Quantum Technologies at DESY

What are the present activities ? - What are the prospects ?

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HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

Quantum Technologies are the Future.

Quantum Technologies are one of the most ambitious technological goals of science today.

Quantum advantage: working on completely different principles than classic technology
→ potential to solve the challenges in our future projects
→ changing science research → maximizing the achievable success

QTs demand for a rethinking of our methods → pioneering work improves already our classical methods.

Worldwide: several extensive research programs, dedicated centers, large-scale research, supported by substantial funding programs on national, European and international level.

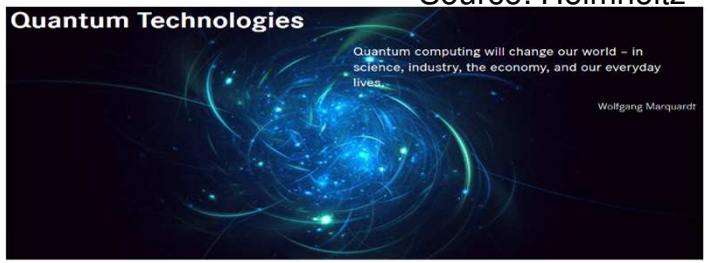
DESY: excellent scientific competences and facilities for R&D in QT
crucially complementary to the running research projects (as recognized by the Helmholtz QT Platform)
cross-cutting activities like QT are in DESY's DNA

→ unique pole position to drive the evolution and assume a leading role in dedicated QT topics.

Helmholtz: five primary active areas
https://www.helmholtz.de/en/research/quantum-technologies/

- **Quantum computing**
- **Simulation, numerical and ML methods**
- **Quantum sensors**
- **Quantum materials and basic research**
- **Quantum communication**

Source: Helmholtz



In addition, Helmholtz develops and operates powerful **infrastructures** for researching quantum technologies

Helmholtz Quantum Platform

Coordinate quantum technology activities within Helmholtz

Mandate and Tasks

- Update the developed roadmap Quantum Technologies
- Link researchers and management
- Organize workshops
- Provide input for communication with government

Present members :
Tommaso Calarco, FZJ (spokesperson), Georgy Astakhov, HZ Dresden,
Wolfgang Ertmer, Institute for Quantumoptics, U Hannover
Karl Jansen, DESY, Christoph Marquardt, DLR, Oliver Rader, U Potsdam
Ferdinand Schmidt-Kaler, U Mainz, Thomas Stoehlker, HZ Jena
Wolfgang Wernsdorfer, KIT, Sabine Attinger, UFZ

QT in POF:

- Cross – Cutting Activity , for example: MT DMA (ST-2) collaboration between Matter, Information and others (DESY, Jülich, DLR, HZDR, UFZ…)
- Quantum Materials are part of research in MML.
- Quantum Sensors are part of MT but likewise also in MU.

In general QTs are part of the enabling technologies and on the other hand part of applied technology in ambitious experiments.

https://www.helmholtz.de/fileadmin/user_upload/04_mediathek/21_Quantum_Strategy_Brochure_WEB.pdf

Quantum Technologies at DESY

Introduction

DESY has excellent competences in the areas of Quantum Technologies:

complementary activities presently concentrating in FH and in FS,
all divisions can greatly benefit, eg. computing for complex simulations, optimization challenges.

DESY has unique facilities

→ unique profile to drive evolution of QT and to play a leading role on the various levels.

Three initial pillars for QT topics at DESY

- **Development of quantum computing algorithms for applications**
- **Materials and photonics research and development towards a useful quantum computer**
- **Quantum sensors as evolving/enabling and also applied technology**

The DESY QT Taskforce

Members - FH, AP, FS, now also M

Present Members (reachable via email qt-task-force@desy.de)

Ilya Agapov(M), Martin Beye(FS), Kerstin Borras(FH),Volker Gülzow(IT-FH), Cigdem Issever(FH), Karl Jansen(FH), Dirk Krücker(FH), Kai Rossnagel(FS), Hubert Simma(FH), Steven Worm(AP), Klaus Ehret (DIB), Ilka Mahns (ITT)

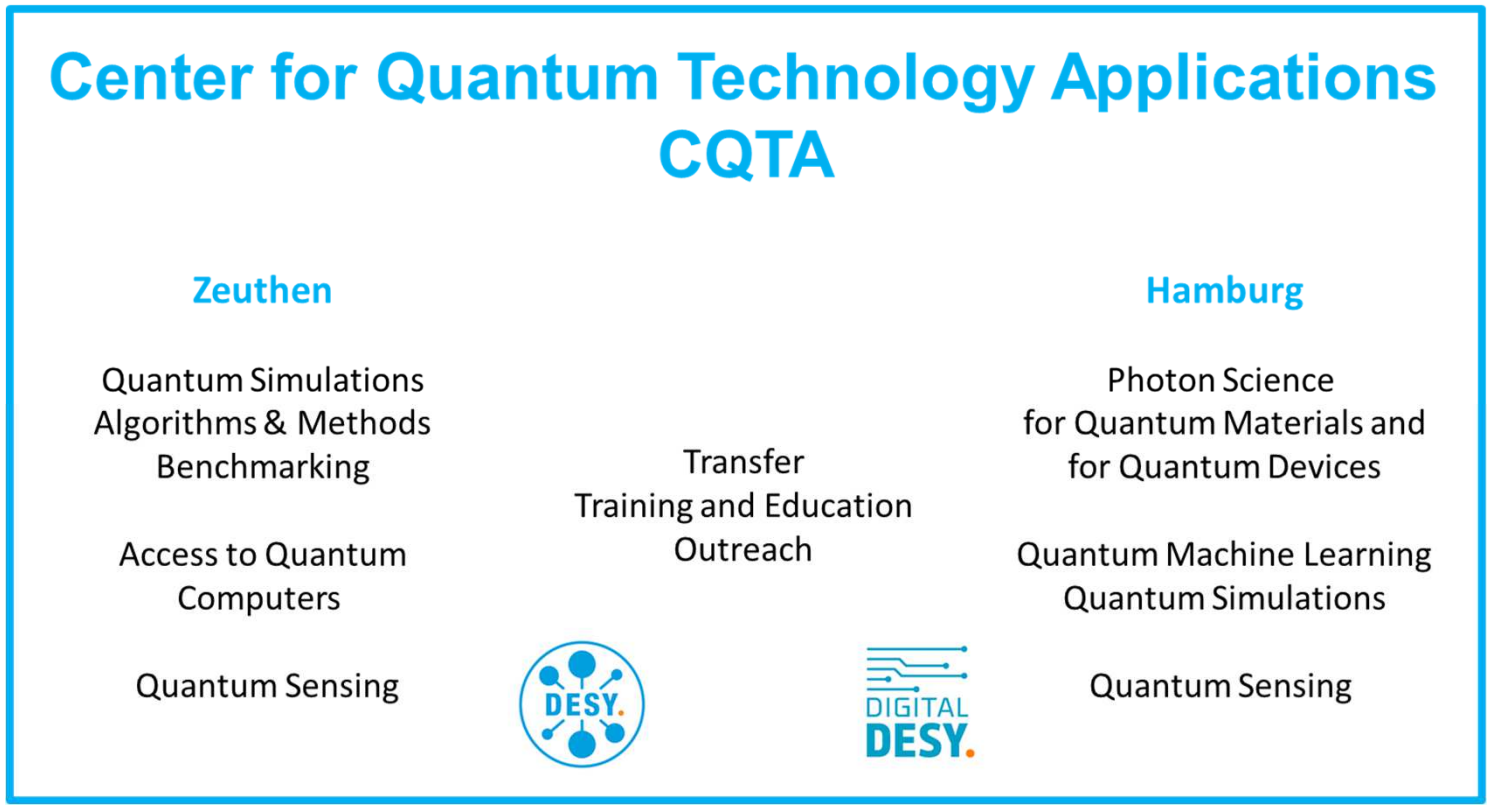
Mandate:

Evaluate the various topics of Quantum Technologies for DESY

- ✓ Assess and evaluate the opportunities for Quantum Technologies at DESY
- ✓ Identify running or planned QT activities on the whole DESY campus (Hamburg, Zeuthen, partner institutes and universities)
- Assess the importance of QT for all divisions at DESY, for example its relevance for PETRA IV, Particle Physics and beyond…
- Develop a vision for QT activities at DESY

Overarching Goal:

employ novel Quantum Technologies
to enhance and enable cutting-edge science in all divisions
→ DESY wide organization with Campus wide partners



This structure necessary to

- enable synergetic participation of all division and potential campus partners,
- become visible as a competence center for QT and ist applications

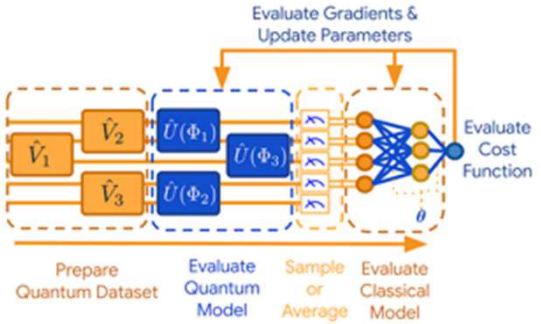
→ enhanced chances in the competition for funding resources on national and international level.

Current activities in FH and AP

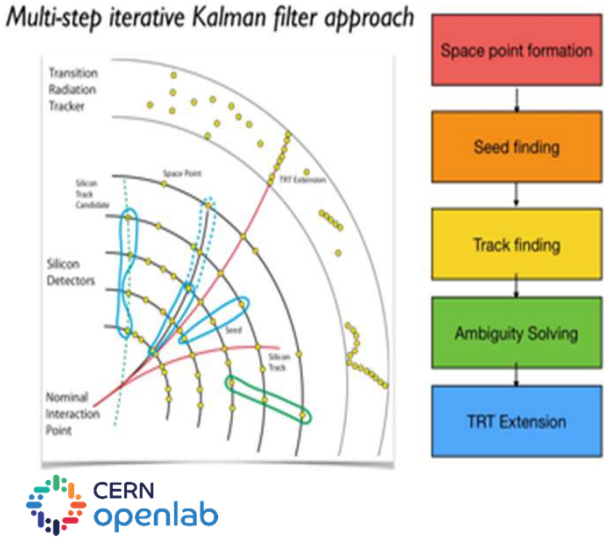
Quantum Computing and Quantum Sensors

Ongoing projects

- Develop algorithms and methods in Theoretical Particle Physics
  - Calculations in Lattice Gauge Theory → frequently demanded by companies to test their novel devices
  - Application to models in high energy and condensed matter physics and others for example flight gate assignment from DLR
  - Error mitigation in QC calculations (DASHH PhD)
- Quantum computing to cope with the vast amount of simulations (HL LHC)
  - Develop machine learning and tensor network methods for QC
    Q-GAN simulations for detectors (CERN Openlab Gentner PhD),
    Tracking,
    Anomaly detection, e.g. in Dark Matter search
- Explore, develop and apply quantum sensors and electronics in particle and astro-particle physics experiments and beyond
  Established contacts to other Helmholtz Centers and EU wide projects



Source: https://ai.googleblog.com/2020/03/announcing-tensorflow-quantum-open.html



CERN openlab

Any Questions ?

DESY QT Taskforce reachable via **qt-task-force@desy.de**

Interested ? → Sign-up in this common email list **quantum-technologies@desy.de**

Embedding into the Structure of DESY and Helmholtz

- Quantum Computing and Applications:
  → naturally embedded in **Scientific Computing**
- **Photon Science** for Quantum Materials and for Quantum Computers
  → from fundamental understanding of quantum phenomena in materials to the development of tailor-made materials for quantum technology devices, including innovative qubit systems
  →DESY light sources: uniquely powerful quantum tools, PETRA IV: ultimate multi-D quantum microscope
- Quantum Sensing:
  → evolving and enabling technology
  → part of **genuine detector R&D as well as applied** in already operating experiments like ALPS
- All three areas are connected to **Digital DESY** in different ways: QCing as part of SciComp, QSensing for detector R&D (also potential for robotics and autonomous accelerators), novel QMaterials for novel devices
- **Helmholtz QT Roadmap** includes crucial ingredients contributed by DESY and its unique facilities.
- Structure of the CQTA: Three Fora: (QCing, QMaterials, QSensing), Steering Board, Advisory Board, **International and National Networking**, **Transfer**, **Training** and **Outreach** (in backup)

Presently ongoing projects exploring Quantum Technologies

Experimental Methods:

- FH: Gentner-PhD: K.Borras, D.Krücker, CERN Openlab: Simulation of a calorimetric detector
- FH: InnoPool-LUXE: B.Heinemann, K.Jansen: QC for tracking in LUXE
- FH: InnoPool-ACCLAIM: F.Gaede, D.Krücker et al: Exploration of QC
- FH: ENGAGE: K.Borras, C.Issever, K.Jansen, D.Krücker
  MSCA Co-Fund for PhD Training, three different topics
- M: Idea: Quantum Machine Learning for particle beam dynamics

Error Mitigation:

- FH: K.Jansen et al: Method for Error Mitigation
- FH: DASHH - PhD: M.Riebisch (UHH), K.Jansen, K.Borras, D.Krücker: Error Mitigation with modelling methods from software engineering
- FH: InnoPool-VQCS: K.Jansen, C.Issever, K.Borras, D.Krücker:
- Variational Quantum Computer Simulations for complex quantum systems and optimization problems, error mitigation

Quantum Circuit Expressivity:

- FH: K. Jansen et al: Optimizing Quantum Circuits

Photon Science Facilities for Quantum Materials and Quantum Computer Technologies

- FS: K.Rossnagel, M.Beye: Scientific challenges and photon science opportunities for various Quantum Computer technologies
- FS: InnoPool-MaDQuanT: M.Beye et al: Materials and Dynamics for Future Quantum Computers

Quantum Sensing:

- FH: S.Worm et al: Transition Edge Sensor (TES) for ALPS II
- FH/AP: S.Worm: Search for ultra-light Dark Matter using Quantum Sensors
- AP: S.Worm et al: TES-based high-resolution, high-speed spectrophotometers
- FS: R. Röhlsberger, H. Chapman, I. Vartaniants: X-ray Quantum Imaging

Ideas for Quantum Computers and Quantum Simulators:

- FS/FH: K. Jansen, R.Röhlsberger: One-way Quantum Computing
- FS: FOQUS: F.Kärtner: Fiber Optic Quantum Simulation