
CERN

The CERN Quantum Technology Initiative

Atelier QT2I – CPPM Marseille

QUANTUM
TECHNOLOGY
INITIATIVE

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CERN openlab Head
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CERN

"Science for peace"

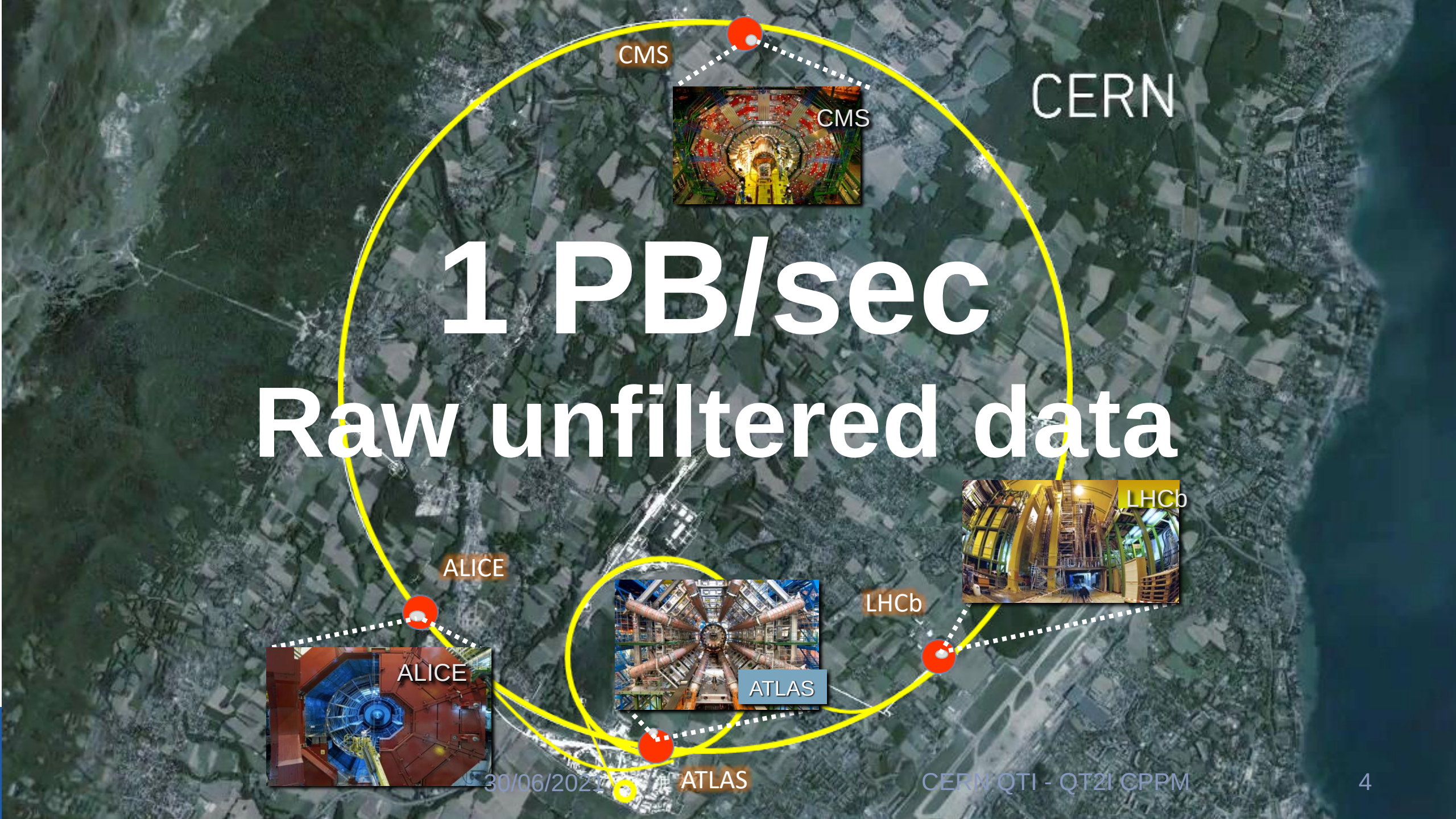
- International organisation close to Geneva, straddling Swiss-French border, founded 1954
- Facilities for fundamental research in particle physics
- 23 member states, 1.2 B CHF budget
- ~3'200 staff, fellows, trainees, …
- >13'000 associates

1954: 12 Member States

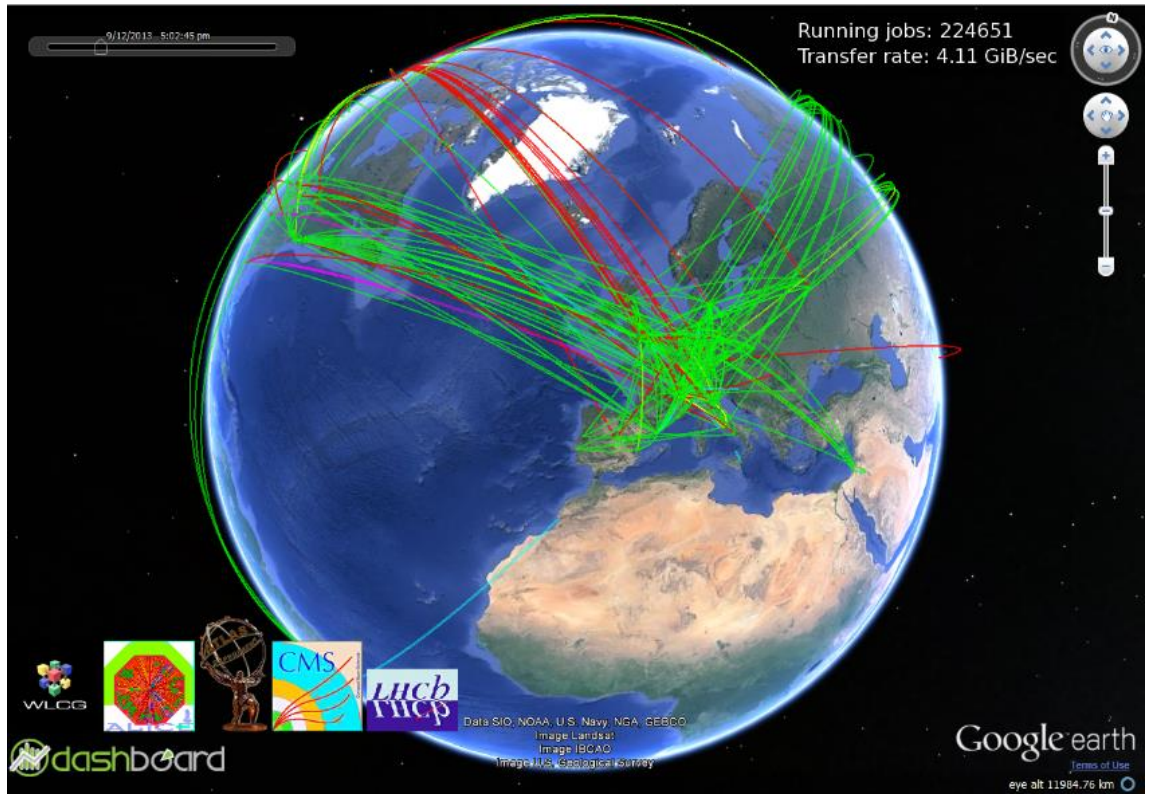
Members: Austria, Belgium, Bulgaria, Czech republic, Denmark, Finland, France, Germany, Greece, Hungary, Israel, Italy, Netherlands, Norway, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, United Kingdom
Candidate for membership: Cyprus, Estonia, Slovenia
Associate members: Croatia, India, Lithuania, Pakistan, Turkey, Ukraine
Observers: EC, Japan, JINR, Russia, UNESCO, United States of America
Numerous **non-member states with collaboration agreements**

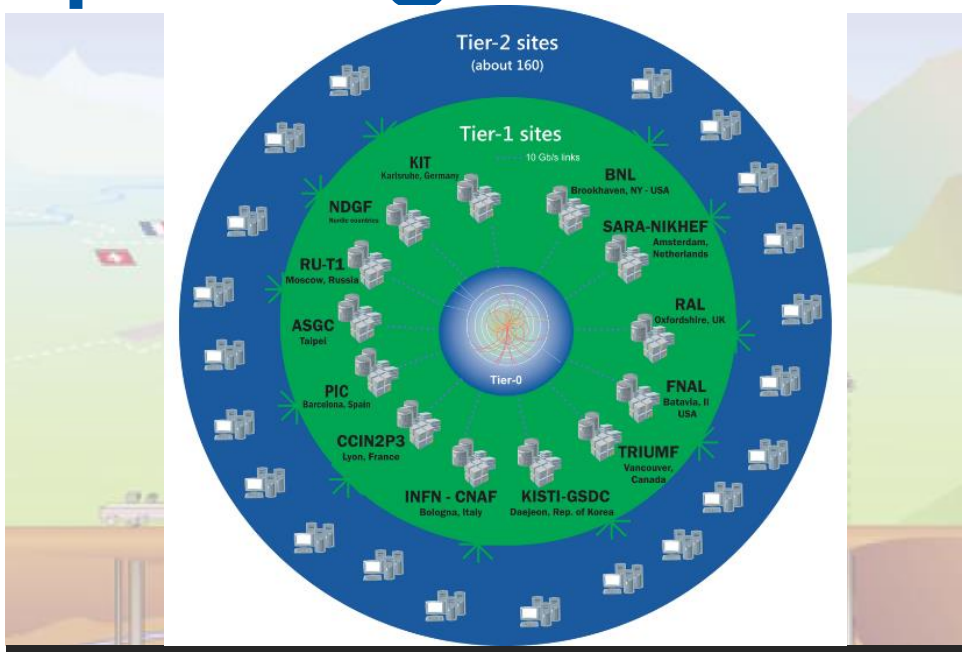
>2'500 staff members, 645 fellows, 21 trainees

7'000 member states, 1'800 USA, 900 Russia, 270 Japan, …


CMS
CMS
CERN
1 PB/sec
Raw unfiltered data
LHCb
LHCb
ALICE
ALICE
ATLAS
ATLAS

Worldwide LHC Computing Grid





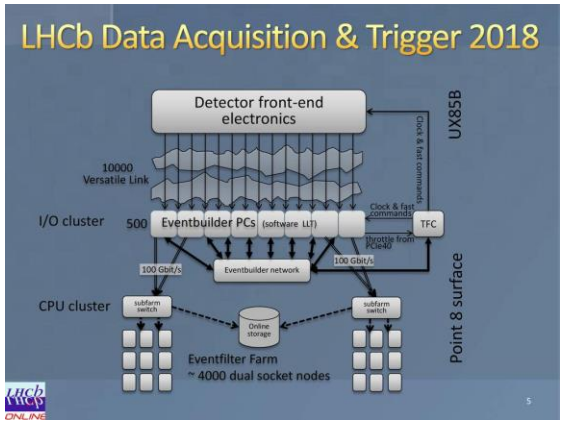
Tier-0 (CERN):
- Data recording
- Initial data reconstruction
- Data distribution

Tier-1 (13 centres):
- Permanent storage
- Re-processing
- Analysis

Tier-2 (42 Countries, ~170 centres):
- Simulation
- End-user analysis

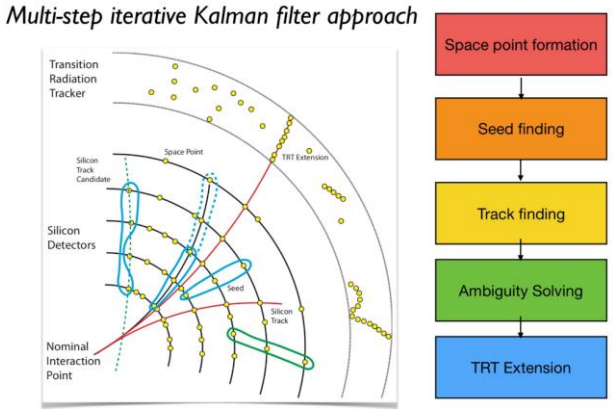
- ~800,000 cores
- ~800 PB

LHC Experiments Computing Workloads

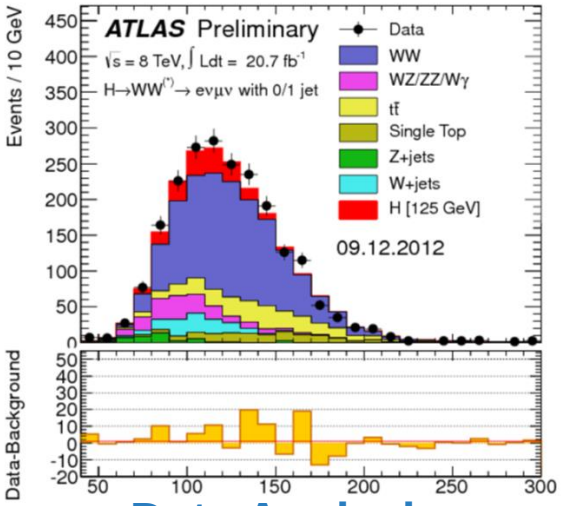


© Niko Neufeld - LHCb

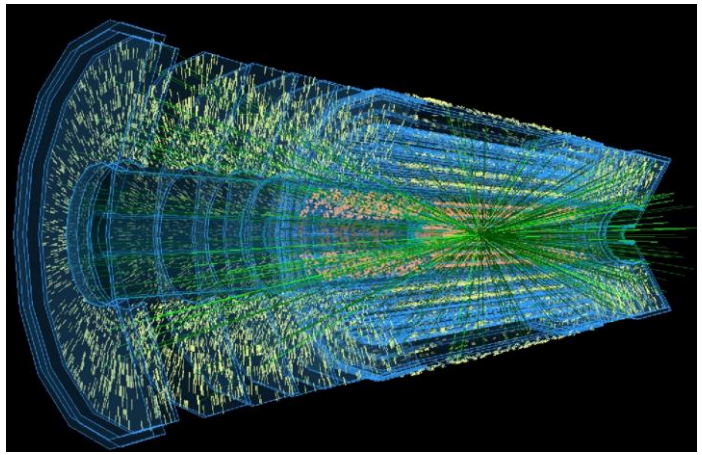
Data Acquisition



Track Reconstruction



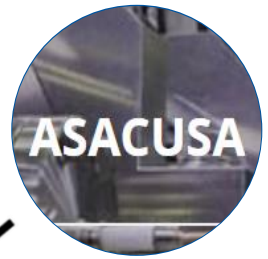
Data Analysis



Simulation

Non-LHC Experiments

Antihydrogen Experiment: Gravity, Interferometry, Spectroscopy (AEGIS)
direct measurement of the Earth's gravitational acceleration, g, on antihydrogen.



Atomic Spectroscopy And Collisions Using Slow Antiprotons
studies the fundamental symmetries between matter and antimatter by precision spectroscopy of atoms containing an antiproton.

Antiproton Trap
compares protons with their antimatter equivalents.

ALPHA (successor of ATHENA)
makes, captures and studies atoms of antihydrogen and compares these with hydrogen atoms.

CERN Neutrino Platform
CERN's undertaking to foster and contribute to fundamental research in neutrino physics at particle accelerators worldwide

CERN Axion Solar Telescope
search for hypothetical "axions", proposed to explain why there is a subtle difference between matter and antimatter.

Theoretical Physics

pQCD and Standard Model — collider physics, parton showers, theory input for precision electroweak, interpretation of data from collision experiments

Heavy Ion — effective descriptions of quark gluon plasma, jets in heavy ion collisions, hydrodynamics of strongly coupled systems

Lattice — theory inputs for nuclear and particle physics, first principle calculations of the low energy aspects of QCD, lattice as a formal tool for understanding QFTS

BSM — collider searches for BSM, dark matter model building, experimental signatures of dark matter, model building of new physics, BSM explanation of experimental anomalies

Strings/QFT — quantum gravity, string theory, conformal bootstrap, AdS/CFT correspondence, information paradox

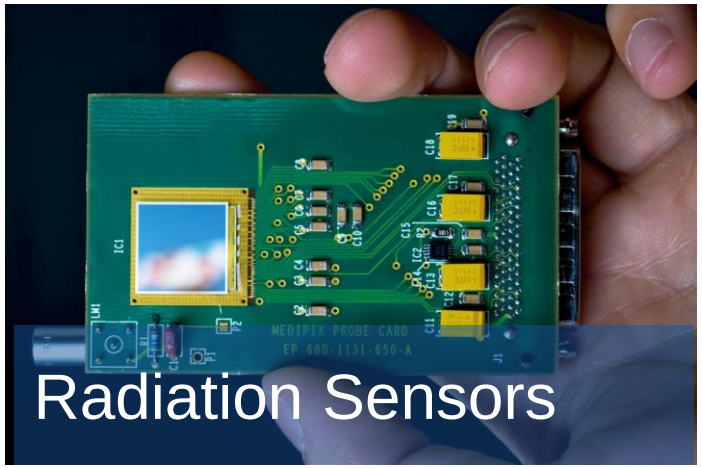
Cosmo/AstroParticle — properties and evolution of the early universe, large scale structure, dark sectors, neutrinos, gravitational waves, CMB

Engineering


Cryogenics

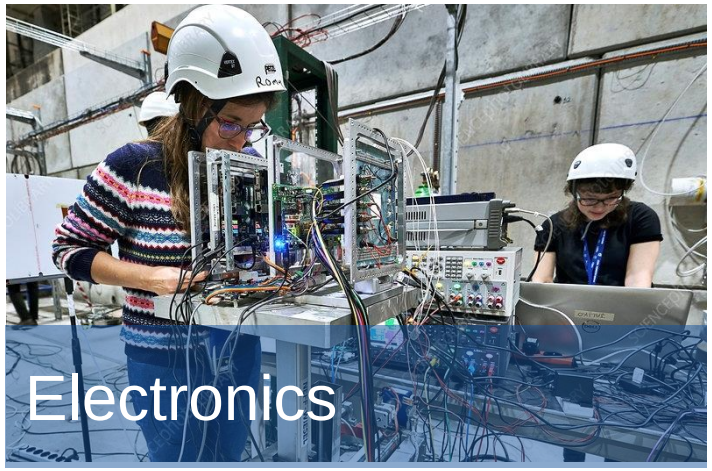

Vacuum


Mechanical Eng.
Material Science



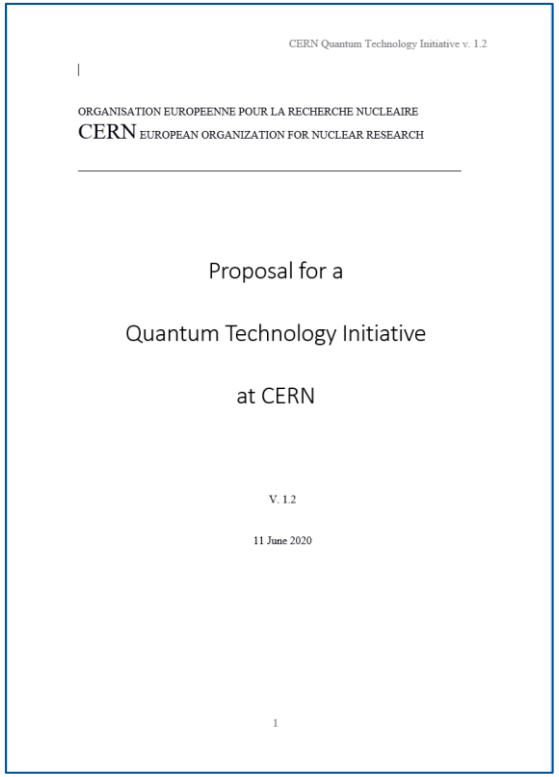
Radiation Sensors


Lasers


Electronics

CERN Quantum Technology Initiative

Discussions about a Quantum Technology Initiative took place in 2020 with representatives of quantum initiatives in the CERN Member States, the CERN community, the Worldwide LHC Computing Grid, the CERN Scientific Computing Forum, with LHC experiments and the HEP Software Foundation


CERN Quantum Technology Initiative v. 1.2

ORGANISATION EUROPEENNE POUR LA RECHERCHE NUCLEAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Proposal for a

Quantum Technology Initiative

at CERN

V. 1.2

11 June 2020

1

Objective 1: Strategy and long-term benefits

- Capitalize on CERN uniqueness, organize the different lines of R&D at CERN under a common initiative and vision and define a **shared roadmap**
- Assess the potential impact of quantum technologies on CERN and HEP research in the timescale of HL-LHC and beyond
- Build over time the required knowledge and capacity to turn the potential into realized impact

Objective 2: Implementation and execution

- Implement the strategy by means of a set of concrete R&D objectives in the four main areas of QT
- Run an international academic, education, and training programme in collaboration with leading experts, universities and industry
- Knowledge sharing within the Member States, the HEP community, other scientific research communities and society at large

CERN Quantum Technology Initiative

Strategy

Coordination

R&D

Capacity building

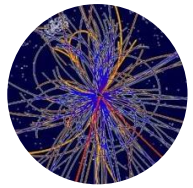
Joint HEP R&D Programme

CERN Management

Advisory Board (**representation of the Member States**)

QT Initiative Management

Sensing, Detectors R&D



Computing & Engineering

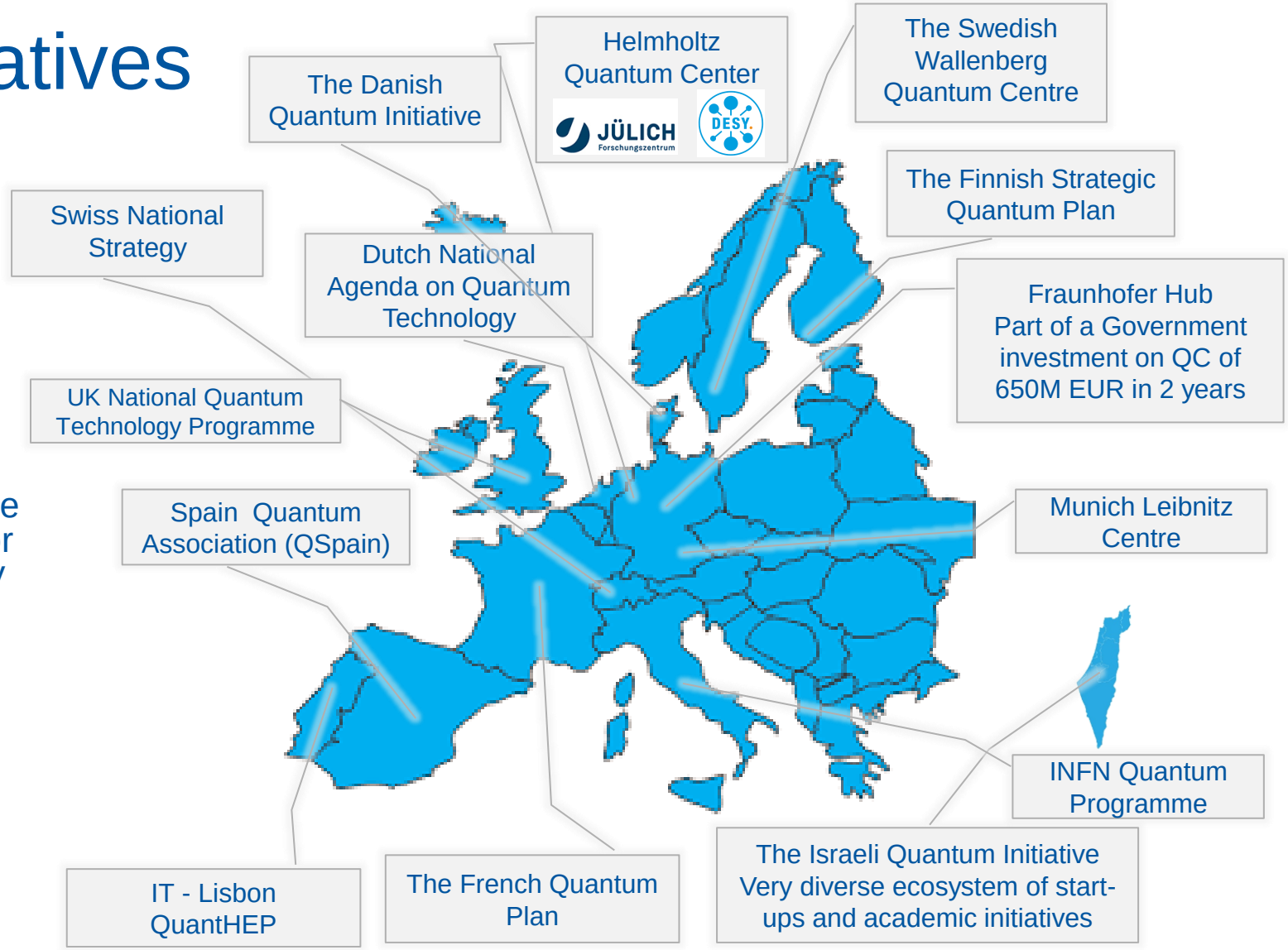
Communication

Simulation, Information Processing

Academic Programmes / Industrial Collaborations

Member States Initiatives

- Many initiatives involving research labs, universities, companies have been announced in recent years
- National initiatives are put in place independently in several countries
- Companies have established large expertise networks: e.g. the IBM Quantum Network or Q-Net (with more than 100 members, many of them in Europe), or the Atos User Club
- Opportunities for joint collaborations and common programmes are emerging in particular in the CERN Member States



Worldwide Initiatives and Investments

Argonne NATIONAL LABORATORY

Argonne Quantum Research Group

TRIUMF

DESY.

Canada-Germany Quantum Computing Network

QUANTUM FLAGSHIP

EC 1B EUR initiative Quantum Flagship

Close collaboration with the EU QF. Management meeting took place in Dec 2020

Quantum Information Science and Quantum Internet Institutes

Russian Quantum Technology Roadmap (Digital Economy National Program – 1B EUR)

Keio University

1858 CALAMVS GLADIO FORTIOR

Fermilab

Fermilab Quantum Technology Institute

Japan-IBM Hub at Keio University
Quantum Programme at Tokyo - IHEP

U.S. DEPARTMENT OF ENERGY

USA National Quantum Initiative Act (1B$, Dec 2018)

218M USD in 2019 for 85 research grants
In 28 institutes (academia and national labs)

Oak Ridge Quantum Hub

OAK RIDGE National Laboratory

Australia-IBM 1B AUD Deal (Melbourne, Canberra, Gold Coast)

Who we are talking to

Organizations and Projects

Industry

IBM Q-Net

Xanadu

Universidad de Oviedo

Academia, Research Labs and Agencies

Who we are talking to

Organizations and Projects

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QuTech

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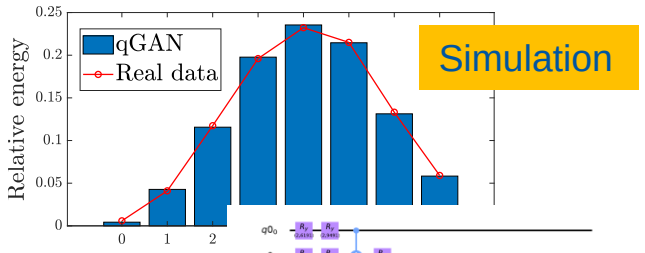
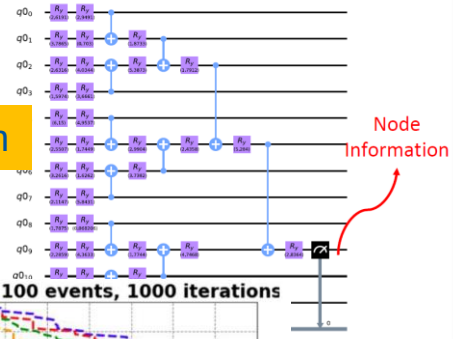
R&D Projects

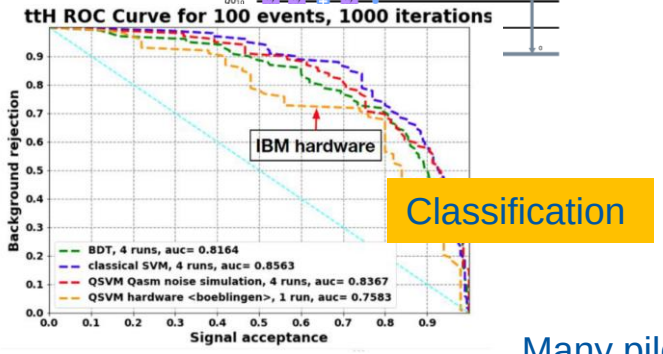
Computing



Simulation

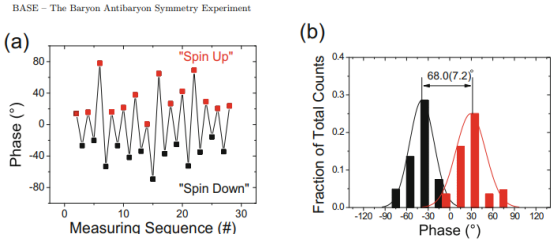


Reconstruction



Classification

Sensing

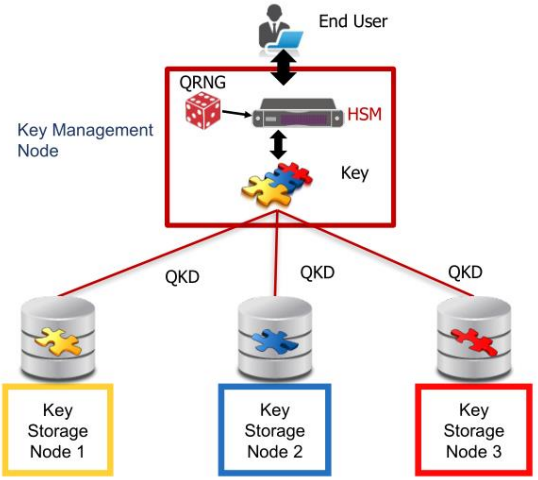


https://doi.org/10.1140/epjst/e2015-02607-4

Low-energy experiments, quantum states measurements, nano-technologies

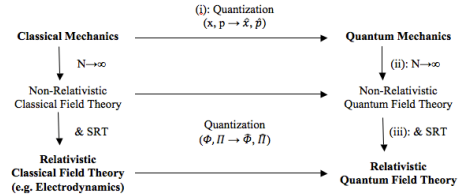
Future HEP Detectors

Communications

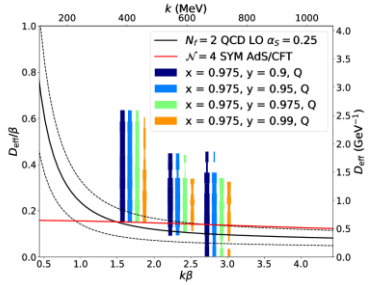


QKD infrastructures Quantum Internet

Theory



Quantum Field Theory

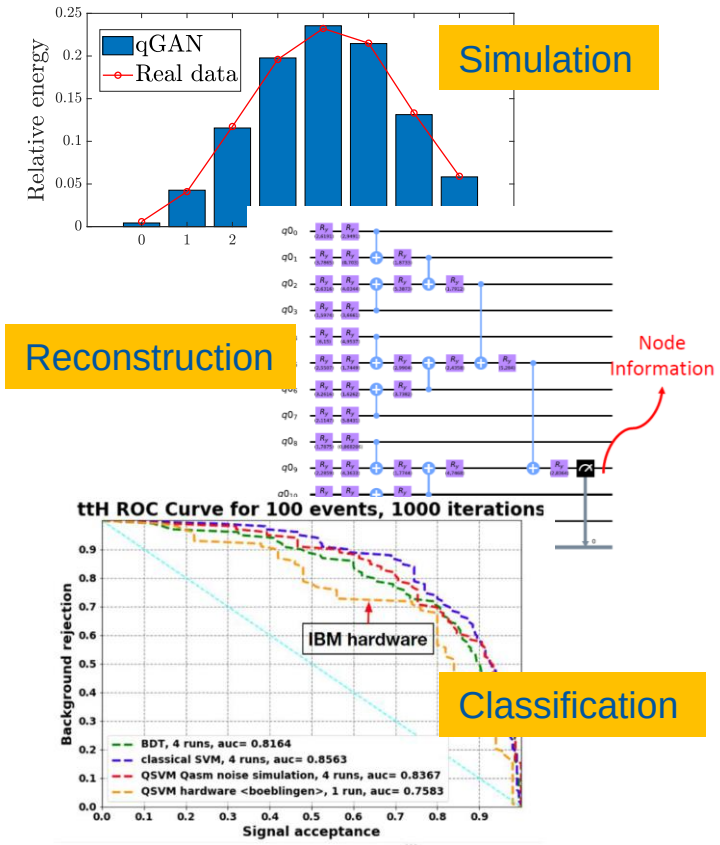


https://cds.cern.ch/record/2703396

Lattice QCD

Many pilot projects already started as part of the **CERN openlab quantum** programme (https://openlab.cern/quantum)

Quantum Computing

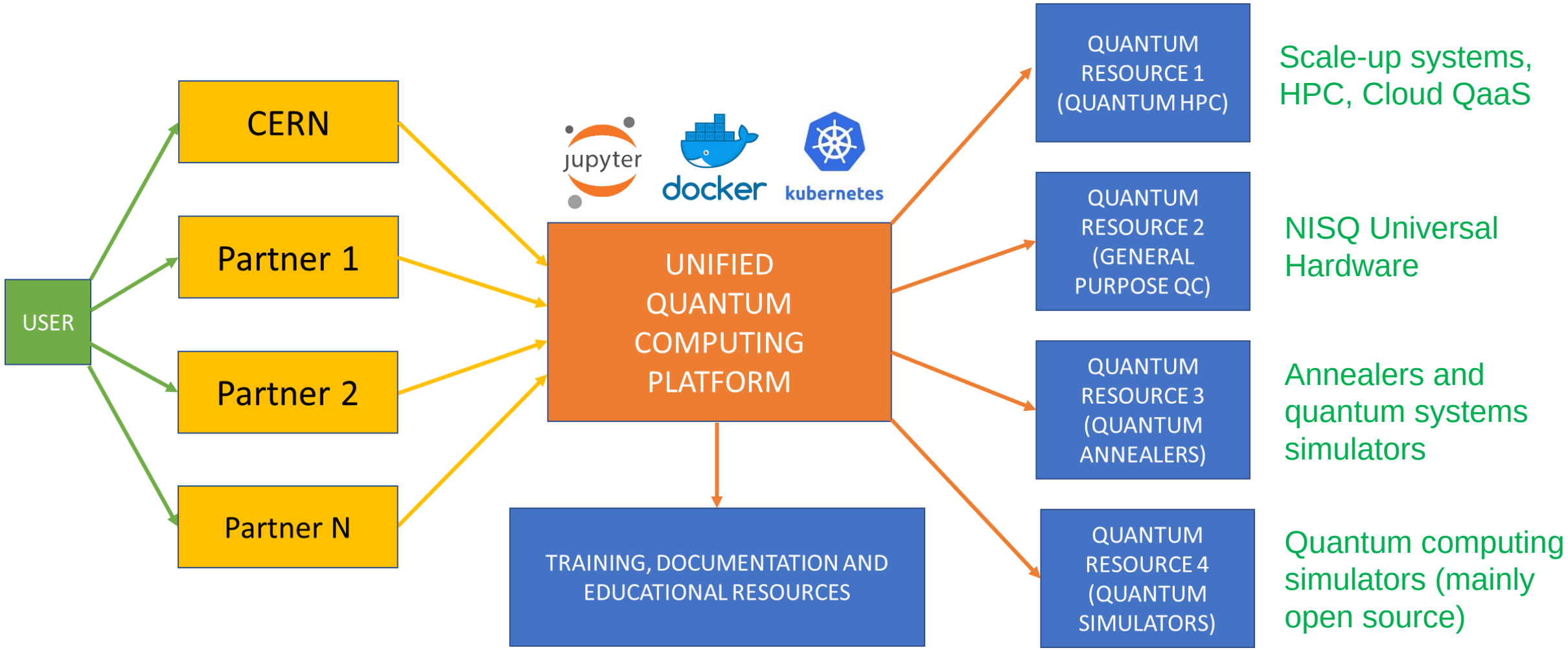


Until today: set a baseline for prioritisation and systematisation

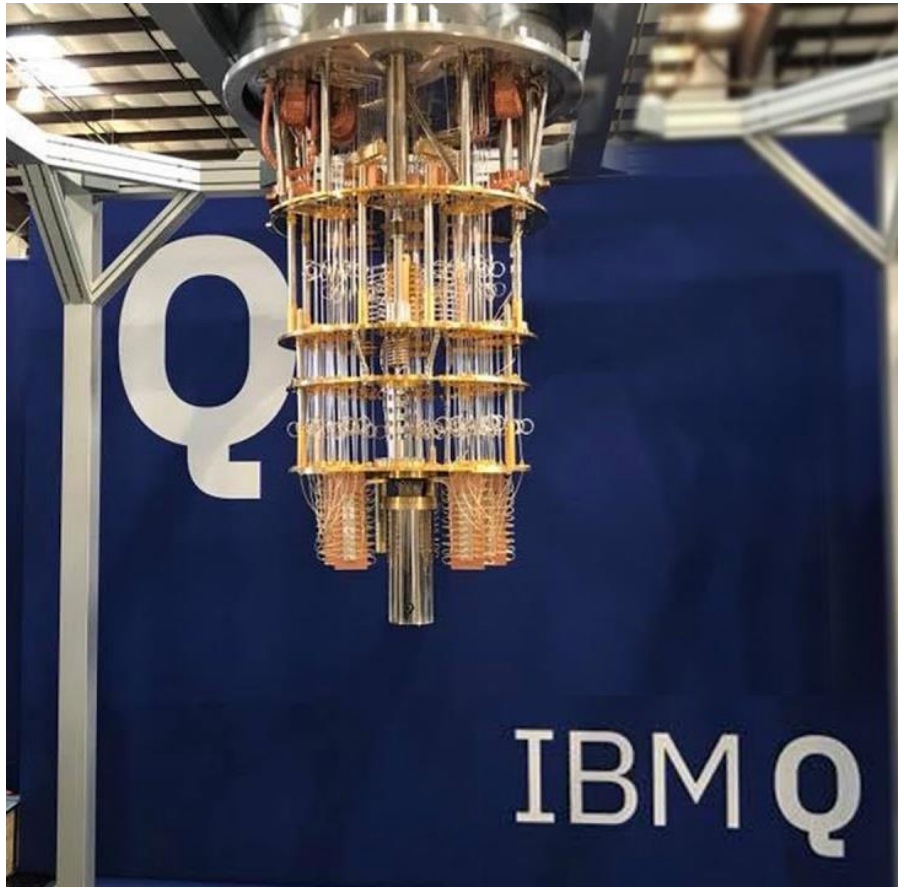
- Quantum **Generative Adversarial Networks** for detector simulation
- Quantum **Graph Neural Networks** for particle trajectory reconstruction
- Quantum **Support Vector Machines** for signal/background classification (Higgs, SUSY,..)
- Workload optimization via quantum **Reinforcement Learning**
-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

Now moving towards a a more formal approach to algorithms, methods, error characterisation and correction, NISQ optimisations, data embedding / scalability / problem dimensionality

Quantum Computing Platforms

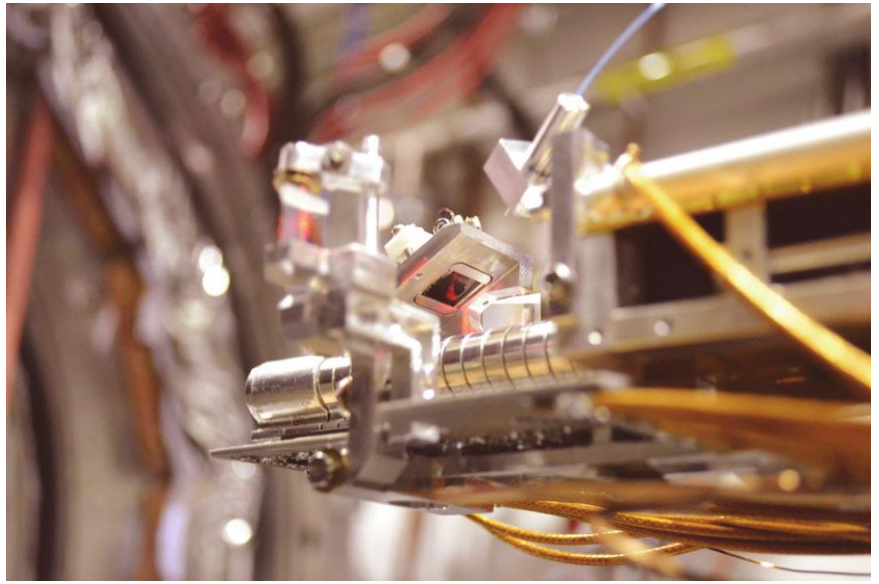


CERN Quantum Hub



- CERN is a Hub Member of the IBM Quantum Network
  - Focus on exploring NISQ computing for scientific research (physics, astrophysics, Earth observation, etc.)
- Access to IBM hardware based on quotas for Hub individual members and projects
- Now **looking for expressions of interest for new members** either for individual membership or projects

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^- 3γ decay: simultaneous measurement of E, polarization and direction

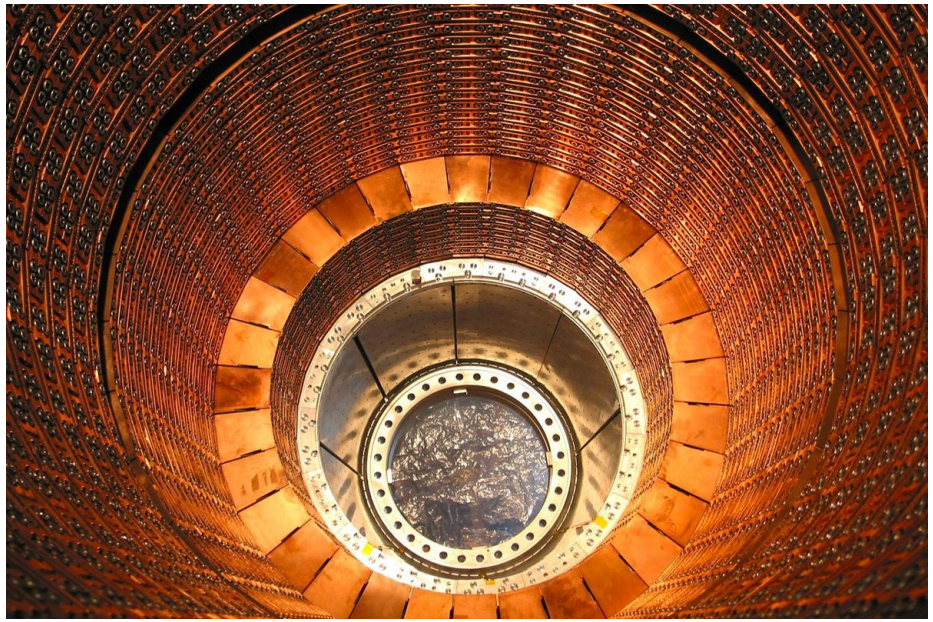
Quantum Sensing for High-Energy Physics

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, nanocrystals (eg. XPbBr3) as scintillator or charged particle tracking for HEP detectors
Calorimeters and low-energy single-particle (photons, mip’s, ions,...) detectors made of arrays of nanowires (SNSPD)
2D-structures (graphene) for gaseous detector signal amplification, synergies with atomic and quantum optics experiment control/DAQ

Quantum Infrastructures

CERN started the Web; we have some expertise it's in our DNA ☺

CERN was part of early quantum networks experiments already 10+ years ago

Interest in taking part in EU and international network deployment initiatives to build the future ***Quantum Infrastructures***

Currently discussing with academic and commercial network and technology providers (GEANT, IDQ) to test devices and protocols with HEP and non-HEP workloads

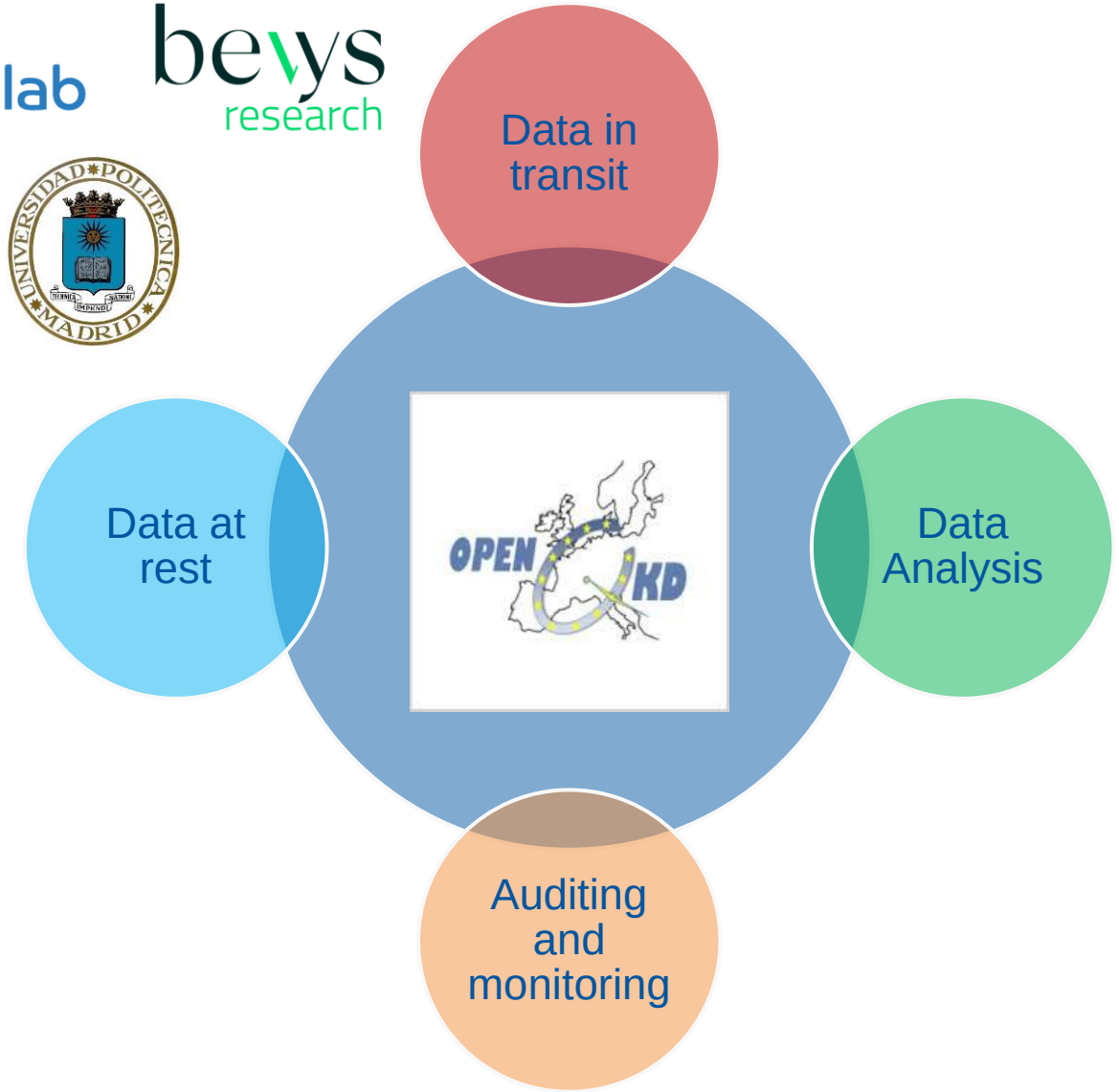
Working on protocols and algorithms (QKD), time synch technologies (White Rabbit), photon sources and lasers

QUANTUMACY

CERN openlab

beyys research

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



Quantum Theory+Simulation Branch*

General Guiding Motivation

How can quantum technology be used to probe the Standard Model and Beyond the Standard Model physics

Develop algorithms to speed up classical methods	Carry out simulations inaccessible on classical hardware	Develop probes of BSM physics using quantum detectors
Quantum Machine Learning for Event Generation	***Lattice Gauge Theory Methodology + Algorithms***	***Atomic Interferometers***
	Simulations of Effective Field Theories for Collider Physics	***Collective Neutrino Oscillations***
Benchmarking Cloud-Based Computing	***Finite Volume Effects in Quantum Simulations***	****Mirrors the role of TH within CERN***

Knowledge Transfer Opportunities

- Measurement & control of quantum-scale systems
- Particle traps technologies
- Excited atoms, ions
- Picosecond Synchronisation
- FPGAs for quantum simulators
- Digital Low-Level Radio Frequency (LLRF) control systems
- Cryogenic system design, measurement & control
- Vacuum system design & control (HV, UHV, XHV)
- Thin film coatings for high-performance applications
- Laser devices

https://kt.cern/competences/cern-tech-quantum-systems

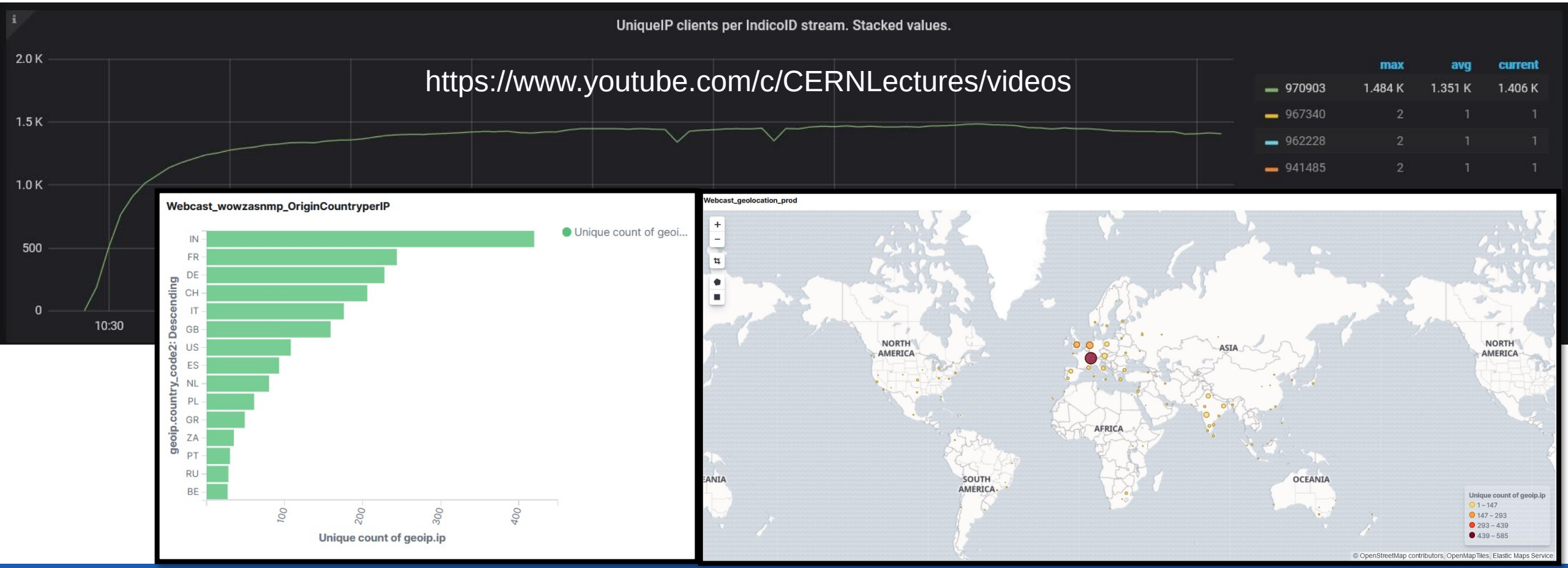
Education Programme

Fundamental component to prepare the community for future applications of quantum technology

- Lectures and seminars with field experts (in collaboration with the CERN Academic Training Services)
- Training courses (in collaboration with academic and industry experts)
- Colloquia and specialistic seminars
- Hackathons
- Summer Students Programmes

“A Practical Introduction to Quantum Computing”

A 7-part lecture series by Prof. Elias Combarro, University of Oviedo, CERN Scientific Associate (06/11-18/12/2020)



Summary of Areas of Collaboration

1

Qubits implementation and control: exploit unique CERN expertise in particle/ion traps, quantum state sensors, cryoelectronics, time synchronisation, lasers to advance the state of the art of quantum computers technologies working with academia and industry in EU and CERN Member States

2

Quantum Computing (Simulation) Platforms: Enable building skills and starting R&D work, both as a preparation to real H/W and to explore “quantum-inspired” computational models. Multiple participating sites, capitalizing on CERN world-level expertise in operating distributed infrastructures, advance EU computing infrastructures

Quantum Algorithms for Science: Develop libraries and tools for quantum computing to address common use cases across different disciplines (data encoding and reduction, image processing, optimisation, computation of graphs, simulation, etc.)

3

Quantum Internet: take part in EU and international network deployment initiatives to build future quantum infrastructures

Thanks!

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