

# CERN Quantum Technology Initiative

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# Quick Overview

1. The CERN Quantum Technology Initiative (in short CERN QTI) was established in June 2020 with final endorsement by the CERN Council in September 2020
2. The management team (the CERN QTI Task Force) is now in place. It is composed of the QTI Coordinator (Alberto Di Meglio – IT Department), three “area coordinators” for the activities of Quantum Computing (Sofia Vallecorsa – IT Department), Quantum Sensing (Michael Doser – EP Department), and Theory (Dorota Grabowska – TH Department). The Quantum Communications area is currently coordinated ad interim by Alberto Di Meglio while a dedicated expert is identified. Other members include representatives of the Legal Service, the KT office, the IT Communication office, and the HEP Software Foundation. The Task Force meets once a month.
3. Names for the QTI Advisory Board are being discussed with the CERN Council Members and the Quantum and HEP communities in the Member States.
4. A first “brainstorming event” to collect input from the CERN and LHC experiments community took place in November. Ideas and proposals are now being solicited to become possible proposals for projects and research activities. More events, presentations and discussions are taking place with initiatives and experts from the Member States and the European Quantum Flagship.



# Quick Overview

1. A technical roadmap describing the first proposals and ideas will be published in Q1 2021 with input from as many stakeholders as possible across the HEP community.
2. The PhD programme has been initiated as part of the standard CERN DOCT programme. A few PhD candidates will be selected in Q1 2021, more will be selected during 2021.
3. A quantum computing simulation platform shared across different institutes in the CERN Member States is being discussed and designed. It will include classic accelerated hardware for simulation, optimised quantum simulation appliances and remote access to real quantum hardware from selected providers.
4. The first education and training activities have been started, they include academic training and specialistic seminars from international experts.



# CERN Quantum Technology Initiative

Strategy



Joint HEP R&D  
Programme



CERN  
Management



QT Advisory Board  
(Member States)

Coordination



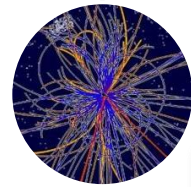
QT Initiative  
Management



R&D



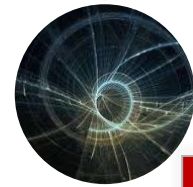
Sensing,  
Detectors R&D



Computing &  
Engineering



Communication



Simulation,  
Information  
Processing

Capacity building



Academic Programmes / Industrial Collaborations / Knowledge Transfer



Quantum Technology  
Initiative

# High-Level Objectives



## Computing

- Assess the potential and role of QML in HEP workloads, work on optimization and more robust mathematical formulations
- Build expertise in the state-of-the-art of the software stack (simulators, compilers, programming models/languages/tools)
- Work on quantum systems simulators (FPGA?)
- Set up a distributed QCS platform



## Communications

- Explore possible applications of QKD
- Comms+sensing for detectors?
- European Quantum Network/Internet



## Sensing

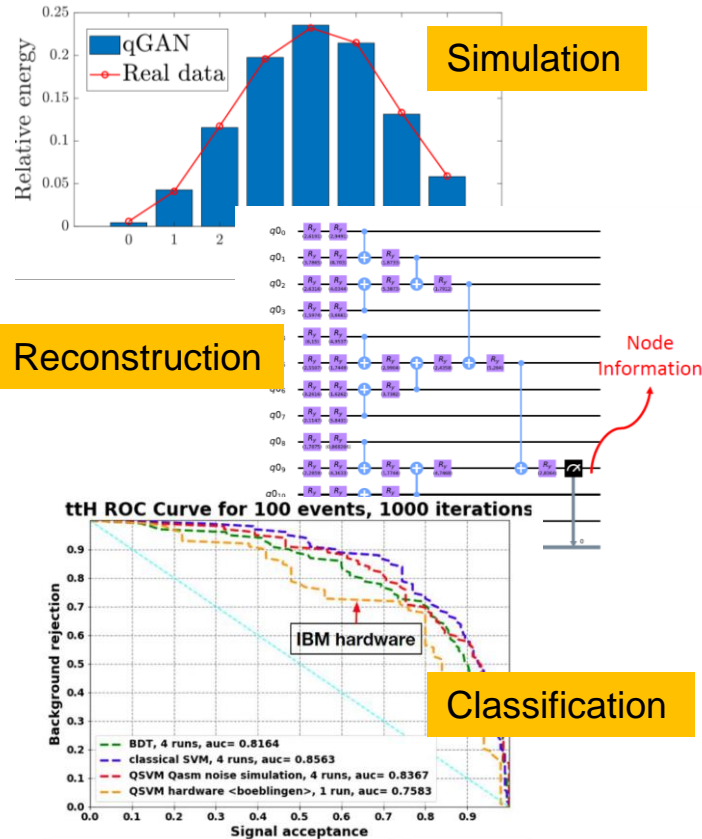
- Ion/particle traps as computing/sensing devices
- Mass/charge/gravity sensors
- Quantum clocks
- Nanowires/nanodots for particle tracking/calorimetry
- Rydberg calorimetry



## Theory

- Simulation of quantum systems not accessible with Monte Carlo models
- Quantum gravity
- Information processing, error mitigation/correction strategies

# Quantum Computing Projects



- Quantum **Generative Adversarial Networks** for detector simulation
- Quantum **Graph Neural Networks** for particle trajectory reconstruction
- Quantum **Support Vector Machines** for signal/background classification (Higgs, SUSY,..)
- Workload optimization via quantum **Reinforcement Learning**
- Quantum **Random Number Generators** tests and integration
- Quantum **Homomorphic Encryption**

# HEP Experiments

- ATLAS
  - Higgs Boson decay classification (Prof Sau Lan Wu, Fermilab)
  - QML for tracking and event classification (with University of Tokyo - ICEPP)
  - Extension of TrackML use cases to GNN and TTN (with METU)
- CMS
  - Quantum algorithms for tracking within PATATRACK (with University of Waterloo)
  - Quantum classifiers for Higgs searches (ETH -CMS)
- LHCb
  - Discussing collaboration with Donatella Lucchesi WG on quantum-inspired algorithms (with University of Padova, Maastricht and others)
- WH on Quantum Computing in the HEP Software Foundation (Riccardo Maria Bianchi)





# QC Simulation Platform

1

Enable building skills and starting R&D work, both as a preparation to real H/W and to explore “quantum-inspired” computational models

2

“Standardized” access to different simulators, hardware, tools, libraries (e.g. pre-packaged containers, Jupyter notebooks, GitHub, etc.)

3

Multiple participating sites, capitalizing on CERN world-level expertise in operating distributed infrastructures

# Quantum Sensing and Low-Energy Physics

Scope

Low-Energy Physics: antimatter, dark matter searches, symmetries, EDM's (AD, AeGIS, ISOLDE, etc.)

Strategy

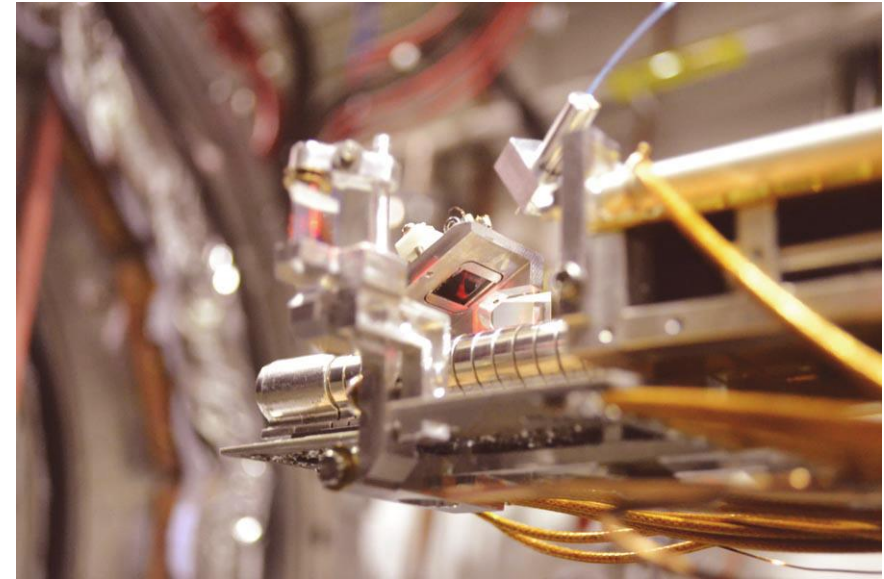
Discrete processes, changes of quantum states

Applications

**Novel devices:** nanowires, photon upconverters, microwaves, magnetic junctions, SQUIDs, TES

**Measurements** of properties of trapped, atoms, ions, molecules, Rydberg atoms, neutral systems

**Correlations of entangled systems:** e.g.  $e^+ e^- 3\gamma$  decay: simultaneous measurement of E, polarization and direction





# Quantum Sensing for High-Energy Physics

## Scope

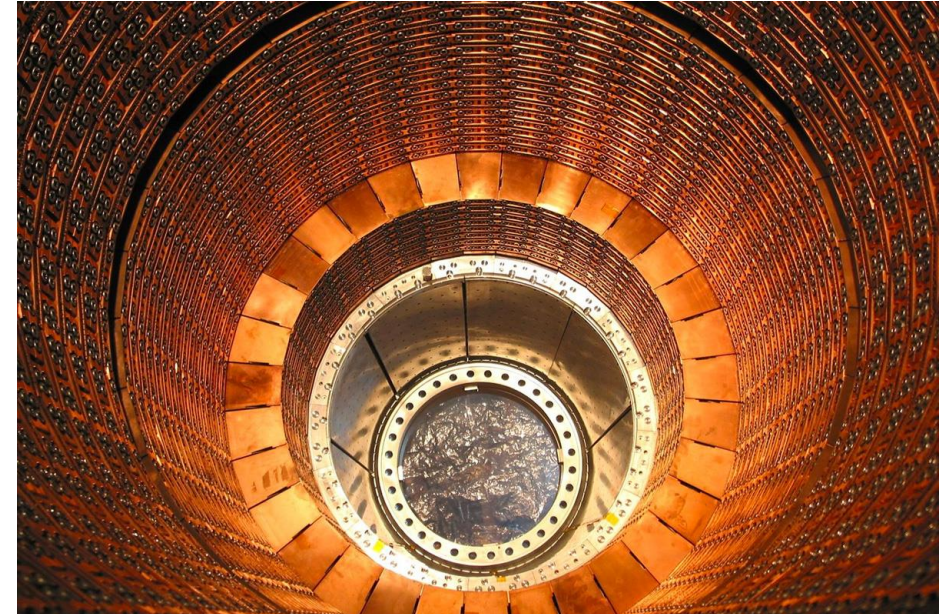
High-Energy Physics, particle tracking, calorimetry, identification in HEP detectors

## Strategy

Quantum “priming” of detectors before measurement, signal enhancement by laser excitation, quantum effects due to size, cryogenics

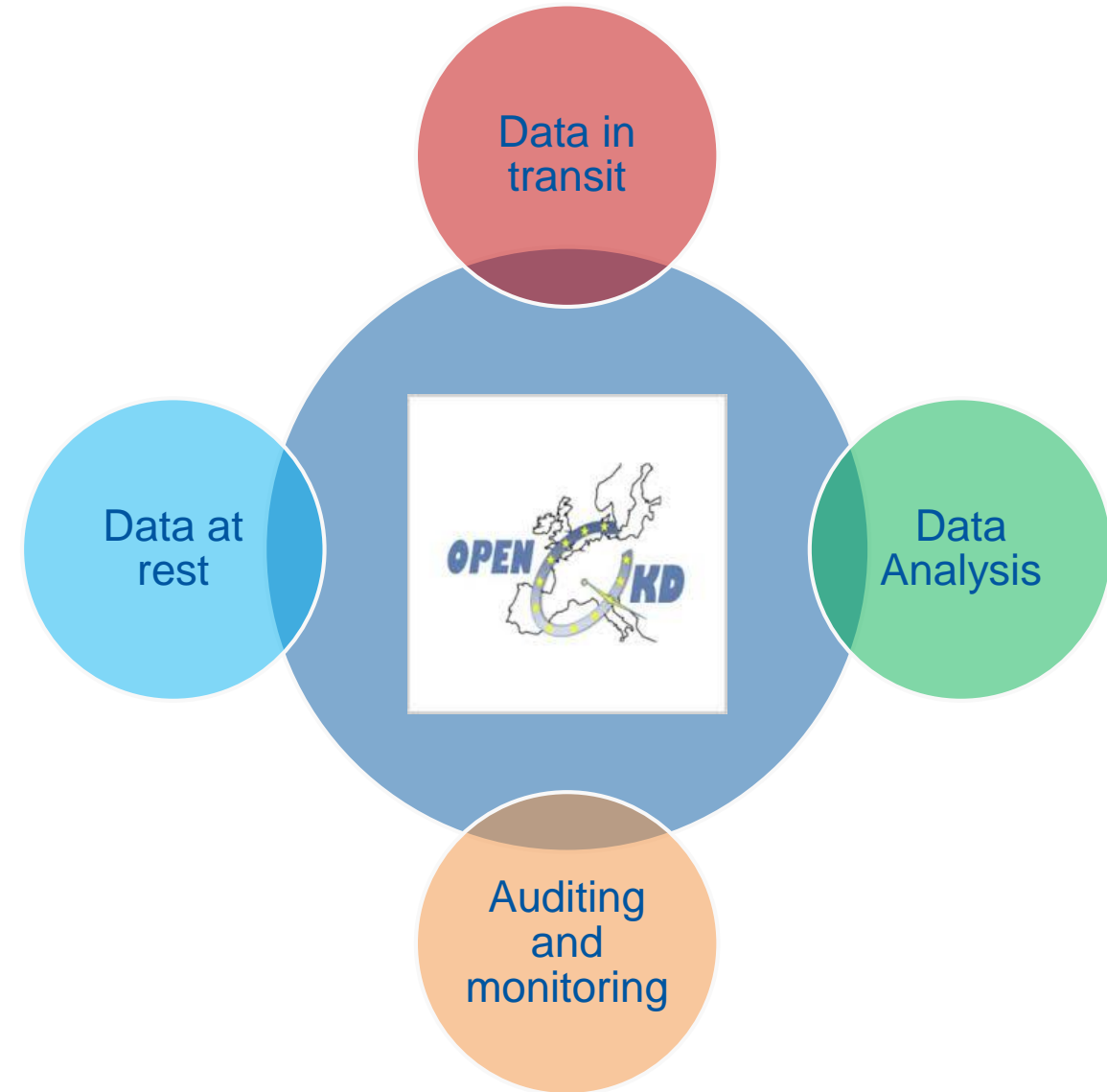
## Applications

Chromatic particle trackers composed of arrays of nanodots of varying size, Calorimeters and low-energy single-particle (photons, mip's, ions,...) detectors made of arrays of nanowires (SNSPD)  
“Rydberg-amplified” calorimeters with high  $dE/dx$



# QUANTUMACY

- **QUANTUM-based privacy and self-determination**
- Funded as an openQKD open call funds
- End-to-end use of QKD to secure distributed data analysis over cloud infrastructures
- Data analysis: **quantum homomorphic encryption**
- Auditing: **quantum block chains**
- Medical use cases: image classification and segmentation for neurological diseases research



# Numerical Methods and Simulations in Particle Theory

Modern day HEP requires high performance computing, relying on Monte Carlo simulations

- Mass Spectrum and Scattering in Low Energy Nuclear Physics
- Hadronic contributions to BSM Experimental Searches
- Event generation for Particle Collisions

Main focus is developing methodologies and algorithms that would allow us to address these questions using quantum computers, without relying on importance sampling

But not every physics problem is amenable to Monte Carlo simulation

- Nuclear Physics at Finite Density (sign problem)
- Interference effects in Parton Showers (must work at amplitude level)
- Transfer Phenomena (must work in real time)
- Baryonic Physics (signal to noise problem)