Quantum Technology Initiative

QUANTUM
TECHNOLOGY
INITIATIVE

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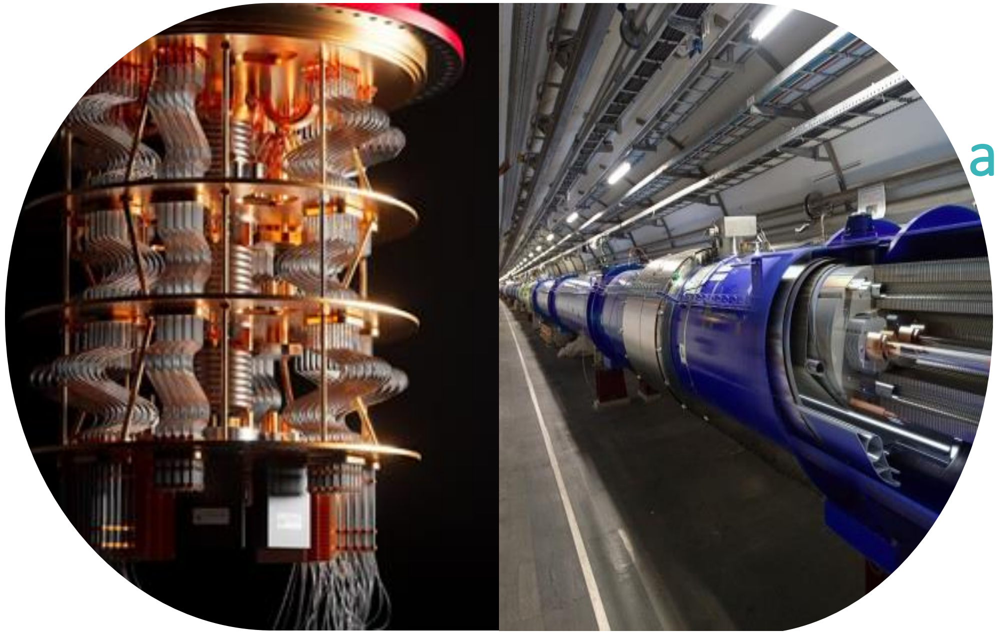
CERN QTI Coordinator

Why a Quantum Technology Initiative at CERN ?

How can future **quantum technologies** contribute to CERN's scientific mission?



How can **CERN's technologies and expertise** contribute to the quantum revolution?

Build expertise through collaborations

CERN Quantum Technology Initiative launched in 2020

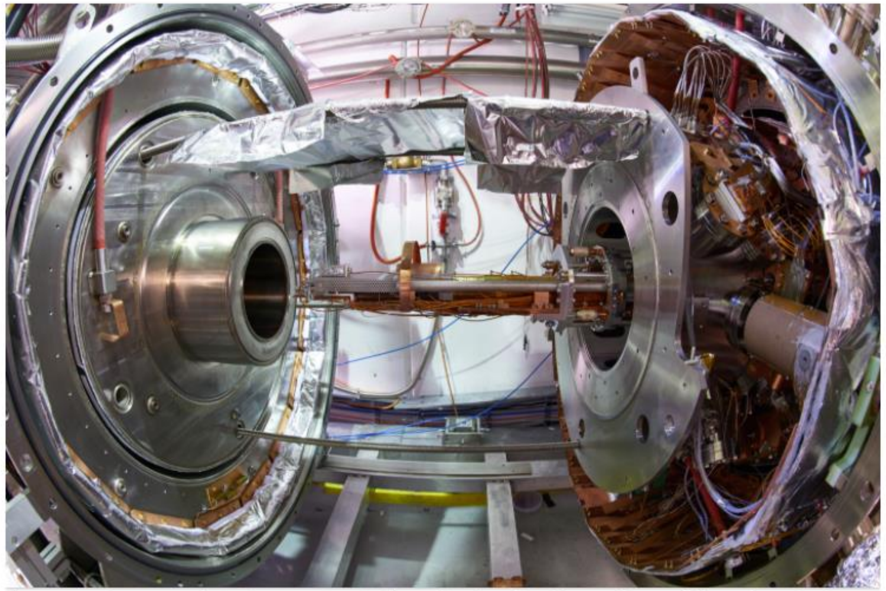
- **Quantum Technologies** can be revolutionary but require **a high level of expertise**
- **A large number of initiatives** exists in the Member States and beyond
- After an initial **exploratory phase** 2020-2023, Phase 2 started in 2024:
- We are developing a **coherent research plan** that can evolve into a **long term strategy** aligned with CERN research program

Voir en français

CERN meets quantum technology

The CERN Quantum Technology Initiative will explore the potential of devices harnessing perplexing quantum phenomena such as entanglement to enrich and expand its challenging research programme

30 SEPTEMBER, 2020 | By Matthew Chalmers

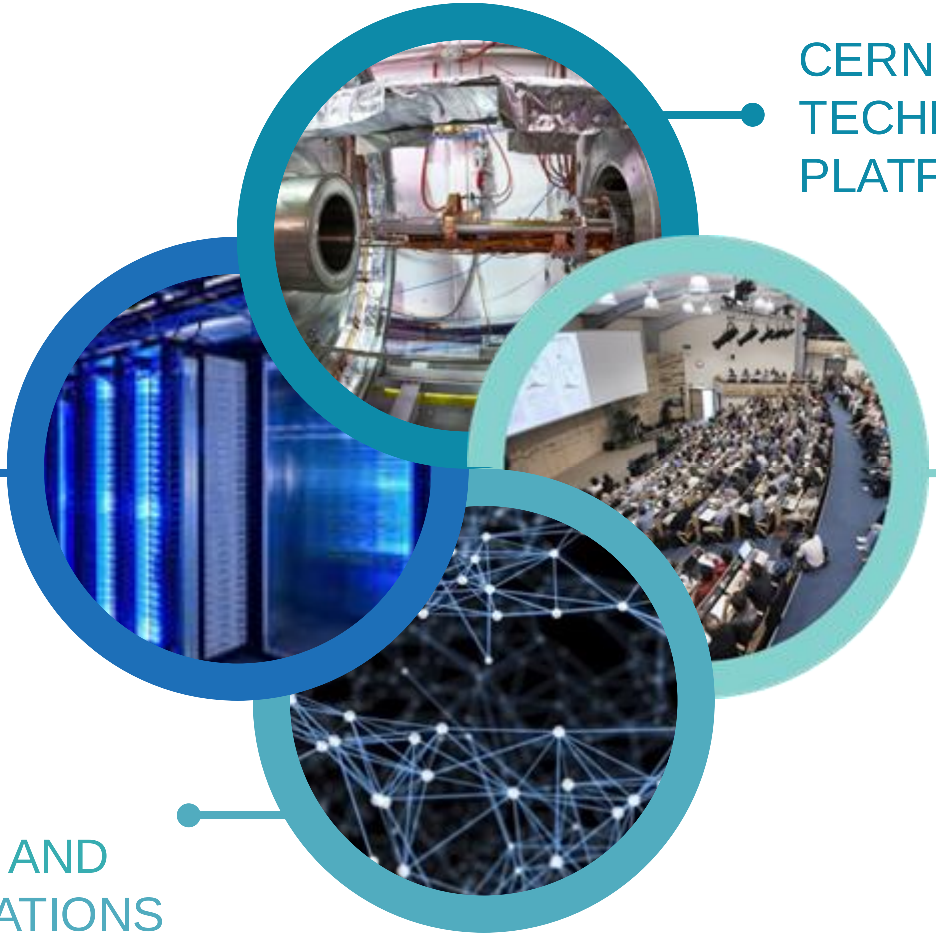


The AEgIS 1T antimatter trap stack. CERN's AEgIS experiment is able to explore the multi-particle entangled nature of photons from positronium annihilation, and is one of several examples of existing CERN research with relevance to quantum technologies. (Image: CERN)

https://quantum.cern

CERN QTI Phase 2

Launched January 2024



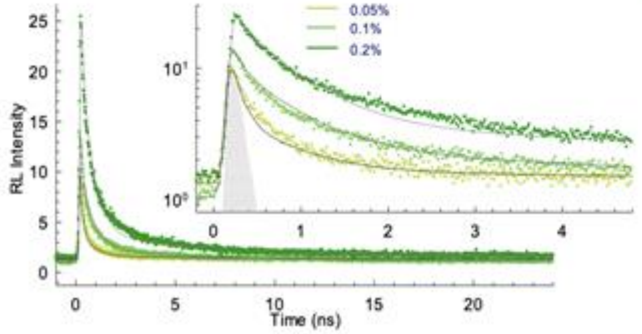
QUANTUM TECHNOLOGY INITIATIVE

A 5 years research plan

QTI Results contribute to CERN program

QTI Areas		CERN Program
Quantum Sensing	⟷	**Accelerators** Technologies and **Future Detectors** R&D
Quantum Simulation	⟷	Theory, **Physics Beyond Colliders**
Quantum Computing	⟷	**Scientific Computing**: Algorithms, Distributed Computing
Quantum Communication	⟷	

Major QTI results



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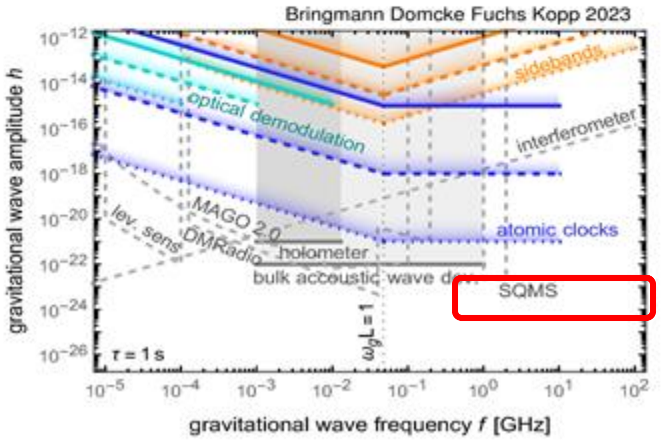
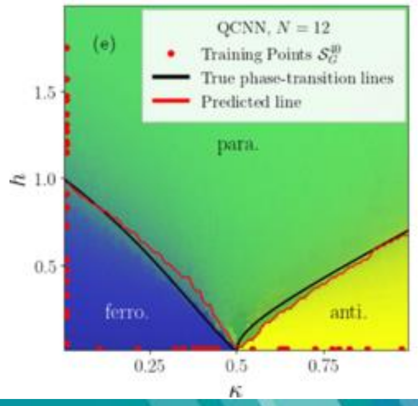




Monaco, S. et al. "**Quantum phase detection generalization from marginal quantum neural network models.**" *Physical Review B* 107.8 (2023): L081105.

Our objectives

Integrate quantum computers within HEP computing model

Make CERN a node of the future European network infrastructure

Play a major role in the development of next generation detectors for fundamental physics

Join the broader quantum ecosystem to multiply impact

QTI Phase 2 Objectives: Quantum Networks

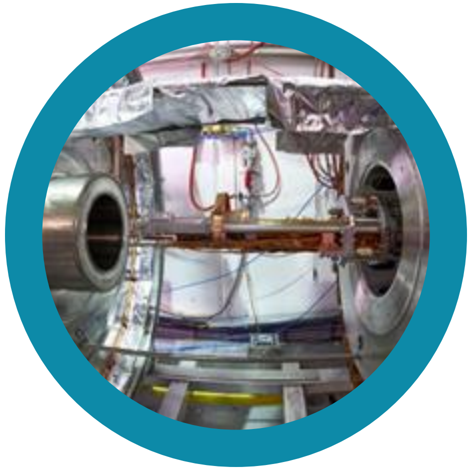
QUANTUM NETWORKS AND COMMUNICATIONS

Make CERN a major node into a distributed network infrastructure for future experiments (discussion ongoing with DRD11)

- Contribute with CERN technology to the implementation of the most novel quantum network/communications protocols
- Contribute to the deployment **of time and frequency distribution infrastructure** and further development of relevant technology.

White Rabbit COLLABORATION

QTI Phase 2 Objectives: Quantum Technology Platforms



CERN QUANTUM TECHNOLOGY PLATFORMS

Play a major role in the development of next generation detectors (QTI is the mechanism for CERN contribution to DRD5)

- Develop quantum sensors to provide new capabilities for particle physics research
- Co-develop applications in quantum technologies (computing, sensing)
- Focus areas: Superconducting RF cavities, hydrogen-like Rydberg ions, and Transition Edge Sensors

CERN has broad expertise and experimental facilities in many areas (superconducting materials, magnets, radiation effects, cryogenics, controls etc.)

QTI Phase 2 Objectives: Hybrid Quantum Computing and Algorithms

HYBRID QUANTUM COMPUTING AND ALGORITHMS

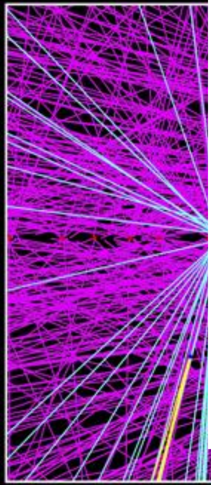
Sustain integration of quantum accelerators within HEP computing model, making sure that infrastructure supports it

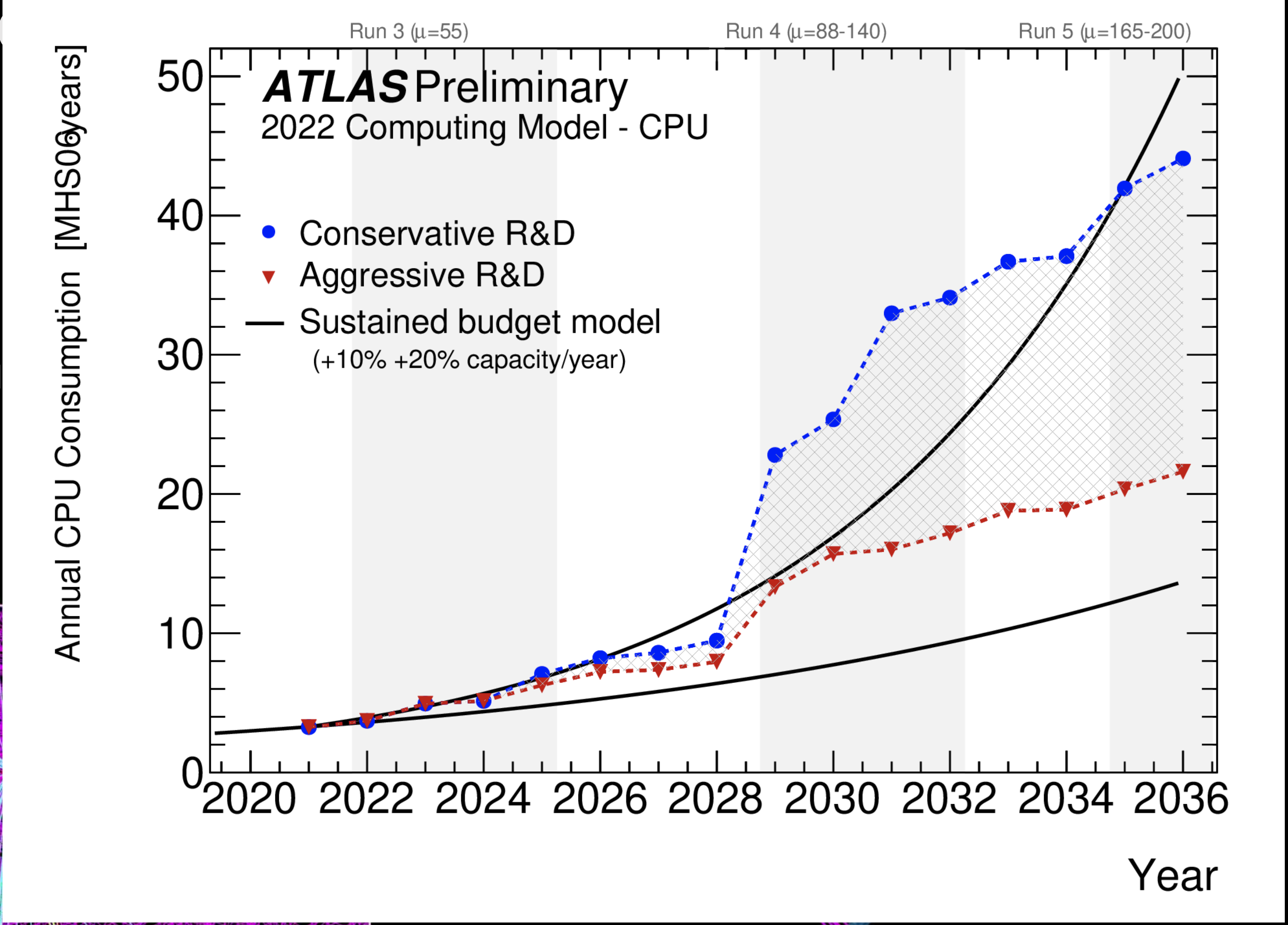
- Develop algorithms with a focus on distributed hybrid computing and Quantum Machine Learning
- Achieve a robust understanding of the performance and optimal use of the (near-term) quantum infrastructure
- Provide use-cases for quantum algorithms and quantum computers in hybrid setups (HPC+ QC, …)

Most of these developments are common to areas beyond HEP

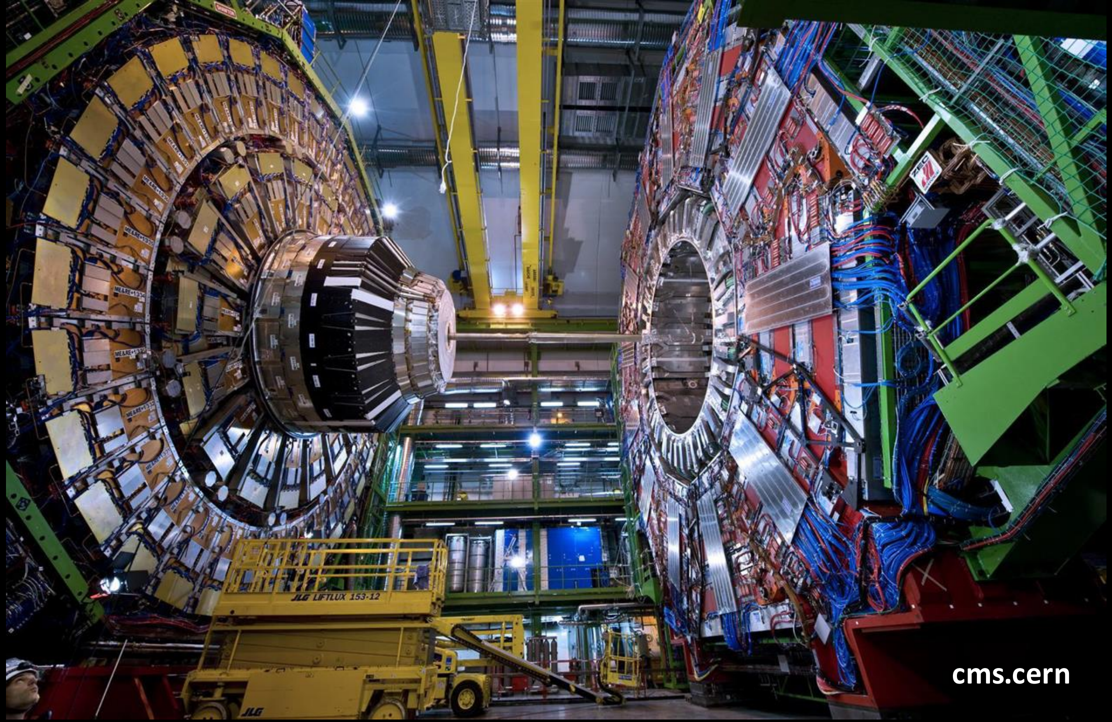
HL-LHC: The

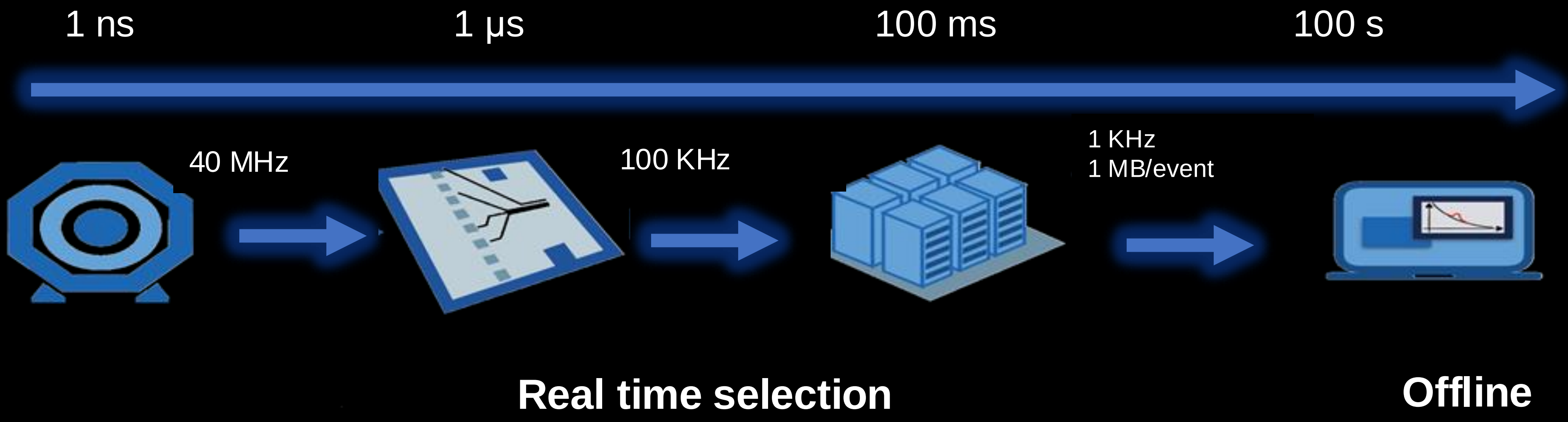
200 simultaneou
collisions!





Complex data processing pipeline





QC @CERN

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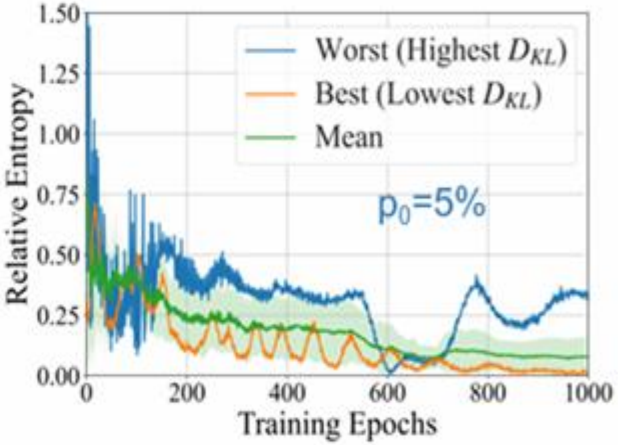

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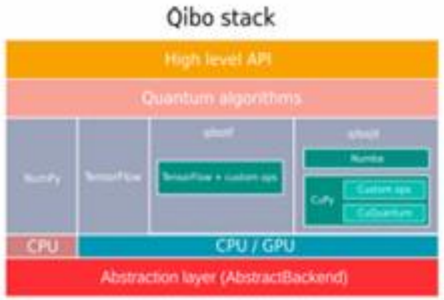

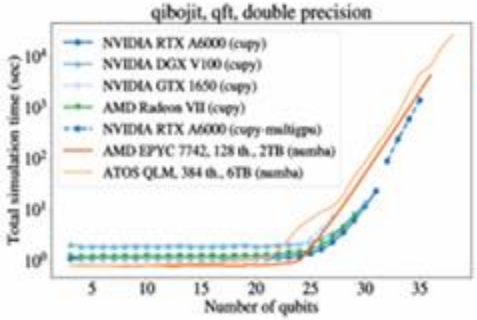

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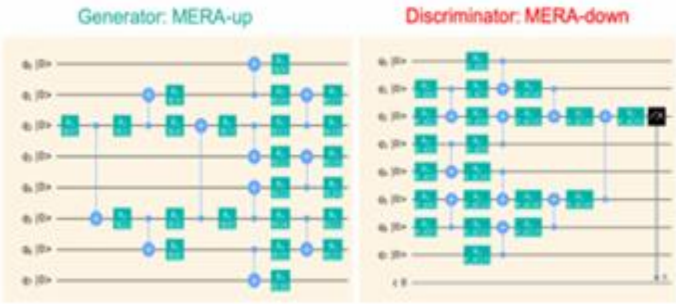

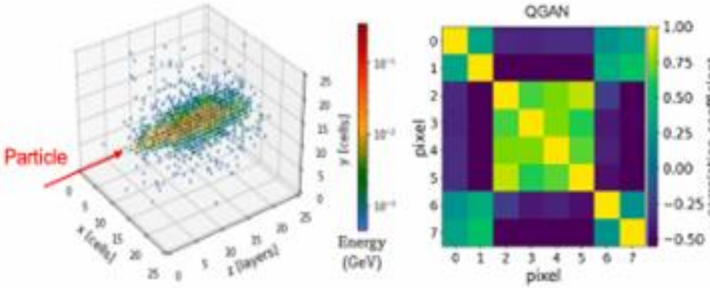

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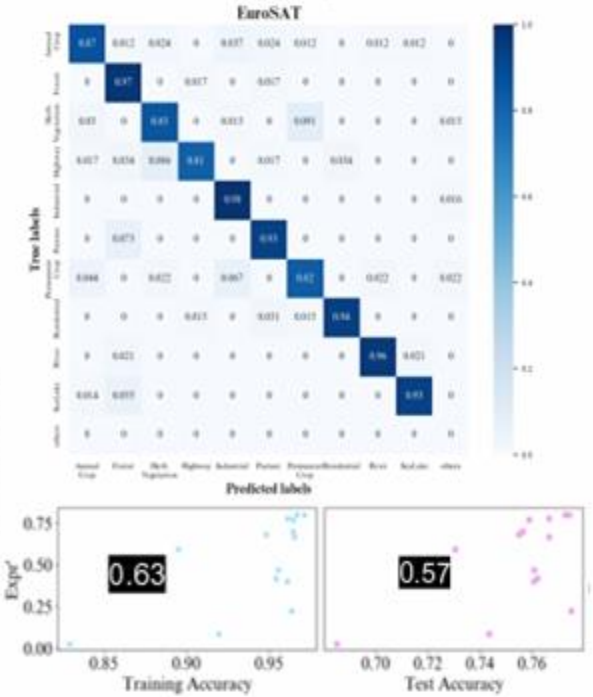

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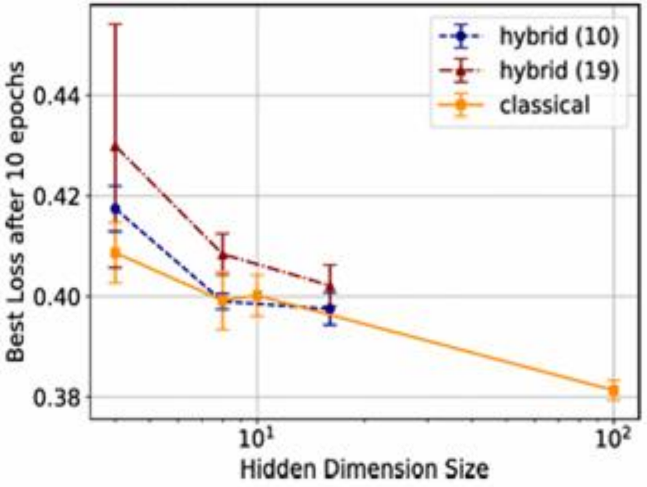

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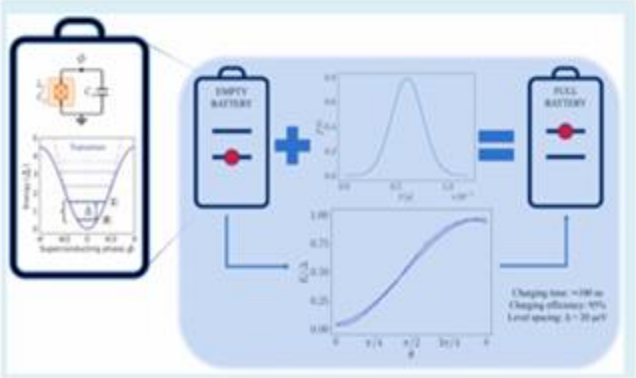

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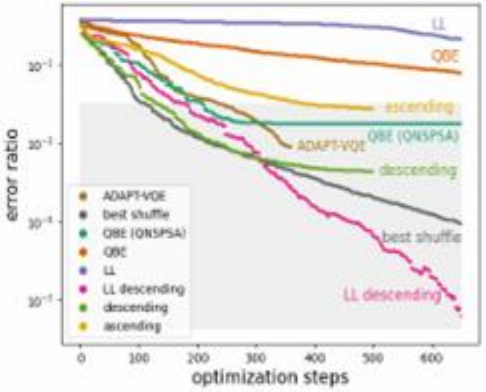

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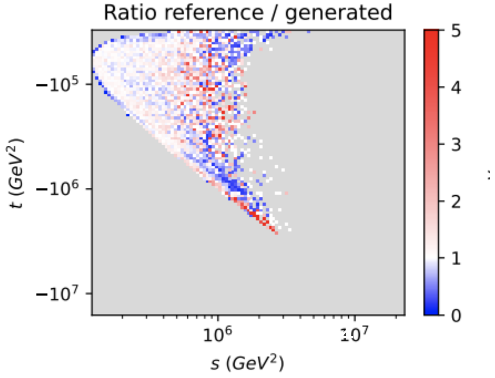
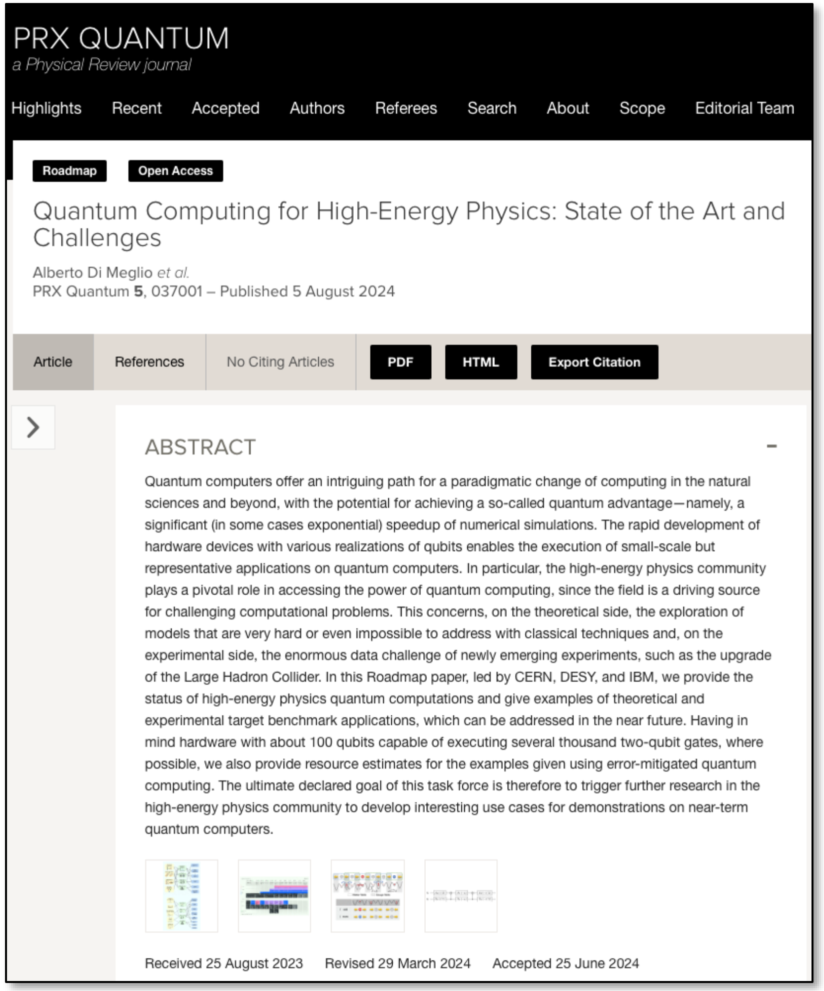


Foster a expert community studying usability of Quantum Computing for HEP

Di Meglio, A. , *et al*. **Quantum Computing for High-Energy Physics: State of the Art and Challenges**. *PRX Quantum* 5.3 (2024): 037001.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Quantum Computing for High-Energy Physics: State of the Art and Challenges

Alberto Di Meglio *et al.*
PRX Quantum **5**, 037001 – Published 5 August 2024

Article References No Citing Articles PDF HTML Export Citation

ABSTRACT

Quantum computers offer an intriguing path for a paradigmatic change of computing in the natural sciences and beyond, with the potential for achieving a so-called quantum advantage—namely, a significant (in some cases exponential) speedup of numerical simulations. The rapid development of hardware devices with various realizations of qubits enables the execution of small-scale but representative applications on quantum computers. In particular, the high-energy physics community plays a pivotal role in accessing the power of quantum computing, since the field is a driving source for challenging computational problems. This concerns, on the theoretical side, the exploration of models that are very hard or even impossible to address with classical techniques and, on the experimental side, the enormous data challenge of newly emerging experiments, such as the upgrade of the Large Hadron Collider. In this Roadmap paper, led by CERN, DESY, and IBM, we provide the status of high-energy physics quantum computations and give examples of theoretical and experimental target benchmark applications, which can be addressed in the near future. Having in mind hardware with about 100 qubits capable of executing several thousand two-qubit gates, where possible, we also provide resource estimates for the examples given using error-mitigated quantum computing. The ultimate declared goal of this task force is therefore to trigger further research in the high-energy physics community to develop interesting use cases for demonstrations on near-term quantum computers.

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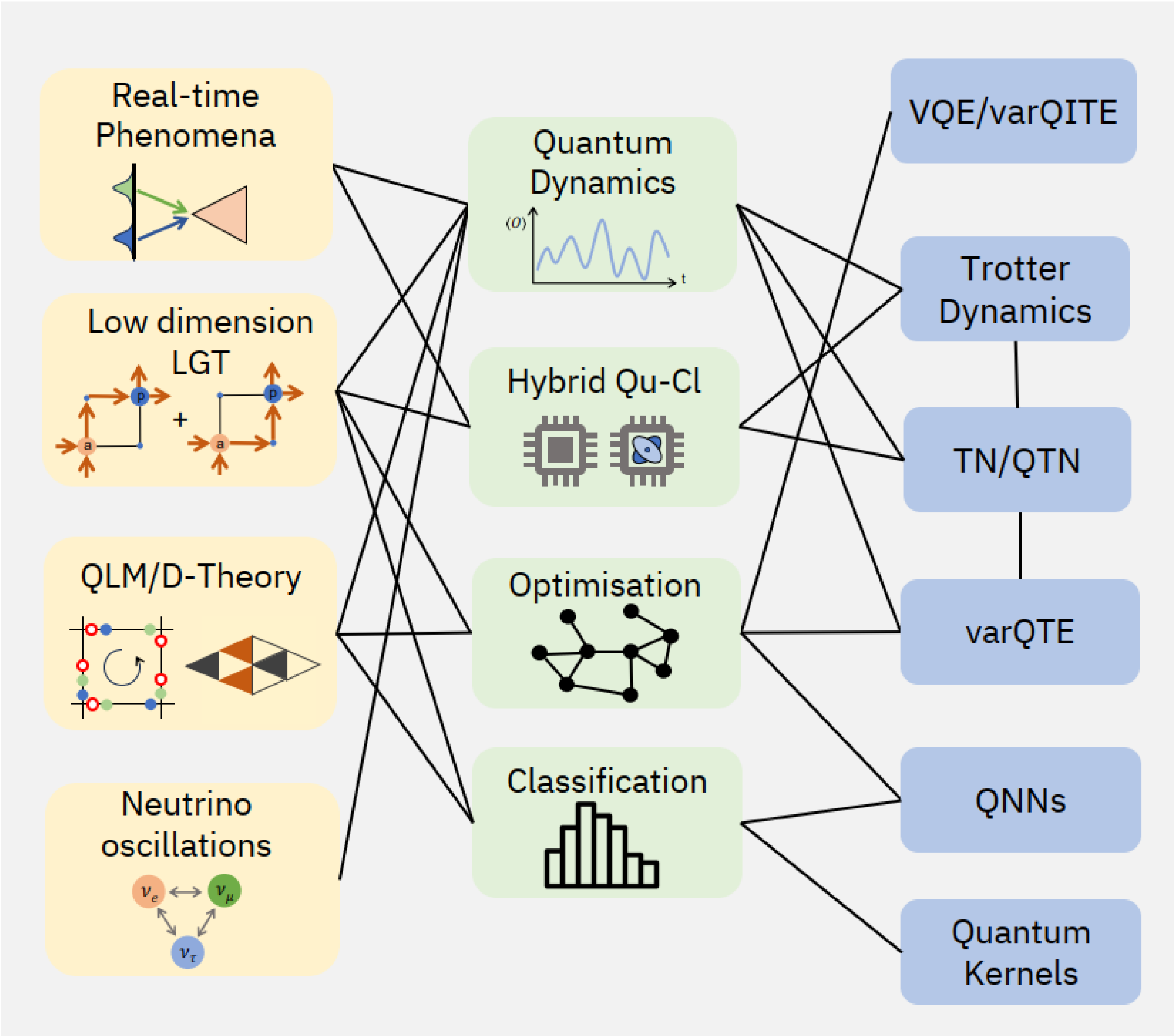
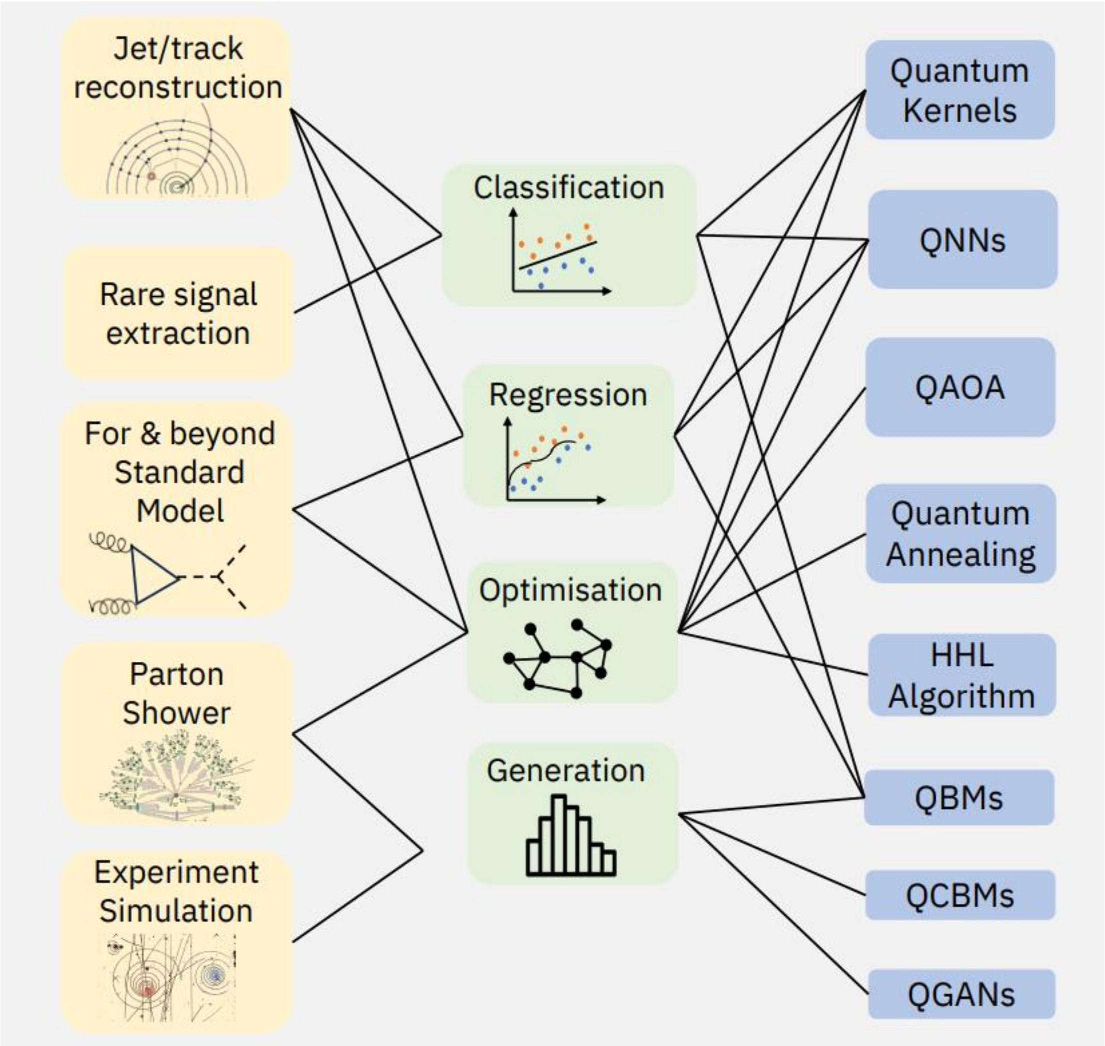
- **Lead the creation of a new community of experts** from the Member States and beyond
- Focus on **concrete challenges of QC for HEP**
- **White Paper** on a realistic roadmap in experimental and theoretical physics → **a seminal paper!**
- Growing impact through increasing **links with different initiatives (Snowmass, …)**
- A number of practical examples of joint projects

CERN IBM DESY.

From the QC4HEO white paper:





QTI Phase 2 Objectives: Collaborations

COLLABORATION
FOR IMPACT

Integrate CERN in the broader Quantum ecosystem to multiply impact

- The **Knowledge Transfer Group** is essential to:
  - Explore co-innovation opportunities with external partners
  - Establish co-development partnerships with companies, institutes and other entities.
- The **Open Quantum Institute** for societal impact

A wide range of collaborations

Organizations and Projects

QuantHEP
QUANTUM FLAGSHIP
esa
gesda
ECFA European Committee for
European Strategy Update
Snowmass 2021

Industry

Google
IBM
IBM Q-Net
intel
aws
Amazon Braket
Microsoft
Xanadu
Atos
PASQAL
QUANTINUUM
IDQ
QUANTUM MACHINES

Academia, Research Labs and Agencies

DESY.
EPFL
ETH zürich
UK NATIONAL QUANTUM TECHNOLOGIES PROGRAMME
UNIVERSITY OF OXFORD
lrz
TUM
Universidad de Oviedo
wigner
cnrs IN2P3
iit ISTITUTO ITALIANO DI TECNOLOGIA
QuTech
Fermilab
OAK RIDGE National Laboratory
PORTUGUESE QUANTUM INSTITUTE
CEFEMA
INFN Istituto Nazionale di Fisica Nucleare
qplaylearn
ICEPP
Brookhaven National Laboratory

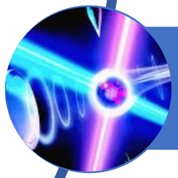
The QTI Hub: A collaboration framework for QTI

The QTI Hub creates a community of partners investigating the different areas of quantum technologies.

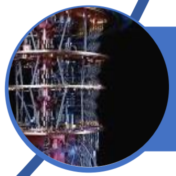
Enable **access to diverse quantum technology and services**

Provide a **unified framework for all collaborative projects** QTI is setting up with multiple partners.

Establish a clear **separation between commercial relationships and R&D collaborations**



Facilitate follow-up and ensure **more efficient coordination of projects** also across departments.



Allow for **multiples approaches to IP protection** according to CERN policies.

Open Quantum Institute (OQI)

Value of OQI at CERN

- Driving values of **inclusivity, global scope, openness, focus on impact**, and fostering collaborations
- Leveraging QTI's mission to explore the **full potential of quantum technologies** and maximise their societal impact
- Strengthening CERN's profile as a scientific institution **addressing society's pressing challenges**

The work of OQI

- The OQI Advisory Committee is formed of 34 members from **industry, academia and diplomacy**, providing strategic input to the OQI team to achieve the goals of OQI
- **Partnership and membership agreements** modelled on CERN openlab, the experiments and open science
- OQI's coordination team formed of **CERN staff, graduates, GESDA staff**, complemented by mandated experts from other locations

Thanks

Questions?