The CERN Quantum Technology Initiative

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CERN QTI Coordinator

QUANTUM TECHNOLOGY INITIATIVE

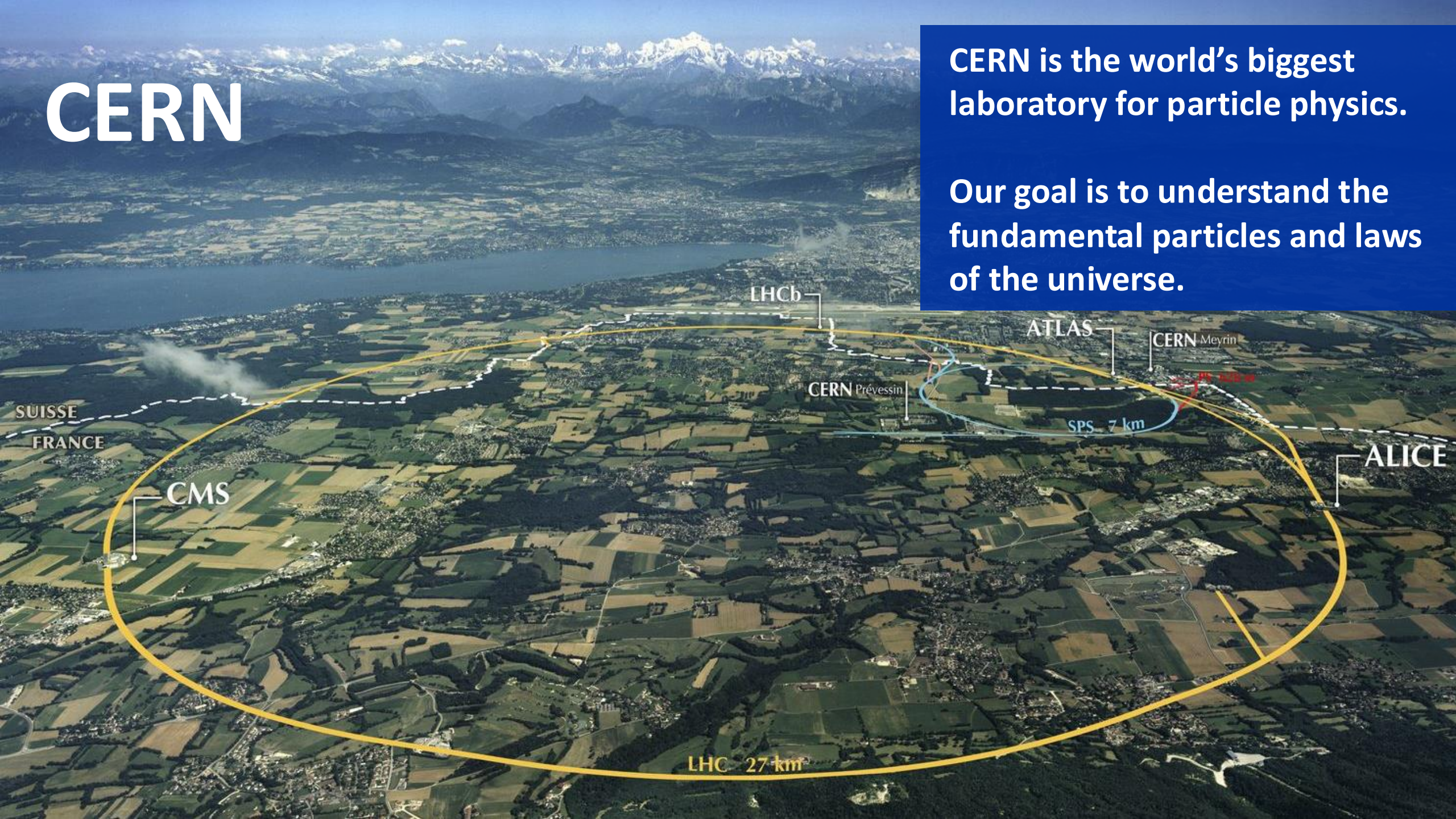
November 25th, 2025


WELCOME TO CERN!

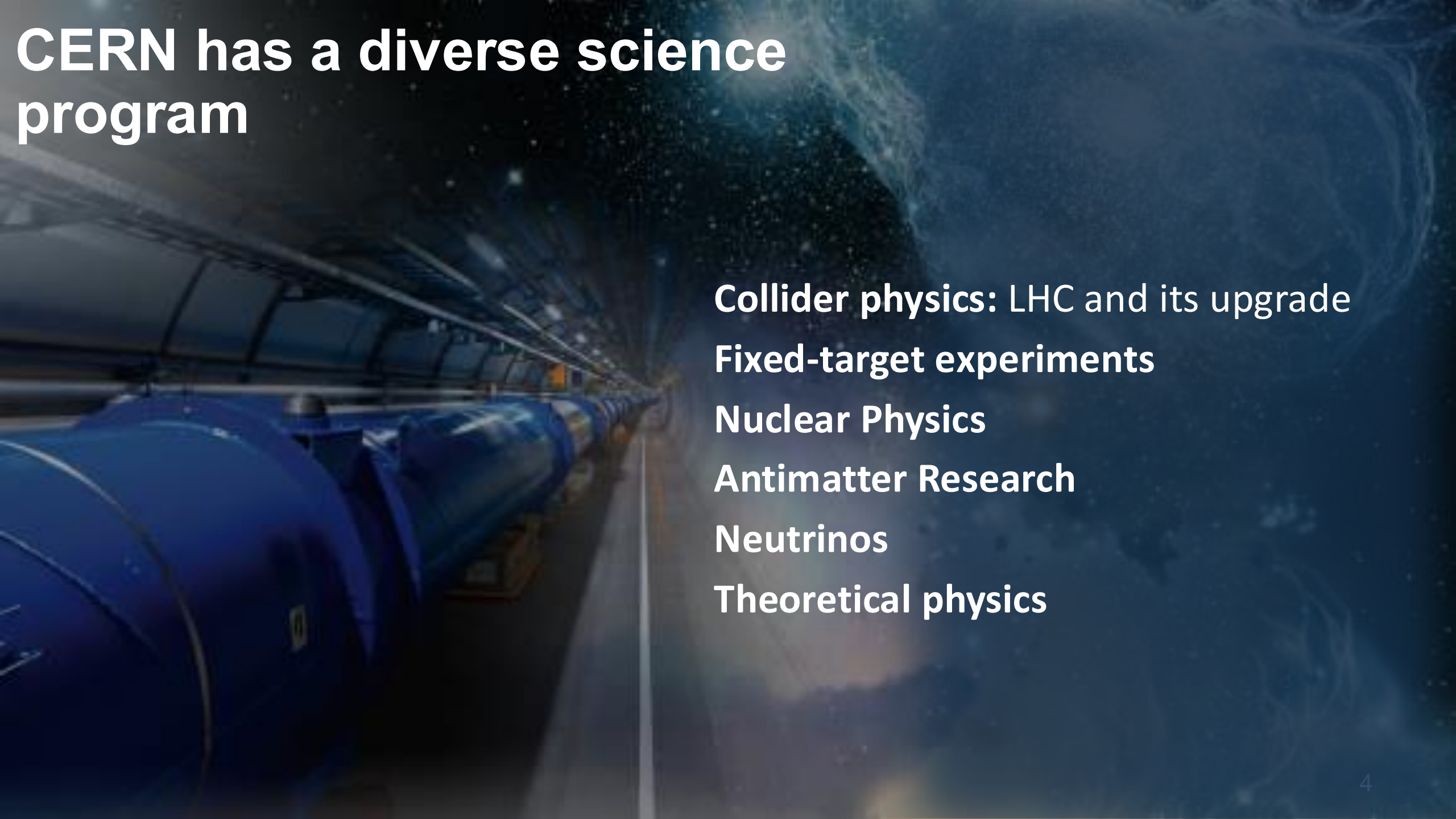
CERN

CERN is the world's biggest laboratory for particle physics.

Our goal is to understand the fundamental particles and laws of the universe.



CERN has a diverse science program



Collider physics: LHC and its upgrade

Fixed-target experiments

Nuclear Physics

Antimatter Research

Neutrinos

Theoretical physics

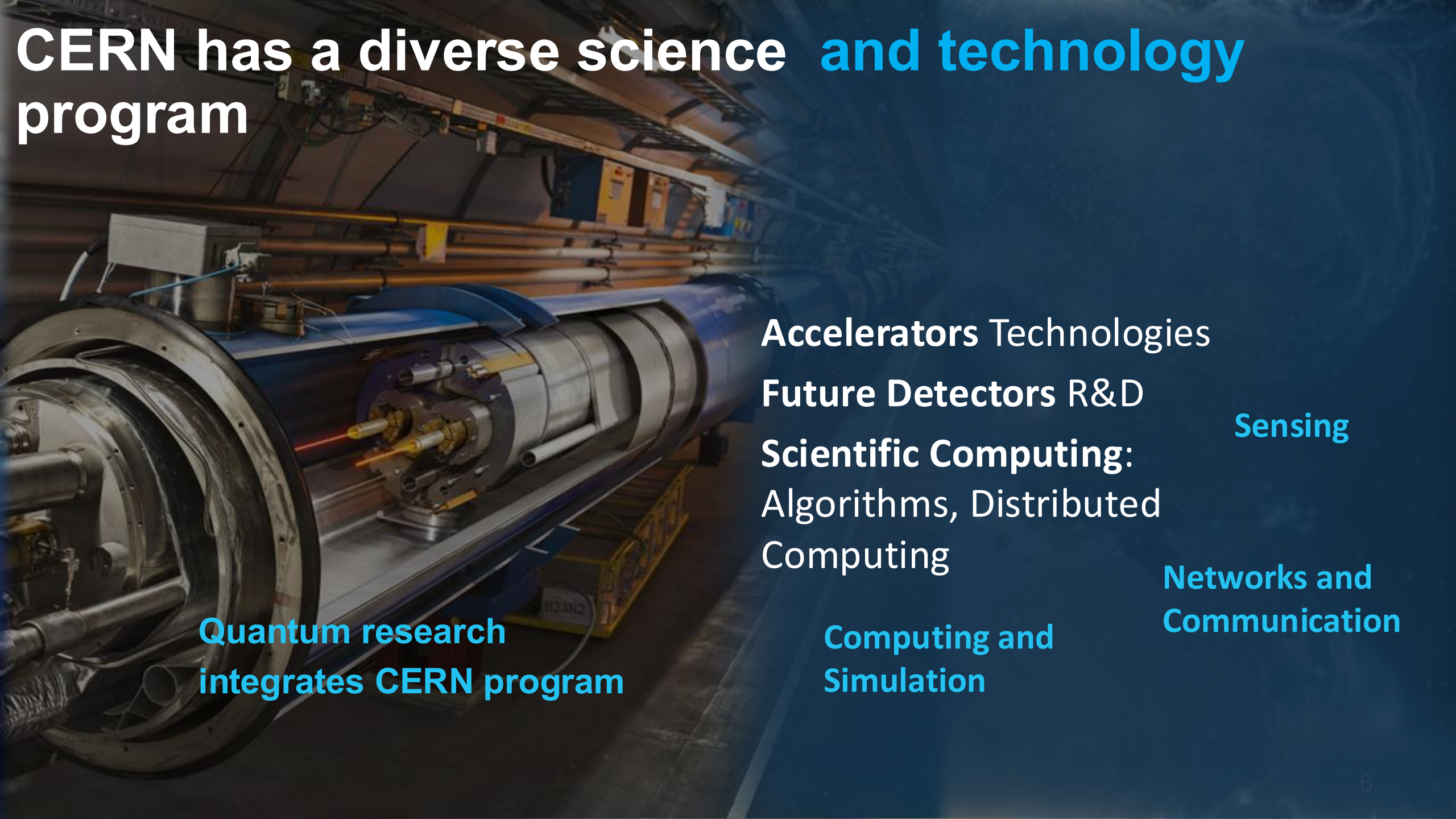
CERN has a diverse science and technology program

Accelerators Technologies

Future Detectors R&D

Scientific Computing: Algorithms, Distributed Computing

CERN has a diverse science and technology program



Accelerators Technologies

Future Detectors R&D

Scientific Computing: Algorithms, Distributed Computing

Sensing

Networks and Communication

Computing and Simulation

Quantum research integrates CERN program

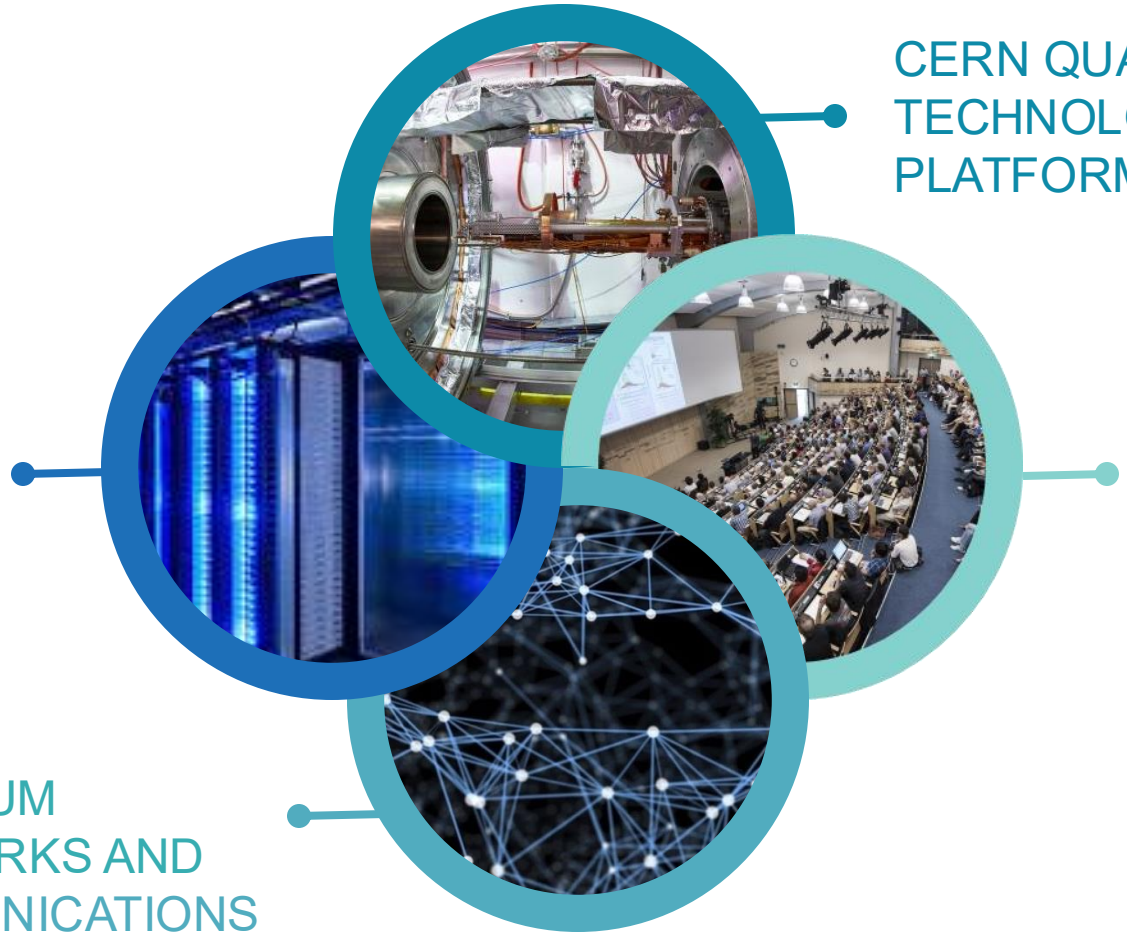
Why a Quantum Technology Initiative at CERN ?

To understand how future quantum technologies contribute to CERN's scientific mission

To evaluate how CERN's technologies and expertise contribute to the quantum revolution

The CERN Quantum Technology Initiative

Launched in 2020



CERN QUANTUM TECHNOLOGY PLATFORMS

HYBRID QUANTUM COMPUTING AND ALGORITHMS

COLLABORATION FOR IMPACT

QUANTUM NETWORKS AND COMMUNICATIONS

Quantum Sensors to detect new physics

Part of a broader effort lead by European Committee on Future Accelerator
DRD5 Collaboration on Quantum Sensing

Drive the development of quantum sensors for next generation detectors

- Superconducting RF cavities
- Exotic atoms
- Atom interferometry
- Superconducting Nanowire Single Photon Detectors (SNSPD)
- Quantum Dots

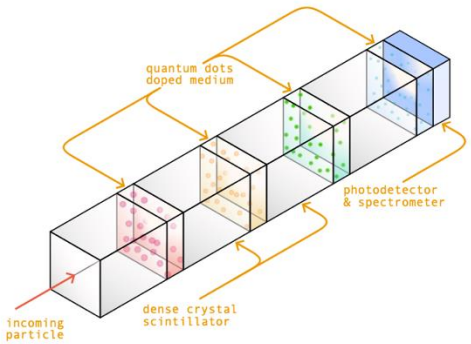
Search for evidence of new physics:

- Physics Beyond Colliders
  - Gravitational waves
  - Dark Matter, Axions, …
- Colliders Physics (High Energy)

https://www.ligo.caltech.edu/page/what-are-gw. **Image credit: LIGO/T. Pyle**

Examples along multiple directions

Optimizing technologies for HEP



Quantum Dot Based Chromatic Calorimetry: A proposal

Yacine Haddad,[1,*] Devanshi Arora,[2] Etiennette Auffray,[3]
Michael Doser,[3] Matteo Salomoni,[4] and Michele Weber[5]

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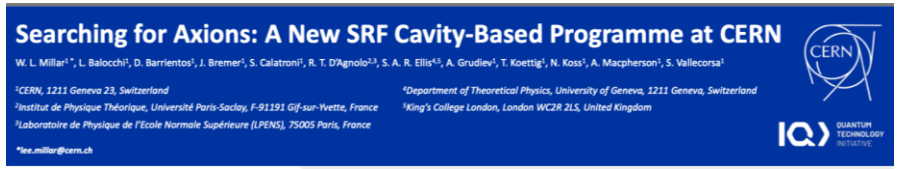
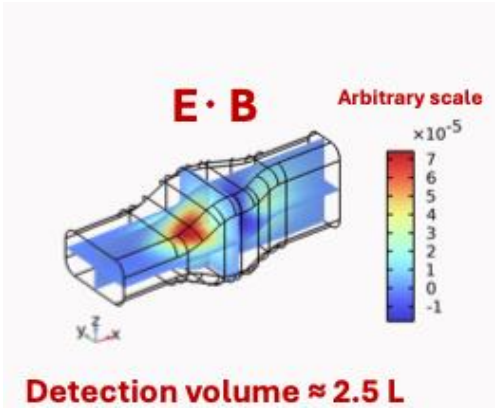
[5] *University of Bern, CH-3012 Bern, Switzerland*

Designing new solutions





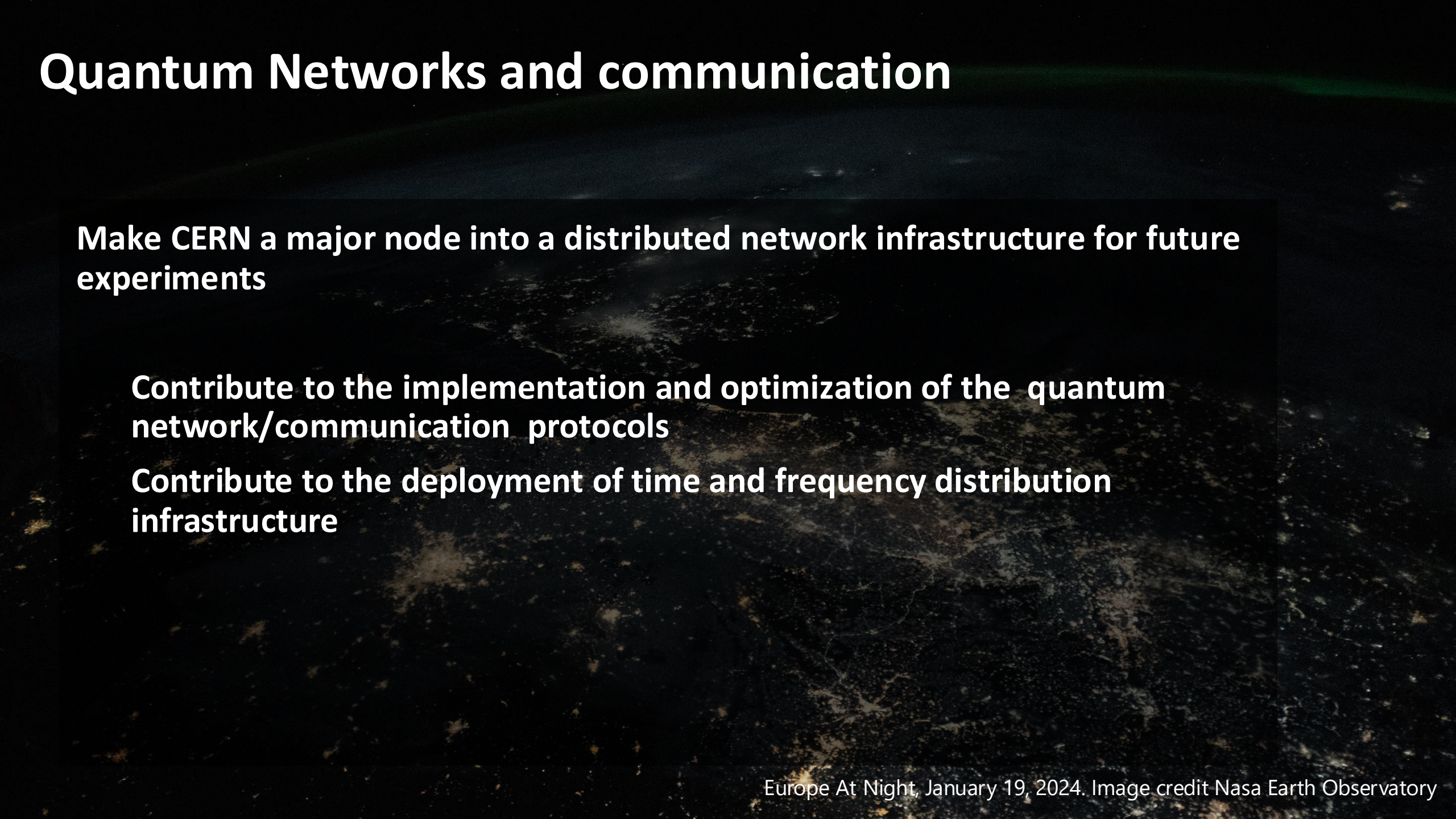
Common infrastructure and shared knowledge

- CERN vacuum expertise to develop quantum computers
- Cryogenics test beam facility for quantum sensors in radiation hard environment
- …

Quantum Networks and communication

Make CERN a major node into a distributed network infrastructure for future experiments

- **Contribute to the implementation and optimization of the quantum network/communication protocols**
- **Contribute to the deployment of time and frequency distribution infrastructure**



Europe At Night, January 19, 2024. Image credit Nasa Earth Observatory

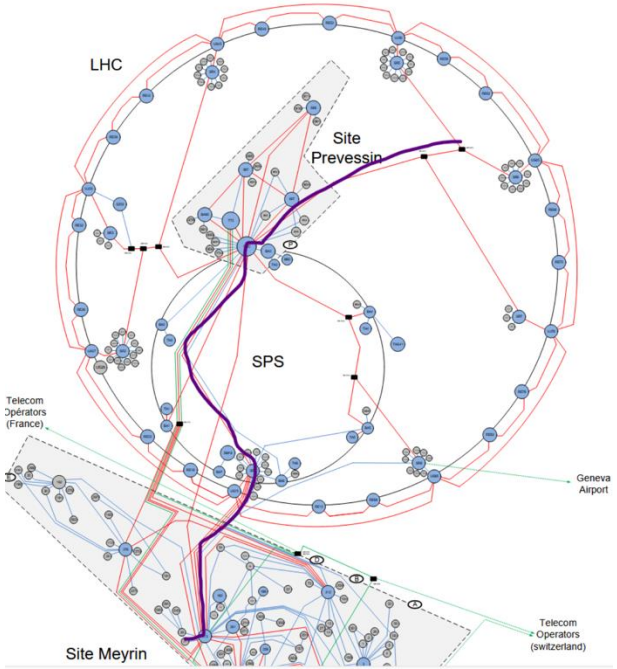
White Rabbit technology for time synchronisation

White Rabbit COLLABORATION

Initially meant for **CERN accelerator complex.** Provides **sub-ns synchronisation**

Open Source and commercially available. **A worldwide collaboration**

White Rabbit for quantum communications



29.5km multiplexed quantum communication link across CERN

White Rabbit for quantum computing

Collaboration with NuQuantum for **enabling data centre-scale quantum computing networks**

nu QUANTUM

Hybrid Quantum Computing

Sustain integration of quantum computing within HEP computing model

- Understand the performance of near-term quantum infrastructure in hybrid setups (HPC + QC, ..)
- Study scaling toward fault tolerant

→ Theoretical characterization of quantum algorithms

→ Applications to HEP

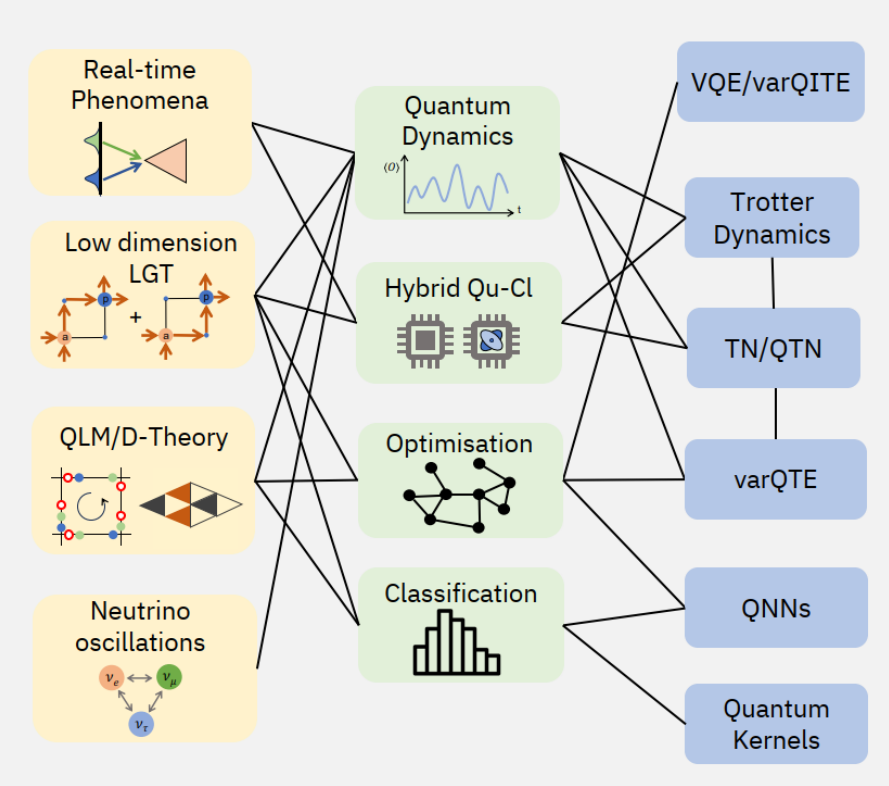
→ Practical usability of quantum computers

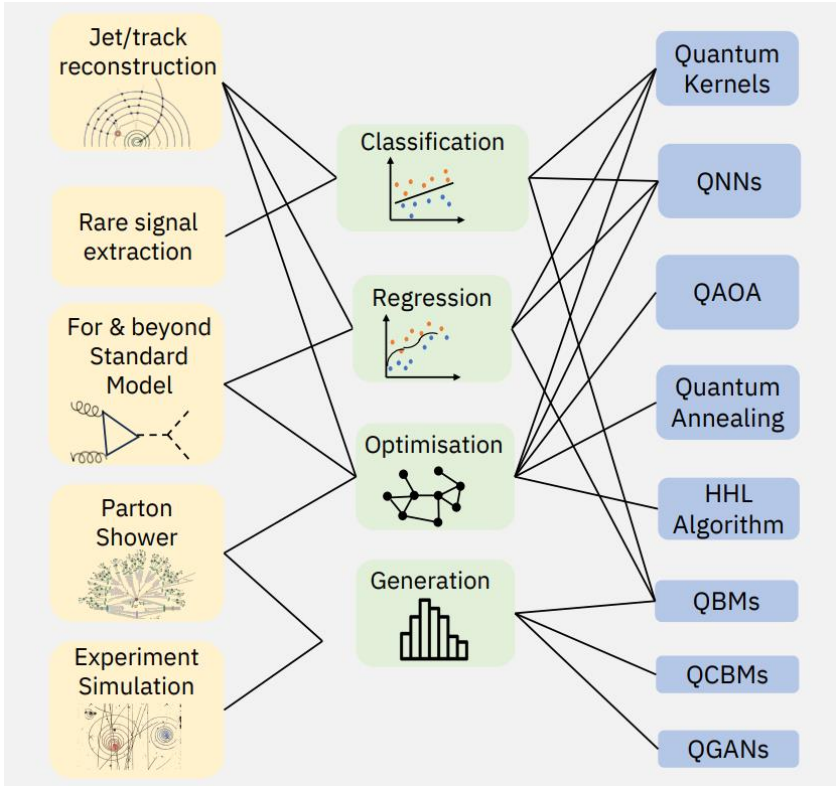
Most of these developments are common to areas beyond HEP

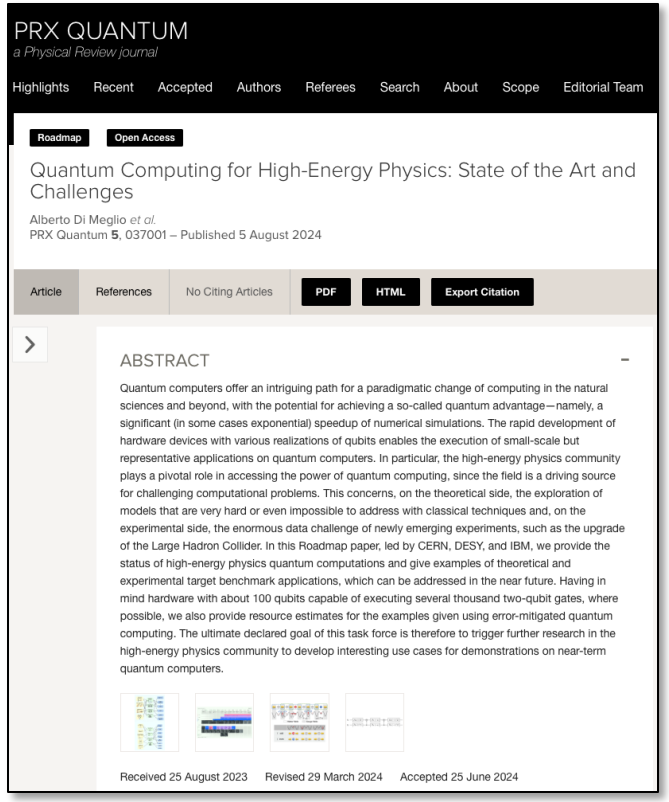
Image credit: CERN

Mapping HEP problems to quantum algorithms

A white paper from the QC4HEP working group



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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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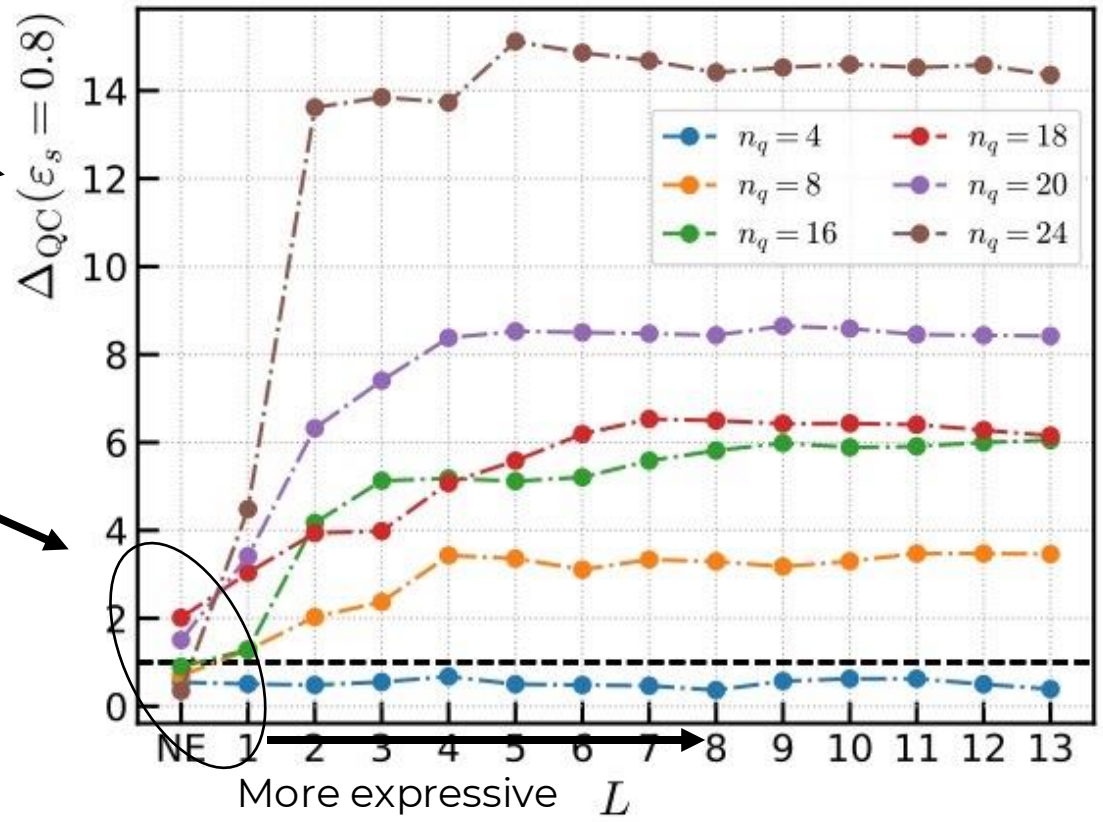
Quantum Computing for High-Energy Physics: State of the Art and Challenges. *PRX Quantum* 5.3 (2024): 037001.

One example: Anomaly Detection on quantum computers

24 qubits SVM yields **14 times** the performance of the classical model
Performance driven by quantum entanglement

Quantum/Classical ratio

No entanglement



This is a simulation.
Behaviour confirmed on IBM Q *Toronto*

Is this evidence for quantum advantage?

The QTI Hub: a collaboration framework for QTI

Born in February 2025, the QTI Quantum Hub expands QTI reach across the Member States

About 20 agreements already signed or in the pipeline

Algorithmiq (Finland, Company)

Deutsche Telekom (Germany, Company)

Pasqal (France, Company)

Qunnect (Netherlands, Company)

Single Quantum (Netherlands, Company)

University Politecnica Catalunya (Spain, University)

…

Collaborations beyond the Member States:

ICEPP, EC-JRC, WR,…

A Journal by Scientists for scientists

JQuant
Journal of Quantum Science

Why JQuant?

A **unique journal** at the intersection of **quantum information** with **High Energy Physics**, **statistical mechanics** and **condensed matter theory**.

Why now?

On the occasion of the 2025 International Year of Quantum Science and Technology.
It is time to recognize the **emergence of this interdisciplinary research community**.

Why SISSA Medialab?

Since 1997 SISSA Medialab publishes **JHEP**, the leading journal of the HEP community, and other internationally recognized journals…

… under the motto “by scientists for scientists”

SISSA
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Sustainable Diamond Open Access model

JQuant
Journal of Quantum Science

Our vision is to build JQUANT as a genuinely **community-owned publication**, reflecting shared responsibility and **collective investment in the future of open, high-quality science**.

We are **inviting both scientific and institutional engagement** - including financial contributions - to help establish and sustain the journal.

CERN, SISSA and ICTP among others have already pledged their **institutional support to JQUANT**.

Interested in sustaining this project?

Reach out to JQuant at jquant-eo@medialab.sissa.it

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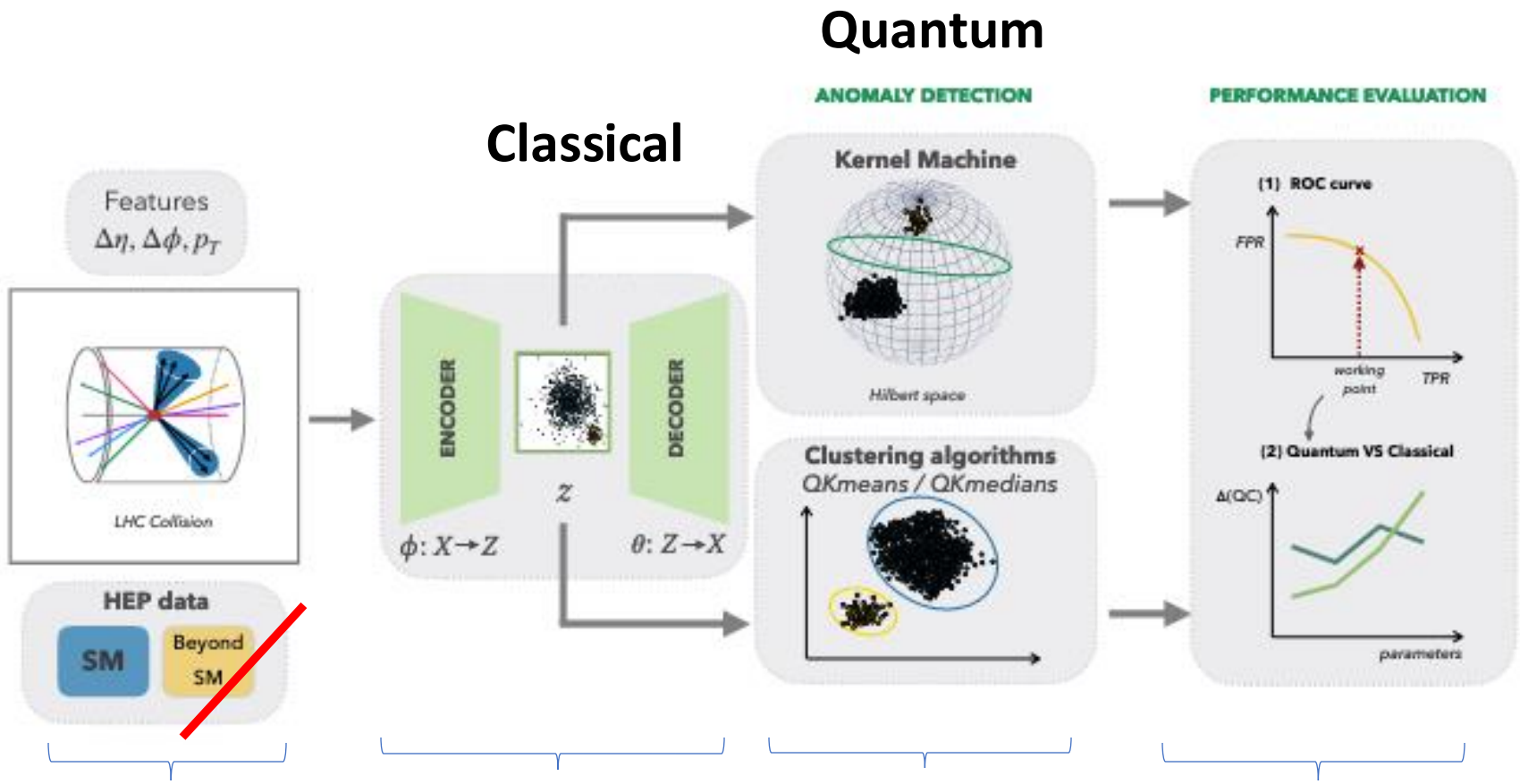
Enjoy the Summit!

Anomaly Detection on Quantum Computers

Hybrid implementation:
Use a classical data compression

Model Agnostic approach:

- Train using baseline data
- New physics will be flagged as an anomaly



Open questions

- Today's approach to Quantum Machine Learning is variational or kernel based
  - Currently **gradient based optimisation is suboptimal**
  - Can we **train Quantum Machine Learning algorithms effectively**?

- How do we define **advantage** ?
- What is the definition of a fair classical benchmark ?

- Experimental High Energy Physics data has high dimensionality
  - Can **we reduce the impact of data reduction** techniques?
- Experimental High Energy Physics data is shaped by **physics laws**
  - Can we leverage them to build better algorithms?