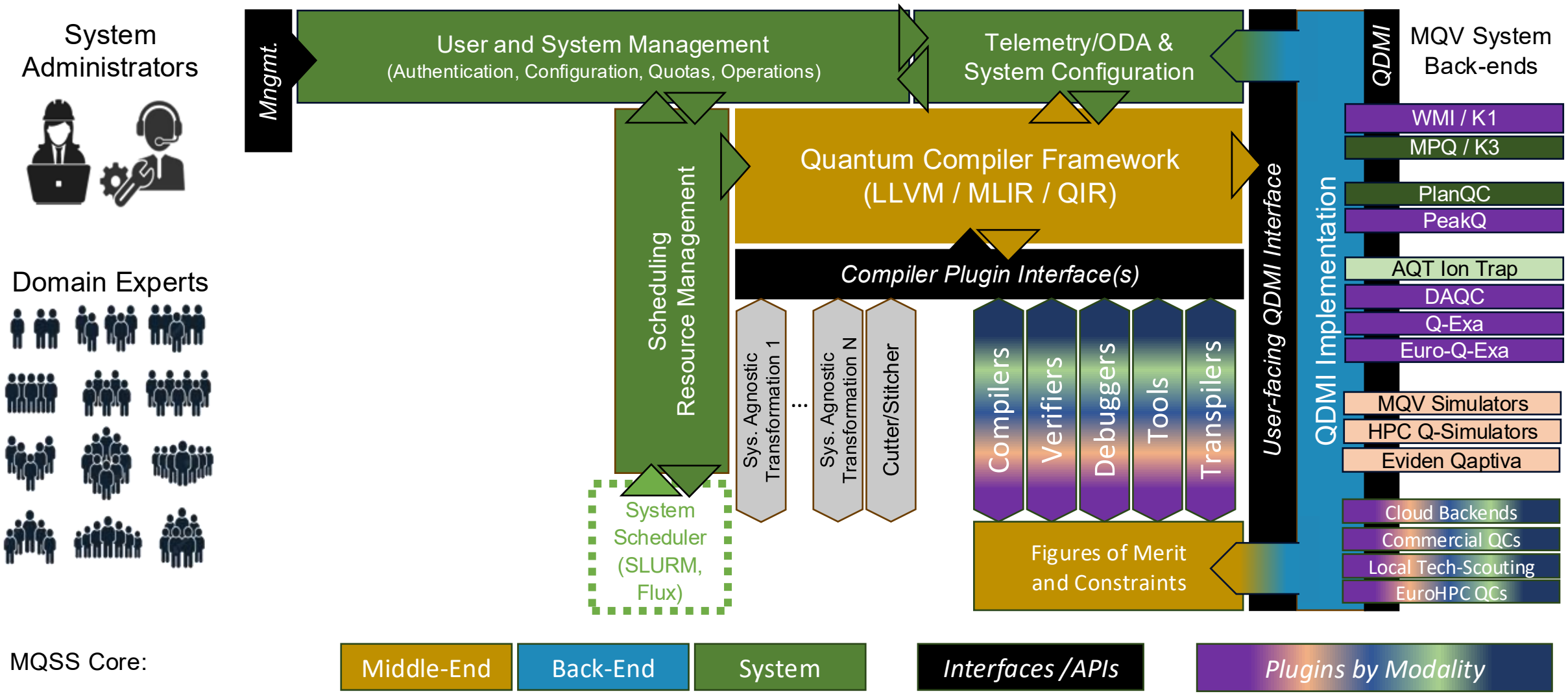
HPC scheduling
- LRZ/LS & TUM/MS: Nufail Farooqi

Operations, Configuration, Calibration
- LRZ/LS: Matt Tovey and Xiaolang Deng

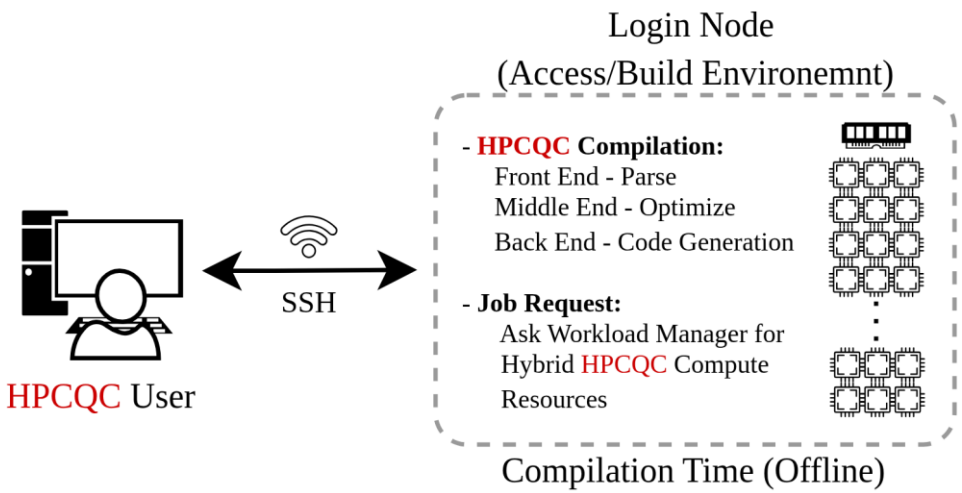
MQSS Architecture



MQSS Architecture



HPCQC Workflow



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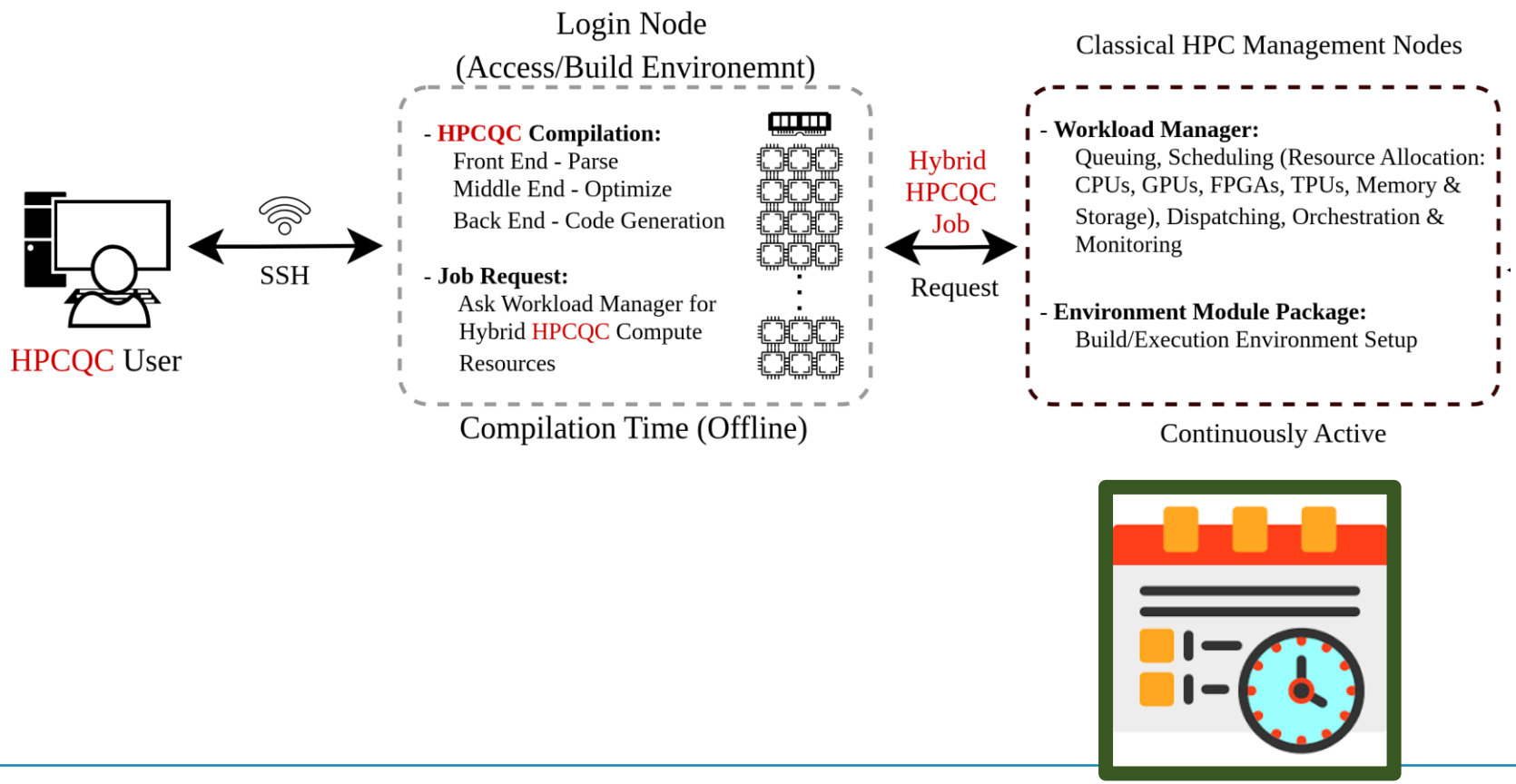

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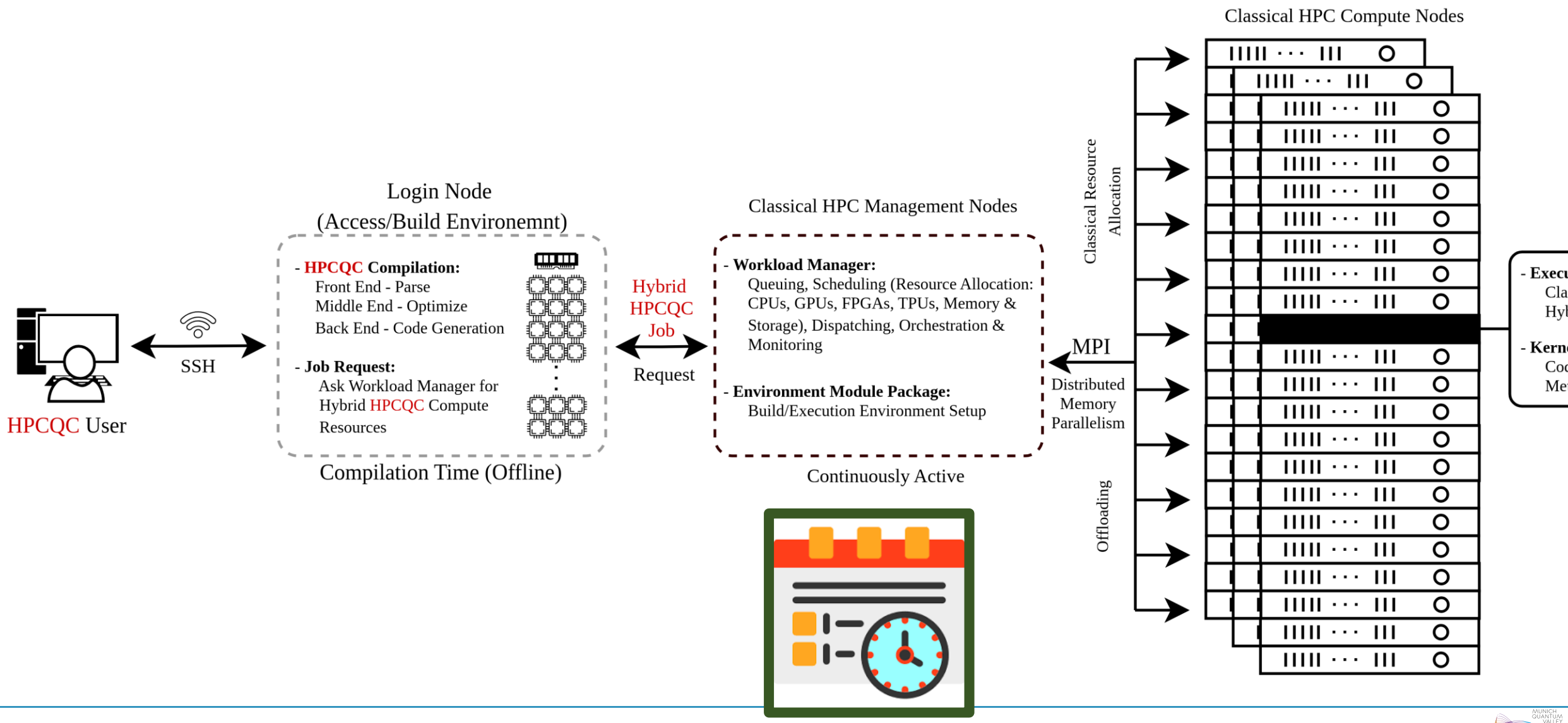
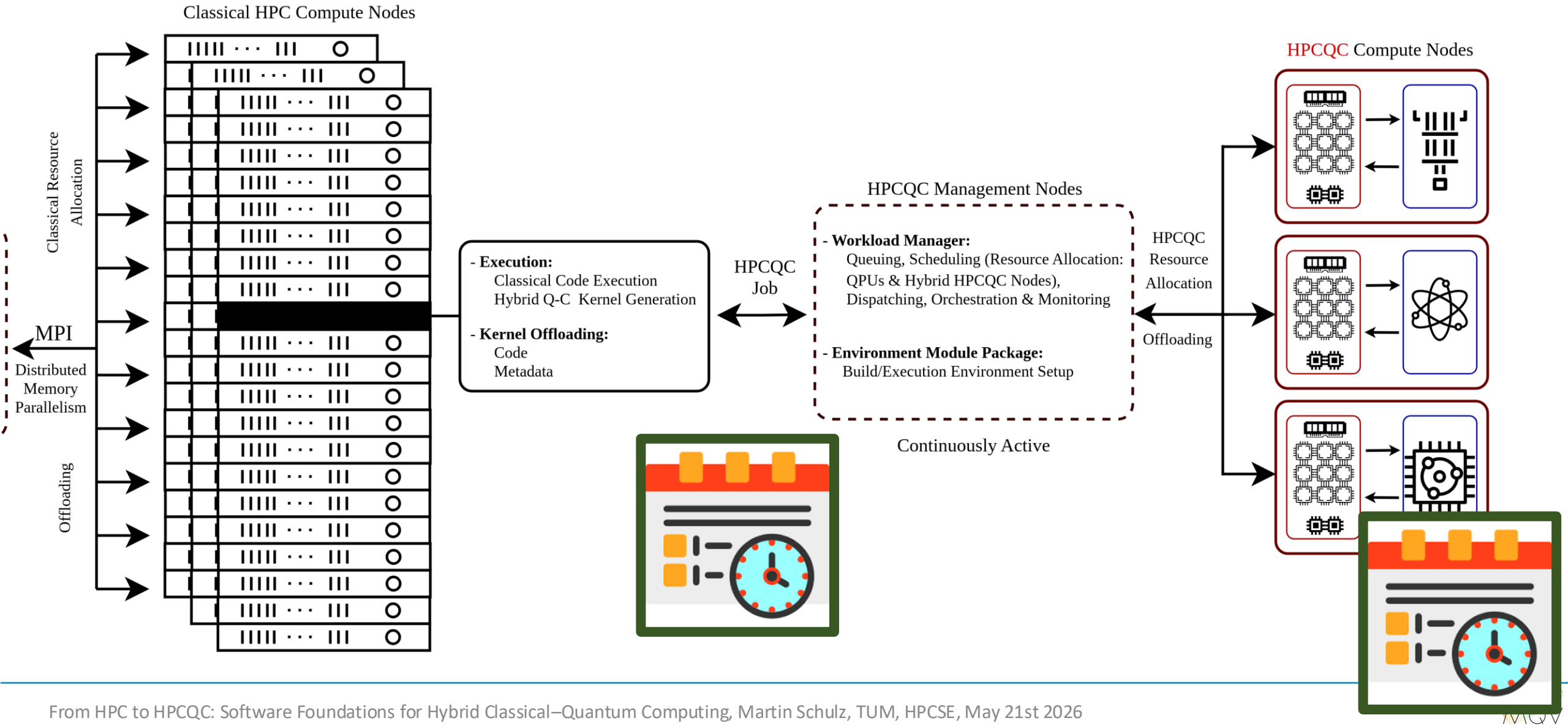
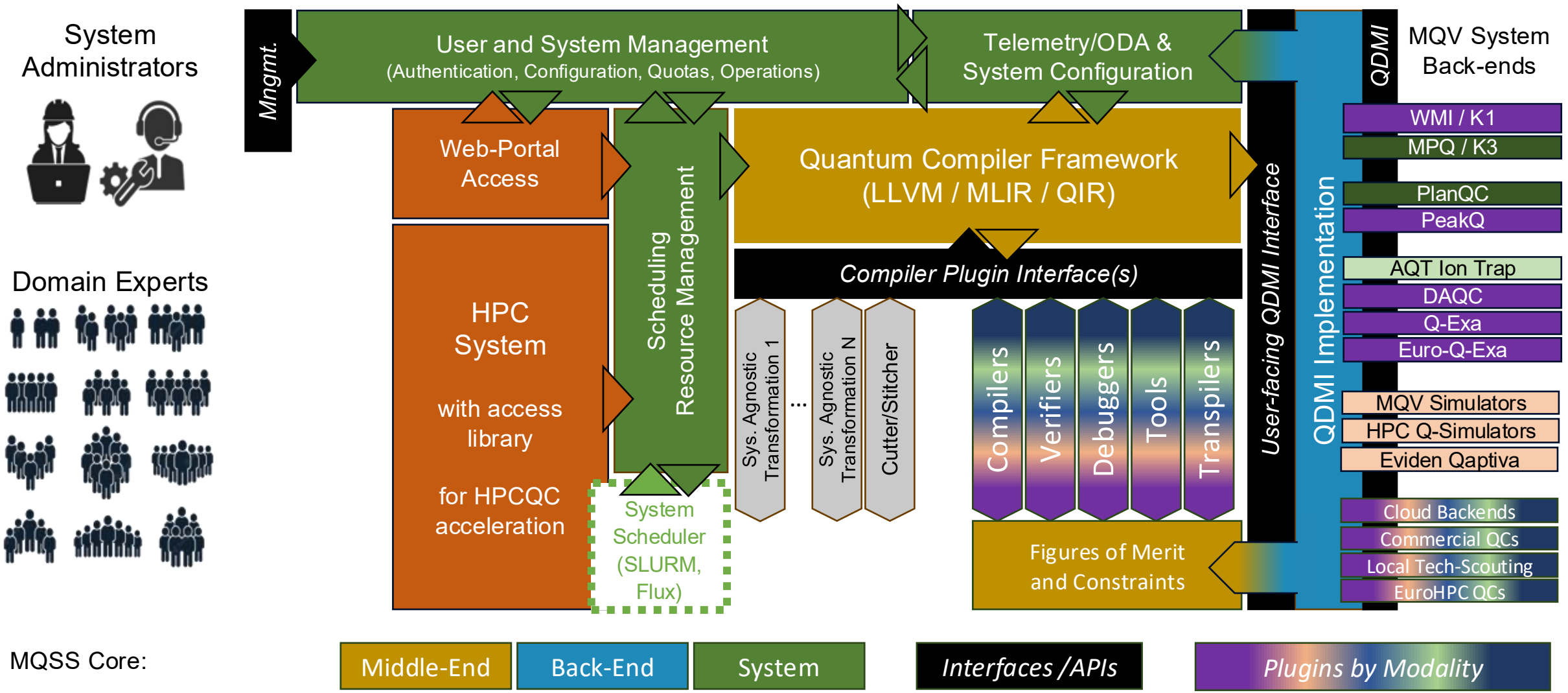


HPCQC Workflow

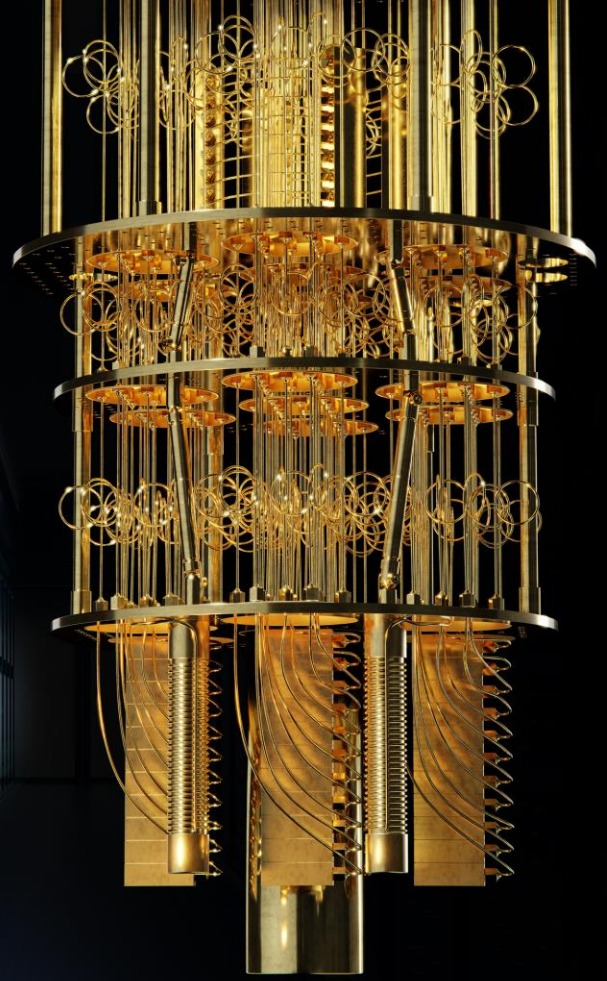


MQSS Architecture



Challenges

- Hardware Integration of the QC control system
- Building a Hybrid HPCQC Software Stack
- HPC-inspired Hybrid Programming Approaches

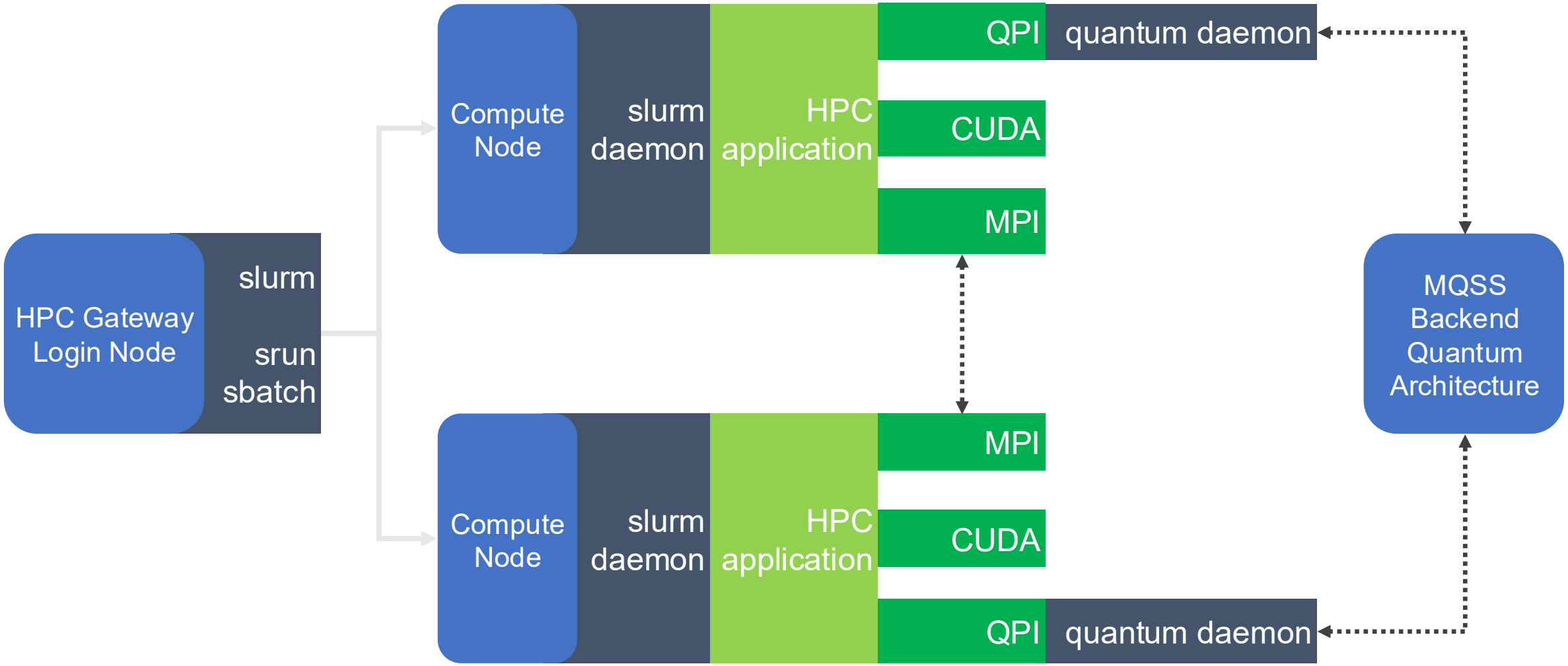


Why HPC-QC?

Quantum Computing
=
High-Performance Computing

New compute capability that adds to the supercomputing portfolio.

HPC Accessing QC via QPI



Quantum Programming Interface

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Aims to provide similar abstraction to Qiskit

- Abstracts architecture
- Vendor neutral

Users are legacy HPC applications

- C-based API
- Accelerator concept

Maps well to task-offload model and doesn't force data structure

```c
#define QPI_1
#include <qpi.h>
#include <stdio.h>


void bell_0() {
    Qcircuit circuit;
    Qstatus status;

    int states = 4;
    int shots = 1000;

    // 4 states can exist with 2 qubits
    int output[states];

    qCircuitBegin(&circuit);

    qH(0);
    qCX(0, 1);

    qMeasure_all();

    qCircuitEnd();

    qExecute(circuit, shots, &status);
    qWait(status);

    qRead(status, QPI_READ_ALL_STATES, (int*)&output);

    for(int state_idx=0; state_idx < states; state_idx++) {
        printf("|%d>: %d", state_idx, output[state_idx]);
    }
}
```

OpenMP Quantum Tasks Integration

MQSS
Munich Quantum Software Stack

Lower learning curve for HPC users

Benefits from compiler level information instead of a library level

Possibility to includee offloading classical task to “nearby compute”

Quantum Task Offloading with the OpenMP API
Joseph KL Lee, Oliver T Brown, Mark Bull, Martin Ruefenacht, Johannes Doerfert, Michael Klemm, Martin Schulz
Posters at SC23

```c
#include <omp.h>
#include <stdio.h>

void bell_0() {
    int states = 4;
    int shots = 1000;
    int results[states];

    #pragma omp target loop
    for(int shot=0; shot<shots; shot++)
    {
        omp_q_reg result = omp_create_q_reg(2);

        omp_q_h(result, 0);
        omp_q_cx(result, 0, 1);

        int idx = omp_q_m(result);
        results[idx] += 1;
    }

    for(int state_idx=0; state_idx < states; state_idx++) {
        printf("|%d>: %d", state_idx, results[state_idx]);
    }
}
```


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MQSS Architecture

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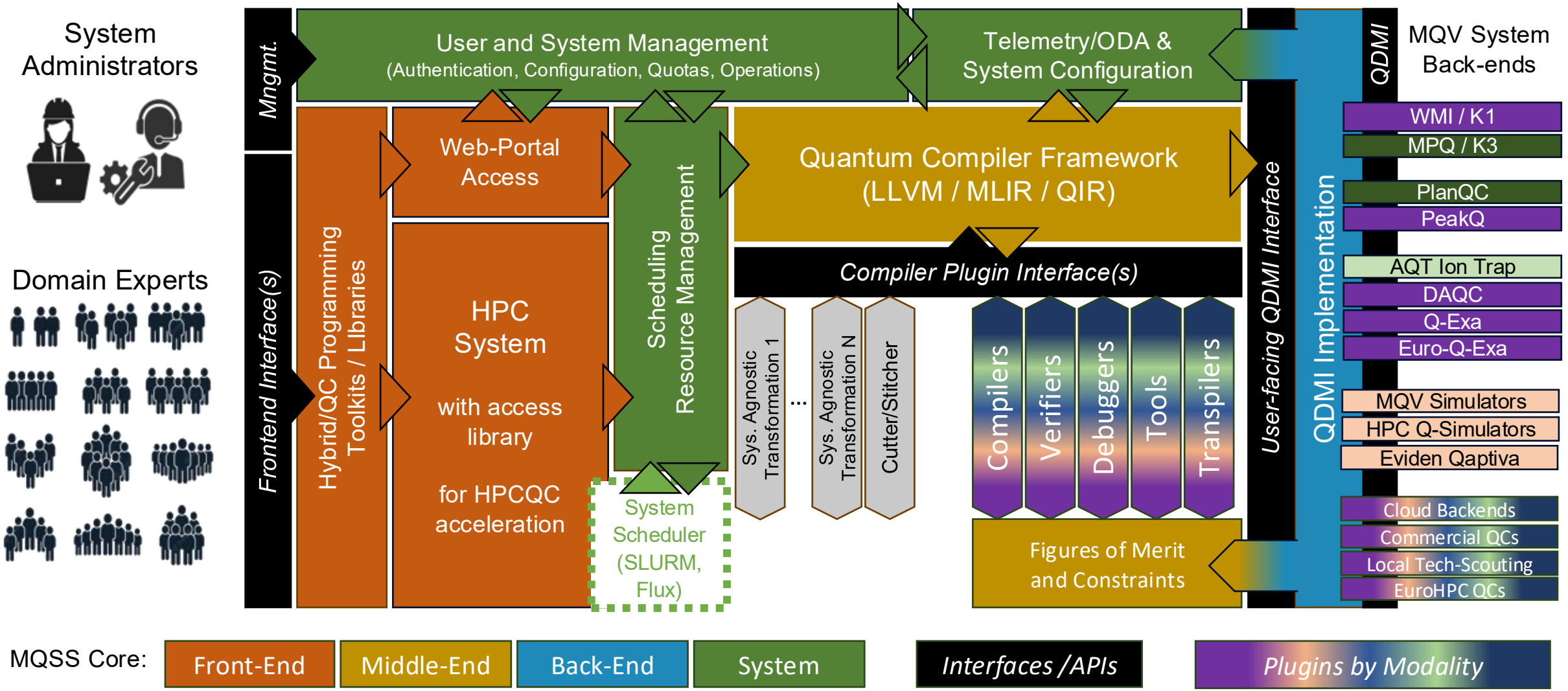
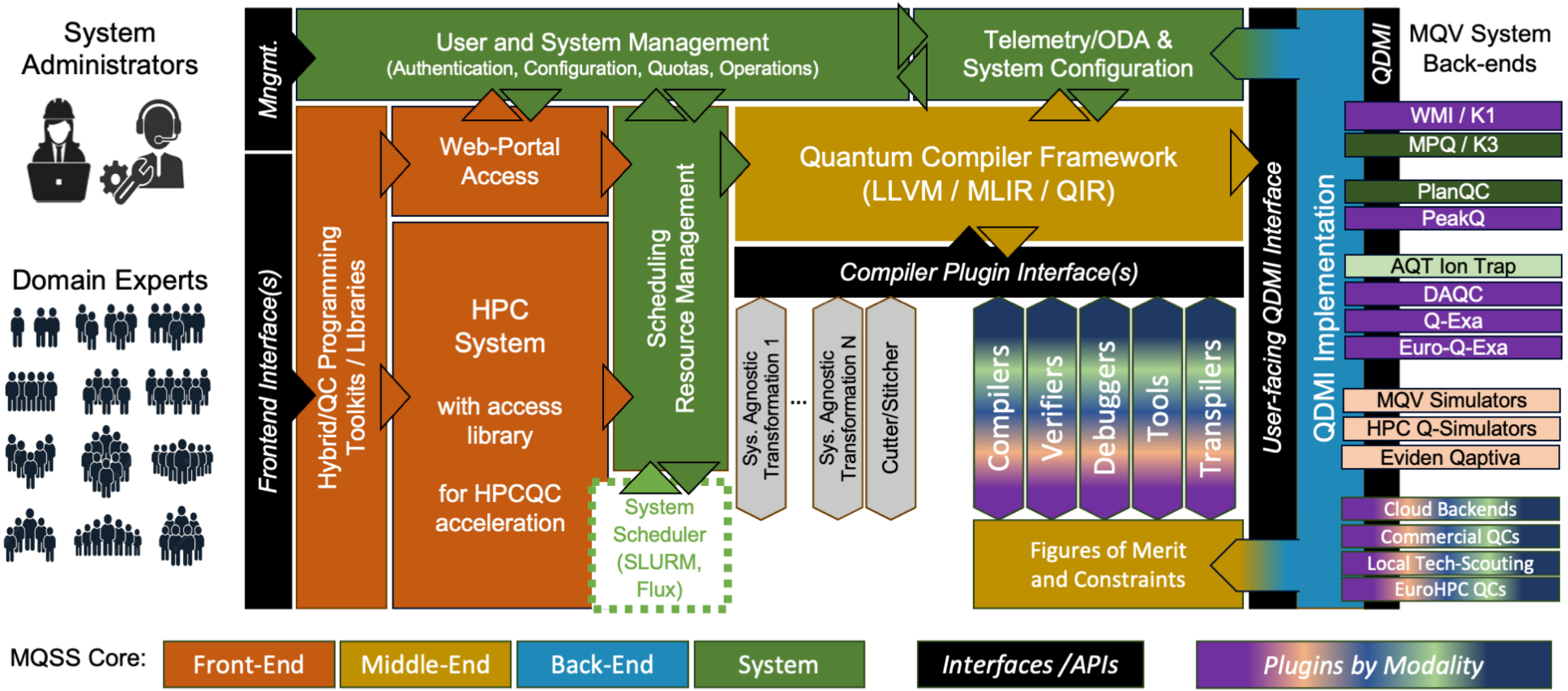


MQSS Architecture

MQSS
Munich Quantum Software Stack

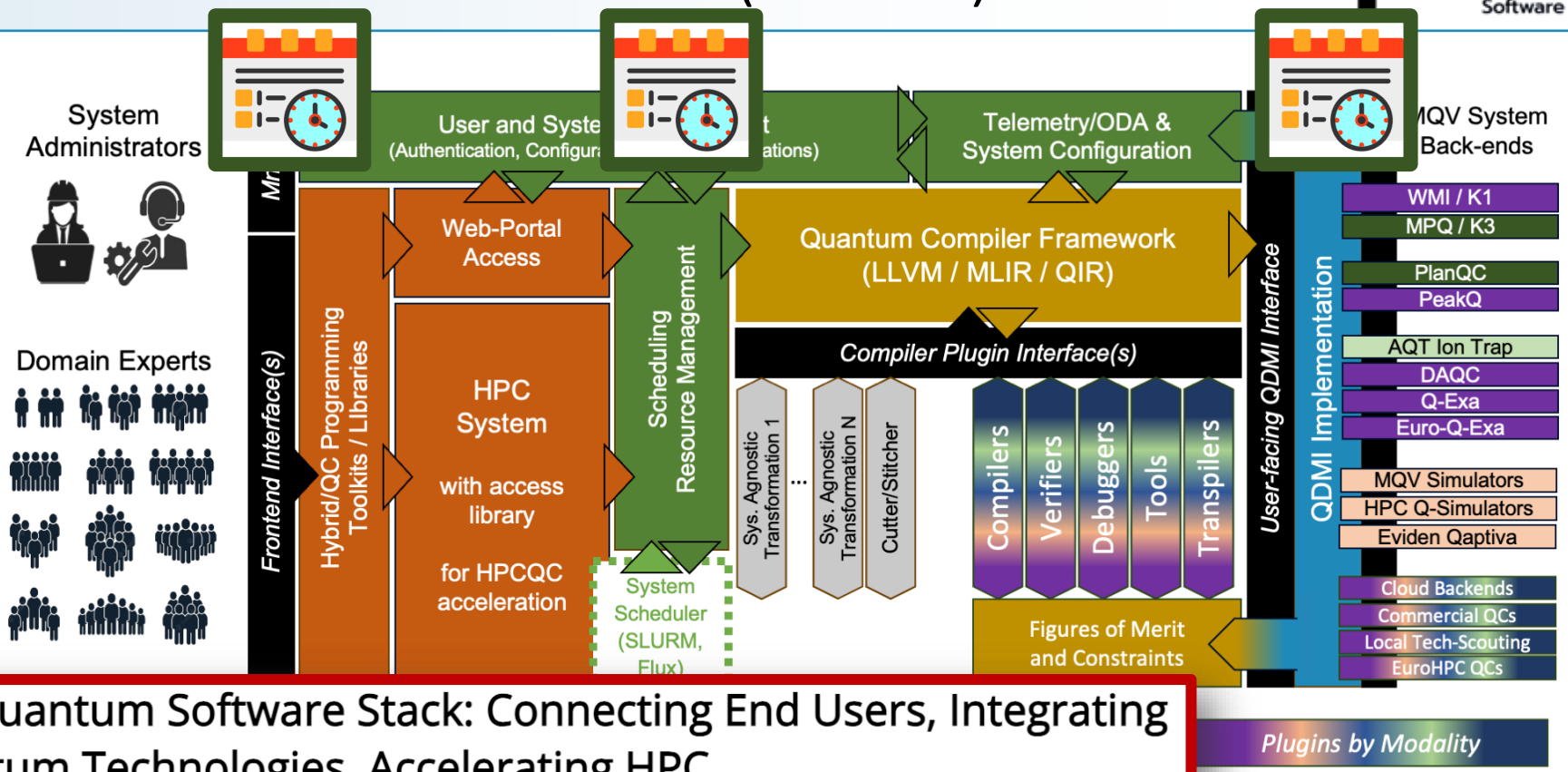


MUNICH QUANTUM VALLEY MQV

The Munich Quantum Software Stack (MQSS)

MQSS
Munich Quantum Software Stack

https://dl.acm.org/doi/10.1145/3773656.3773669



The Munich Quantum Software Stack: Connecting End Users, Integrating Diverse Quantum Technologies, Accelerating HPC

Authors: Lukas Burgholzer, Jorge Echavarria, Patrick Hopf, Yannick Stade, Damian Rovara, Ludwig Schmid, Ercüment Kaya, Burak Mete, Muhammad Nufail Farooqi, Minh Chung, +

4 Authors Info & Claims

SCA/HPCAsia '26: Proceedings of the Supercomputing Asia and International Conference on High Performance Computing in Asia Pacific Region

Pages 55 - 67 • https://doi.org/10.1145/3773656.3773669

Use Case

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Faculty of Mathematical & Physical Sciences
Department of Chemistry
Centre for Computational Science
Advanced Research Computing Centre

UCL

End-to-end Quantum-HPC Workflows for Molecular Simulation and Machine Learning

Prof. Peter V. Coveney
Centre for Computational Science, UCL
Department of Chemistry
Advanced Research Computing Centre, UCL

UCL

Acknowledgements

University College London: TM Bickley, PV Coveney, MW de la Bastida, M Gao, R Martin, A Mingare, A Townsend-Nicholson, M Wang, X Xue

Technical University Munich: C Mendl, M Nibbi, A Orlov

Leibniz Supercomputing Centre: M Chung, M Hernandez Vera, L Iapichino

NVIDIA: Z Chandani, Y Alexeev

IQM Quantum Computers: F Simkovic, PV Sriluckshmy

QMatter: A Ralli, T Weaving

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MQSS
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Centre for Computational Science
Advanced Research Computing Centre

UCL

End-to-end Qu
Molecular Sim

Prof. Peter V. Cov
Centre for Comput
Department of Che
Advanced Researc

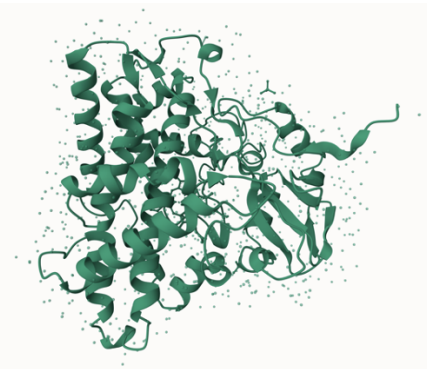
Part 1: A New Era of Biomolecular Simulation – Where Quantum Computing Meets GPU-accelerated Supercomputing

Modern chemistry relies on **predictive rather than descriptive** understanding

Ab initio quantum chemistry enables *mechanistic insight* into:

- **Drug design** (binding, selectivity, mutation effects)
- **Catalysis** (enzyme active sites, proton/electron transfer)
- **Protein dynamics**

If we can accurately compute these mechanisms, we can *design* rather than *search*



Interesting biomolecules tend to be large and complicated

Image source: https://www.ebi.ac.uk/interpro/structure/PDB/1n40/

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Use Case

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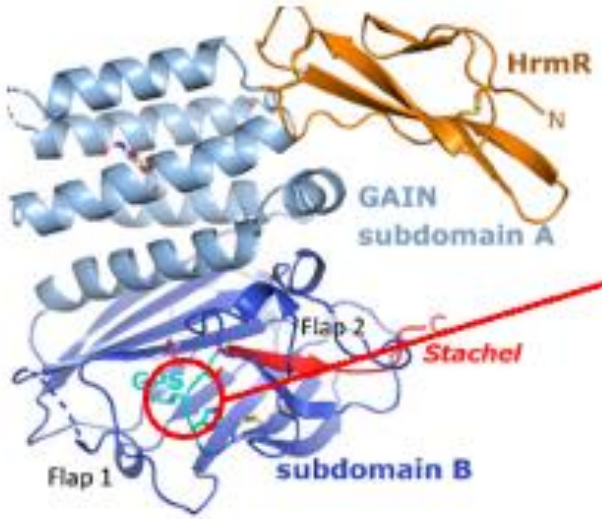
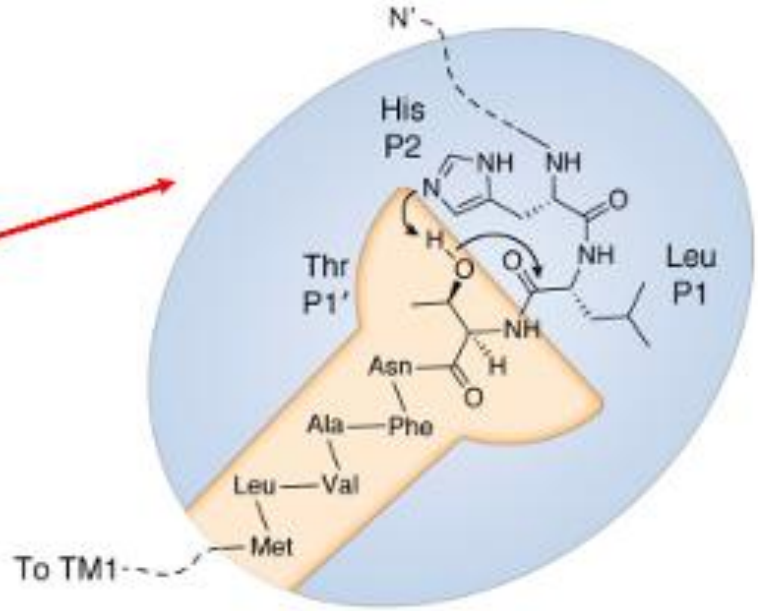
Use Case: Autoproteolysis in G Protein Coupled Receptors





Autoproteolysis: the protein cuts itself into two pieces (yellow and blue region) at the *GPS* (GPCR proteolysis site), i.e., a self-induced *peptide bond breaking*

Images: Pohl et al. (2023): Structural basis of GAIN domain autoproteolysis and cleavage-resistance in the adhesion G-protein coupled receptors. bioRxiv preprint. DOI: 10.1101/2023.03.12.532270
Vizurraga et al. (2020): Mechanisms of adhesion G protein-coupled receptor activation. Journal of Biological Chemistry 295 (41). DOI: 10.1074/jbc.REV120.007423

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UCL

Partitioning the System into Levels of Different Accuracy

1. **Wavefunction region** (*QPU*): the three atoms directly involved in the chemical reaction
2. **Conventional quantum chemistry region** (*CPU*): the direct neighbors of the wavefunction region
3. **Classical environment** (*CPU/GPU*): the remainder of the biomolecule and surrounding water

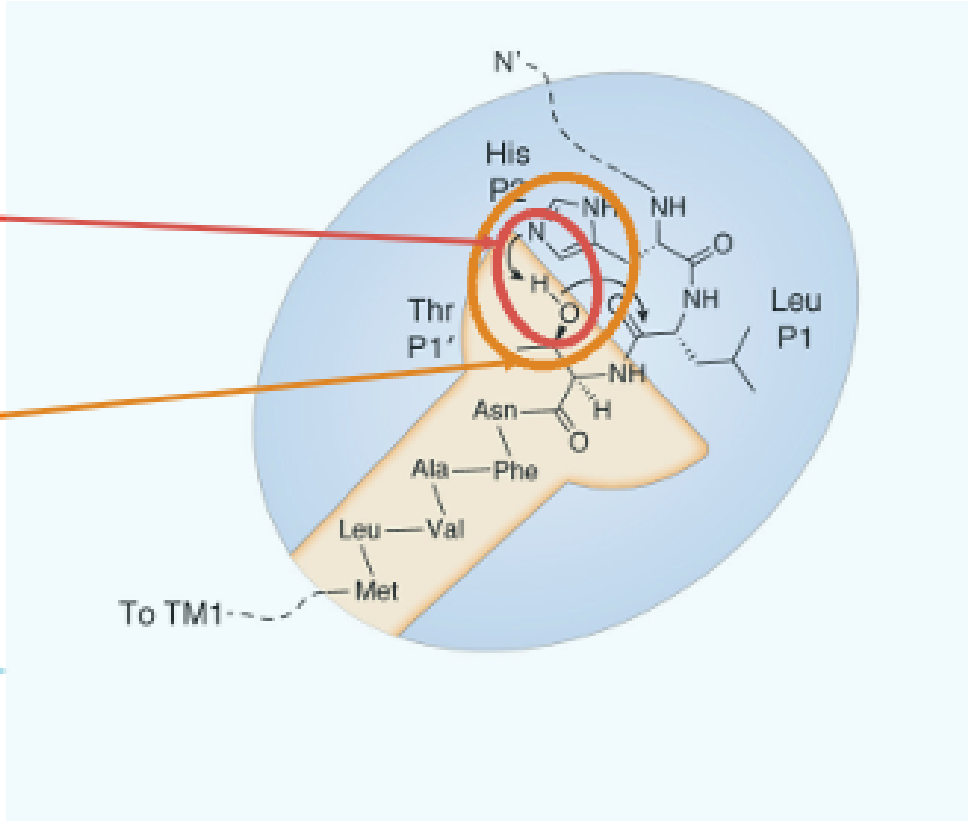

Image: Vizurraga et al. (2020): Mechanisms of adhesion G protein-coupled receptor activation. Journal of Biological Chemistry 295 (41). DOI: 10.1074/jbc.REV120.007423

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Use Case

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Department of Chem
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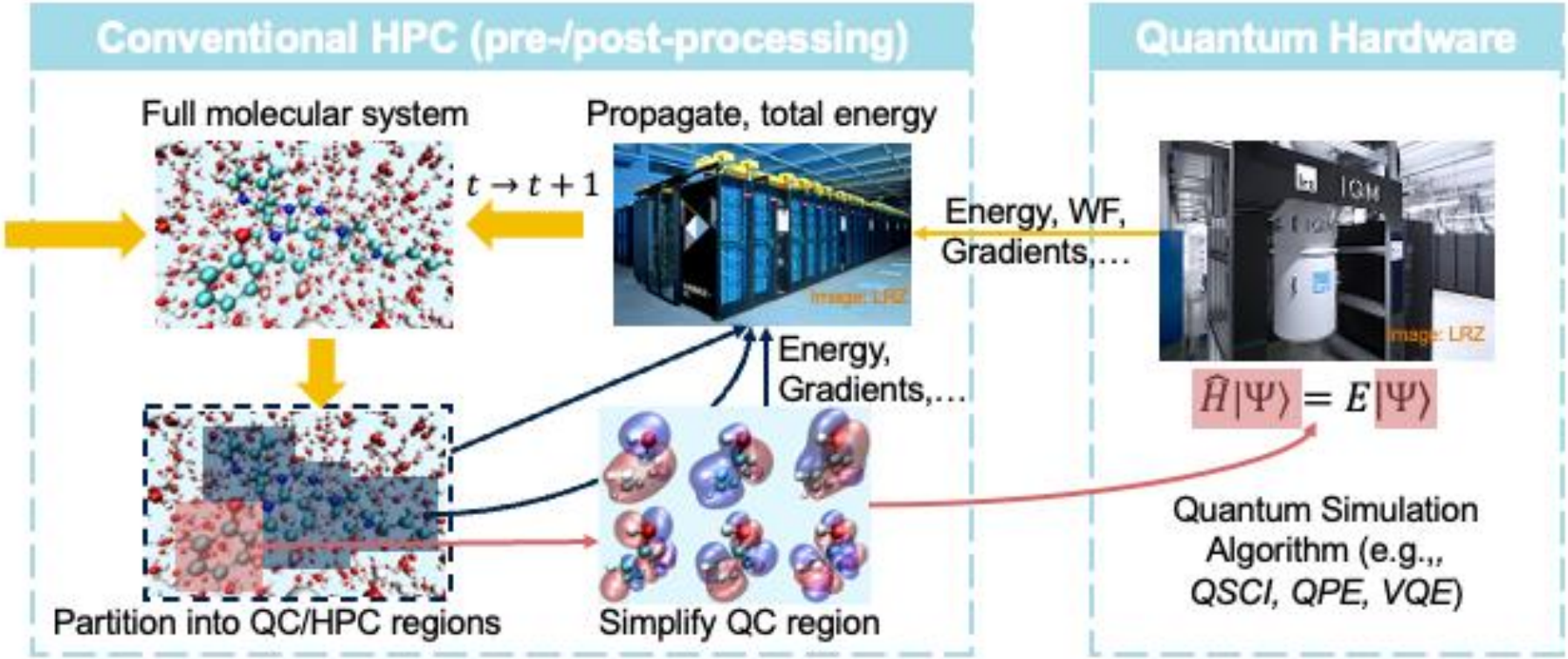
Image: Vizurraga et al. (20

UCL

Multi-scale, Heterogeneous Simulation Workflows



Based on: Bickley T, Mingare A, Weaving T, de la Bastida M, Wan S, Nibbi M, Seitz P, Ralli A, Love P, Chung M, Hernández Vera M, Schulz L, Coveney P. Extending Quantum Computing through Subspace, Embedding and Classical Molecular Dynamics Techniques. Digital Discovery, 2025, Advance Article. DOI: 10.1039/D5DD00225G

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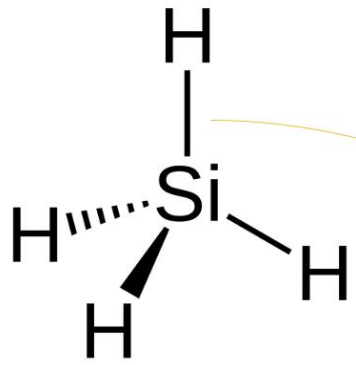
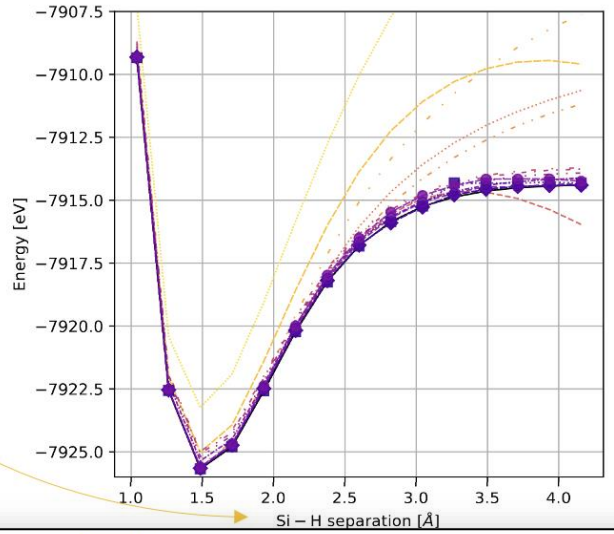
Use Case





QSCI performs similar to gold-standard conventional methods

Degrees of freedom: 18 electrons in 42 spin-orbitals → 42 qubits
Quantum hardware: 54-qubit IQM Emerald superconducting device

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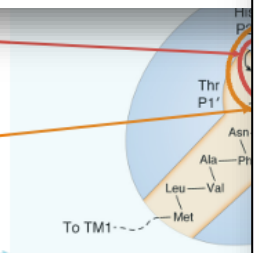


Image: Vizurraga et al. (2020): Mechanisms of adhesion G protein-coupled receptor activation. Journal of Biological Chemistry 295 (41). DOI: 10.1074/jbc.

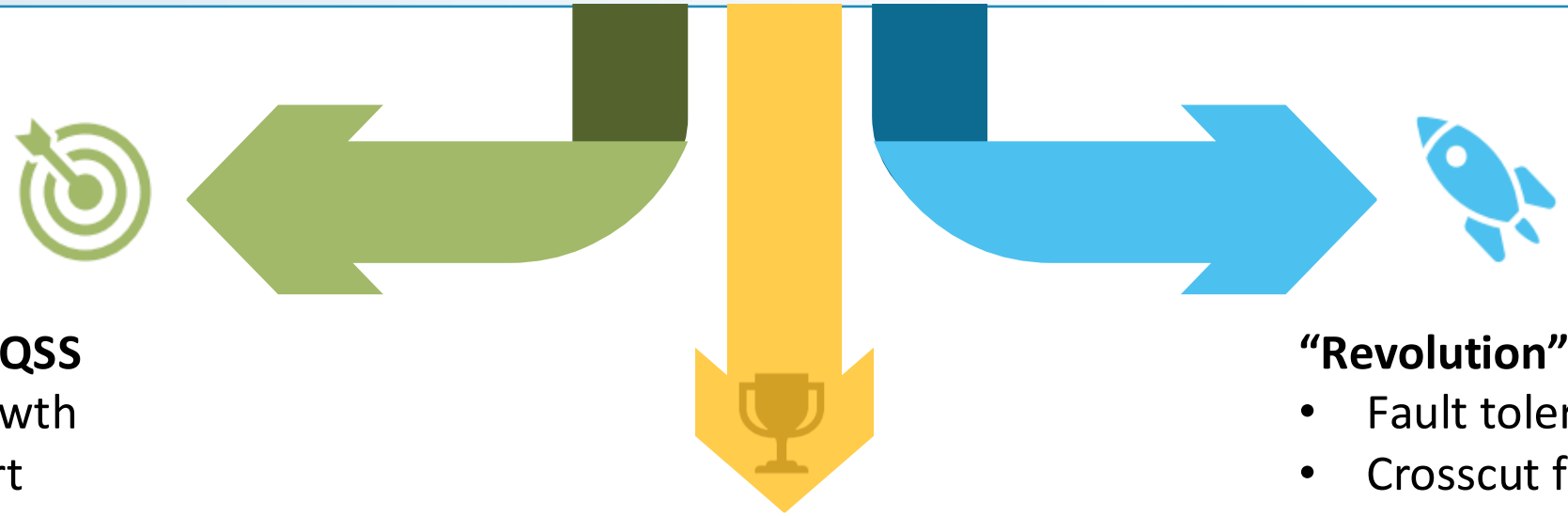
Accelerated Quantum Supercomputing: A Hands-On Tutorial on Quantum-Classical Hybrid Workflows Executed on QPUs and GPUs

Monday, June 22, 2026 2:00 PM to 6:00 PM · 4 hr. (Europe/Berlin)

Hall X4 - 1st Floor

ISC High Performance

Looking Forward: Where Next for MQSS …



Stabilization of MQSS

- Continued Growth
- CI & CD support
- User Interfaces
- Transfer to Operation

“Evolution” of MQSS

- New backends/systems
- Better optimizations
- Easy-to-use abstractions
- User support components

“Revolution” of MQSS

- Fault tolerance / Mitigation
- Crosscut for entire MQSS
- New aspects for close integration of compute

The MQSS Core Team

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Munich Quantum Software Stack

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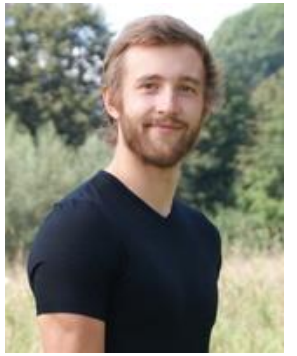

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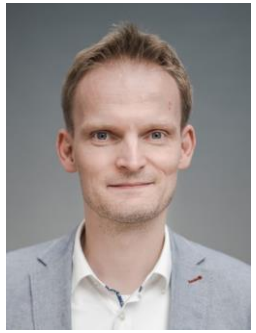

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Alumni: Laura Schulz
Now at Argonne NL
& MQV Scientific Advisor

Contact:
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Thank you to our Groups and the Entire MQV!

MQSS
Munich Quantum Software Stack

CAPS Team @ TUM

CDA Team @ TUM

QCT Team @ LRZ, moving to MQV/TUM

The Entire MQV Team: https://www.munich-quantum-valley.de/

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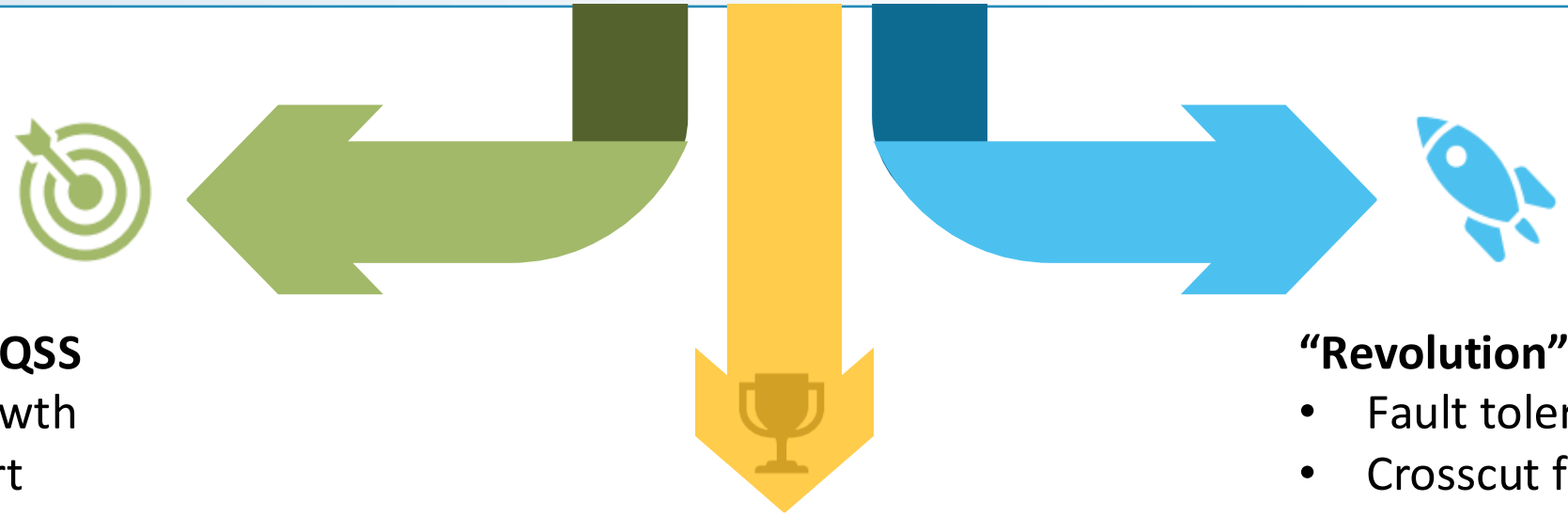
Looking Forward: Where Next for MQSS …

MQSS
Munich Quantum Software Stack



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CAPS HPCQC MQT

Enabling Quantum Acceleration in Hybrid HPCQC Workflows for NISQ and FTQC

MUNICH QUANTUM VALLEY MQV