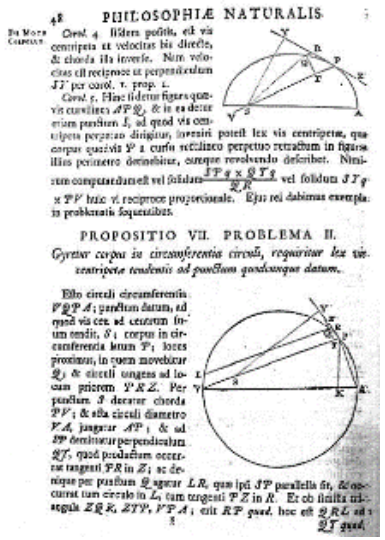
CERN and Quantum Technologies
Overview and Next Steps

Alberto Di Meglio

CERN | QUANTUM TECHNOLOGY INITIATIVE

WORLD QUANTUM DAY APRIL 14

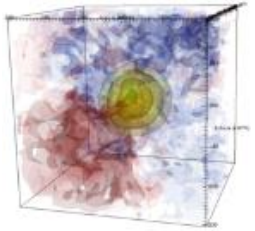
The Four Paradigms of Scientific Research

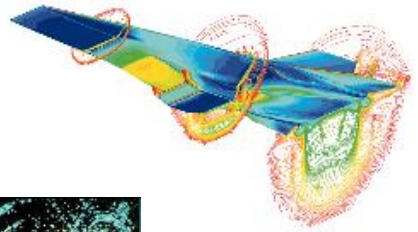


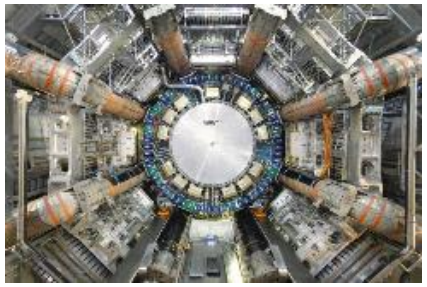
PHILOSOPHIÆ NATURALIS

PROPOSITIO VII. PROBLEMA II.

Gyretur corpus in circumferentia circuli, requiritur lex vis centripetæ tendentis ad punctum quodcunque datum.







4000 years

1 – Empirical observations

500 years

2 - Generalization Theoretical models

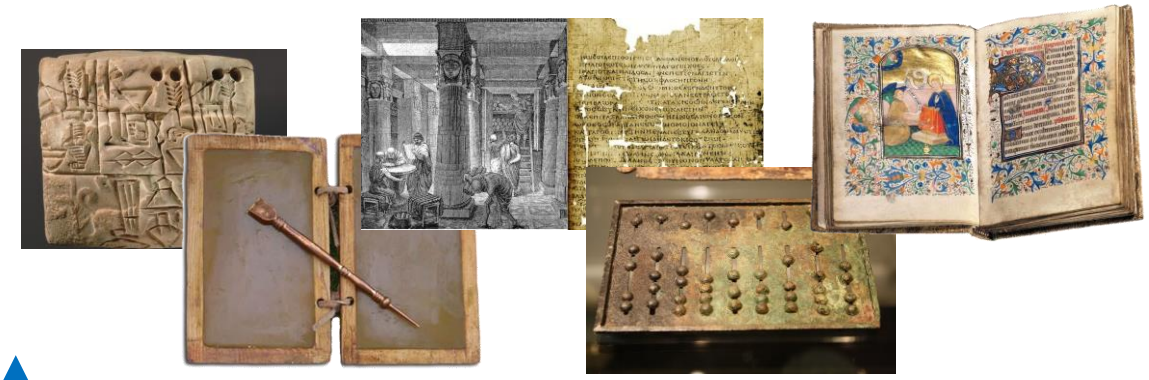
~50 years

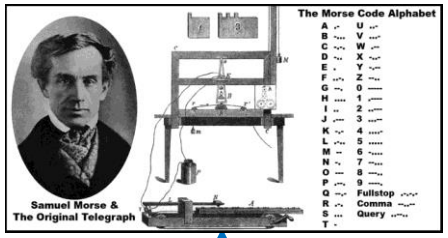
3 - Simulations Computational sciences

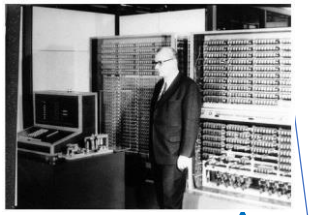
Today

4 - Data-driven science eScience

The 4 eras of Information Science and Computing







Electronic Era
1940 – now

Pre-Mechanical Era
3000 BC – 1450 AD

Mechanical Era
1450 - 1840

Electromechnical Era
1840 - 1940

Electronic Era
1940 – present (?)

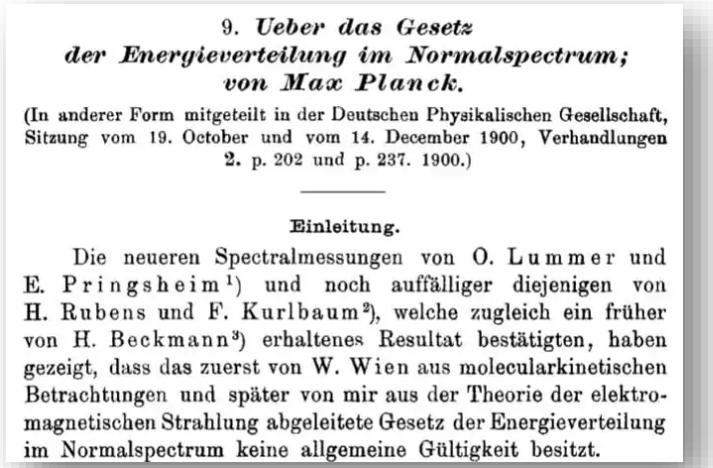
Prehistory/Classical
3000 av. J-C – 476 apr. J-C

Middle Ages
476 - 1492

Early Modern Era
1492 - 1789

Modern Era
1789 - now

The First and Second Quantum Revolution

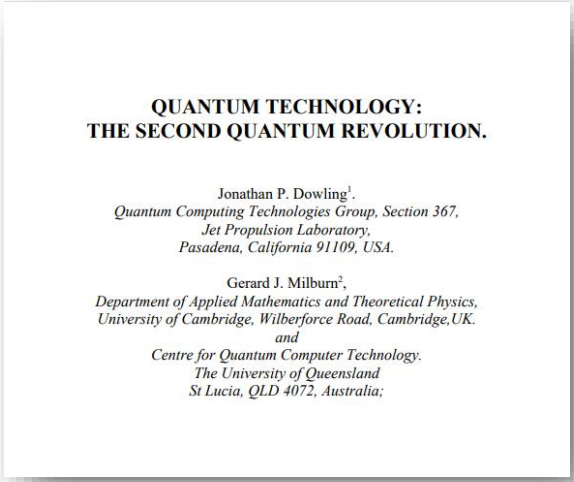


9. *Ueber das Gesetz der Energieverteilung im Normalspectrum; von Max Planck.*

(In anderer Form mitgeteilt in der Deutschen Physikalischen Gesellschaft, Sitzung vom 19. October und vom 14. December 1900, Verhandlungen 2. p. 202 und p. 237. 1900.)

Einleitung.

Die neueren Spectralmessungen von O. Lummer und E. Pringsheim[1]) und noch auffälliger diejenigen von H. Rubens und F. Kurlbaum[2]), welche zugleich ein früher von H. Beckmann[3]) erhaltenes Resultat bestätigten, haben gezeigt, dass das zuerst von W. Wien aus molecularkinetischen Betrachtungen und später von mir aus der Theorie der elektromagnetischen Strahlung abgeleitete Gesetz der Energieverteilung im Normalspectrum keine allgemeine Gültigkeit besitzt.



QUANTUM TECHNOLOGY: THE SECOND QUANTUM REVOLUTION.

Jonathan P. Dowling[1].
Quantum Computing Technologies Group, Section 367, Jet Propulsion Laboratory, Pasadena, California 91109, USA.

Gerard J. Milburn[2],
Department of Applied Mathematics and Theoretical Physics, University of Cambridge, Wilberforce Road, Cambridge,UK. and Centre for Quantum Computer Technology. The University of Queensland St Lucia, QLD 4072, Australia;

The First Quantum Revolution

Max Planck black-body radiation paper

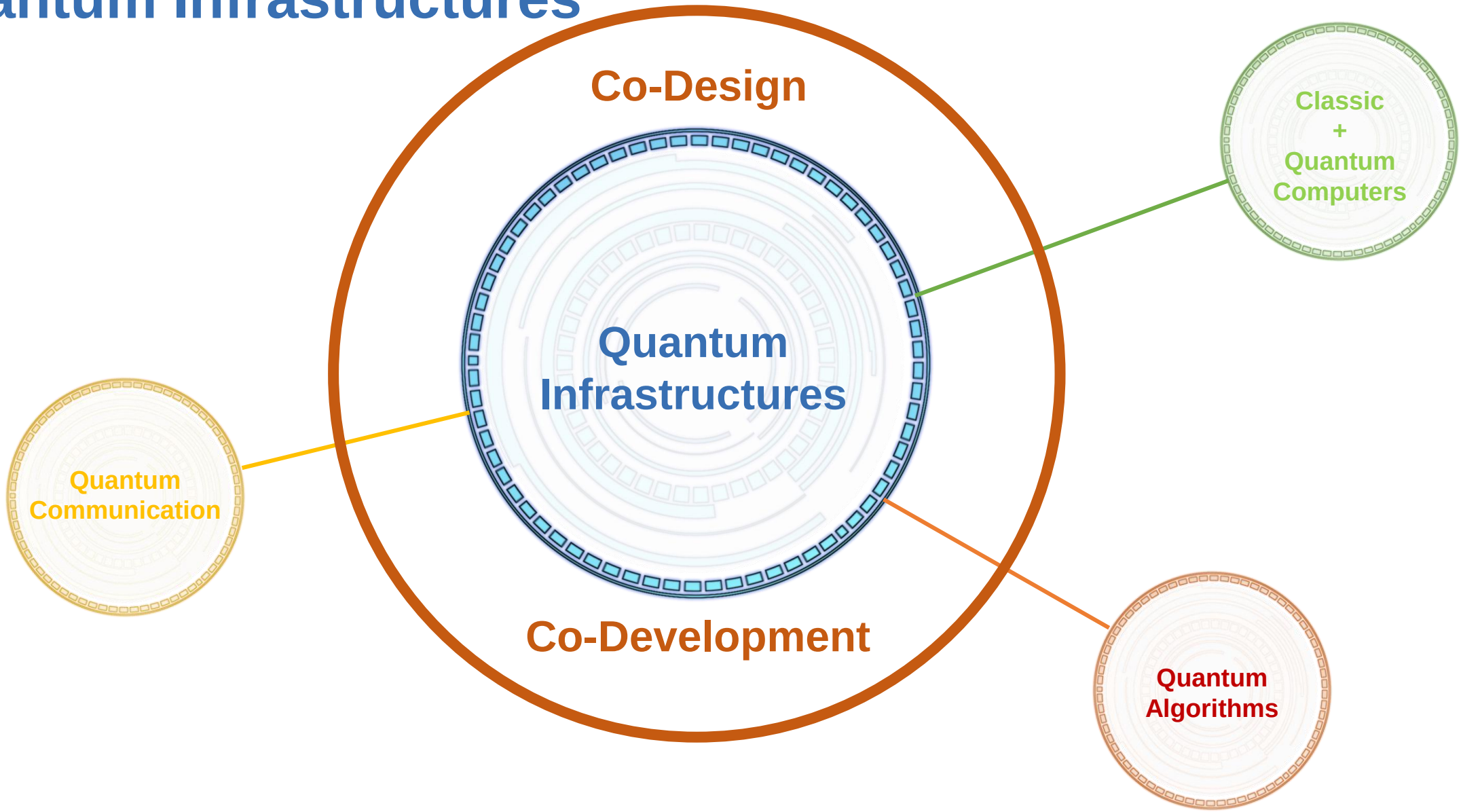
Transistor, laser, atomic clock, computers, optical fibre communication, GPS system

The Second Quantum Revolution

Technological developments enabled by the growing understanding of quantum world, but especially by the possibility of controlling it down to the level of individual particles.

1900 — 2002 — now

Quantum Infrastructures



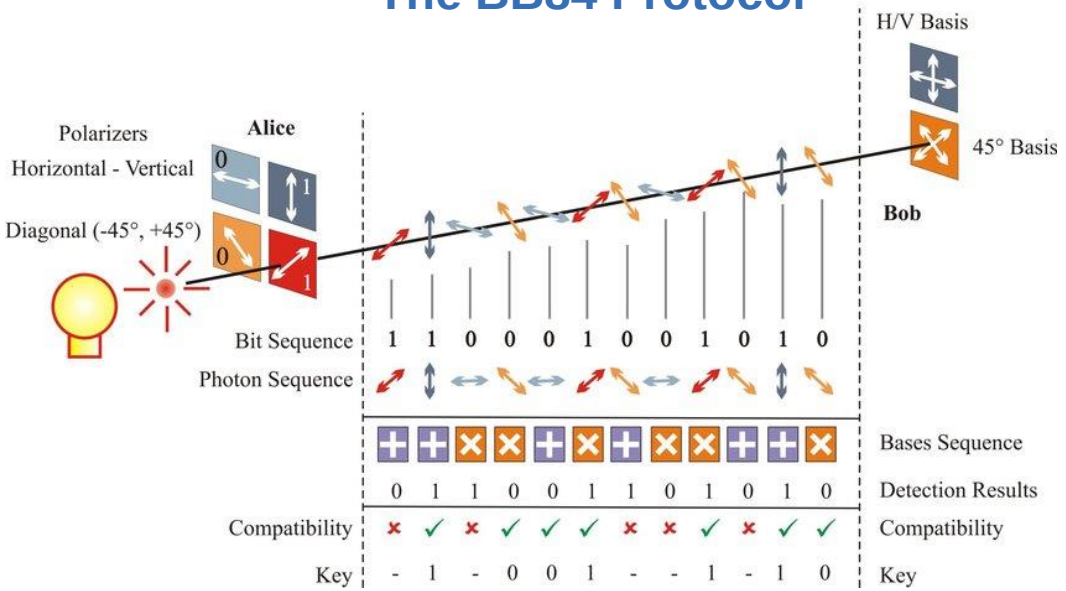
Quantum Communication

Traditional cryptographic techniques used today to transfer information across networks are considered to be at risk when sufficiently large quantum computers become available

Symmetric-key techniques like AES can in principle be attacked using Grover but extending the key length (e.g. from 128 to 256 bit) is considered to be quantum-resistant. However, this type of technique requires the sharing of private keys

Public-key techniques like RSA have the advantage of not having to share the private key, which makes them very suitable to use over distributed communication networks, but they are not quantum-resistant as they can be attacked by using Shor

The BB84 Protocol



Quantum Key Distribution (QKD) protocols allow to generate and distribute quantum-resistant, symmetric keys without ever actually sharing the keys across the channel.

If an attacker tries to listen the keys will not match and Alice and Bob will know of the attack.

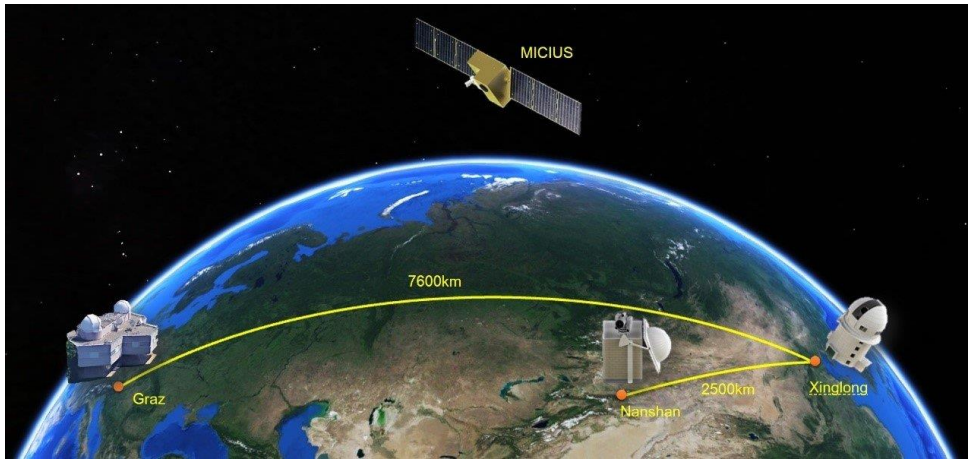
QKD Networks

Reliable transmission of entanglement over long distances is still not feasible today.

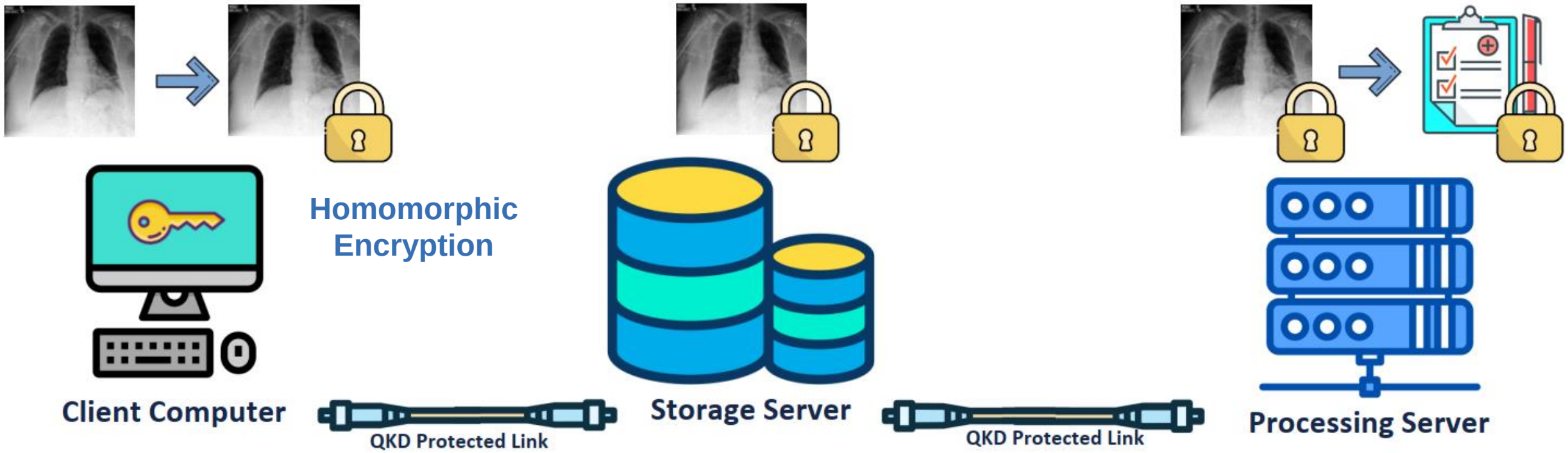
Work on extending the distance of range of quantum communication channels already had CERN and University of Geneva involved in 2009-2011 as part of the SwissQuantum project.

The entangled quantum states cannot be simply copied and retransmitted like with classic digital communication protocols. Communication is point-to-point.

More complex topologies use combinations of point-to-point links and hybrid fibre and line-of-sight links using satellites and telescopes.

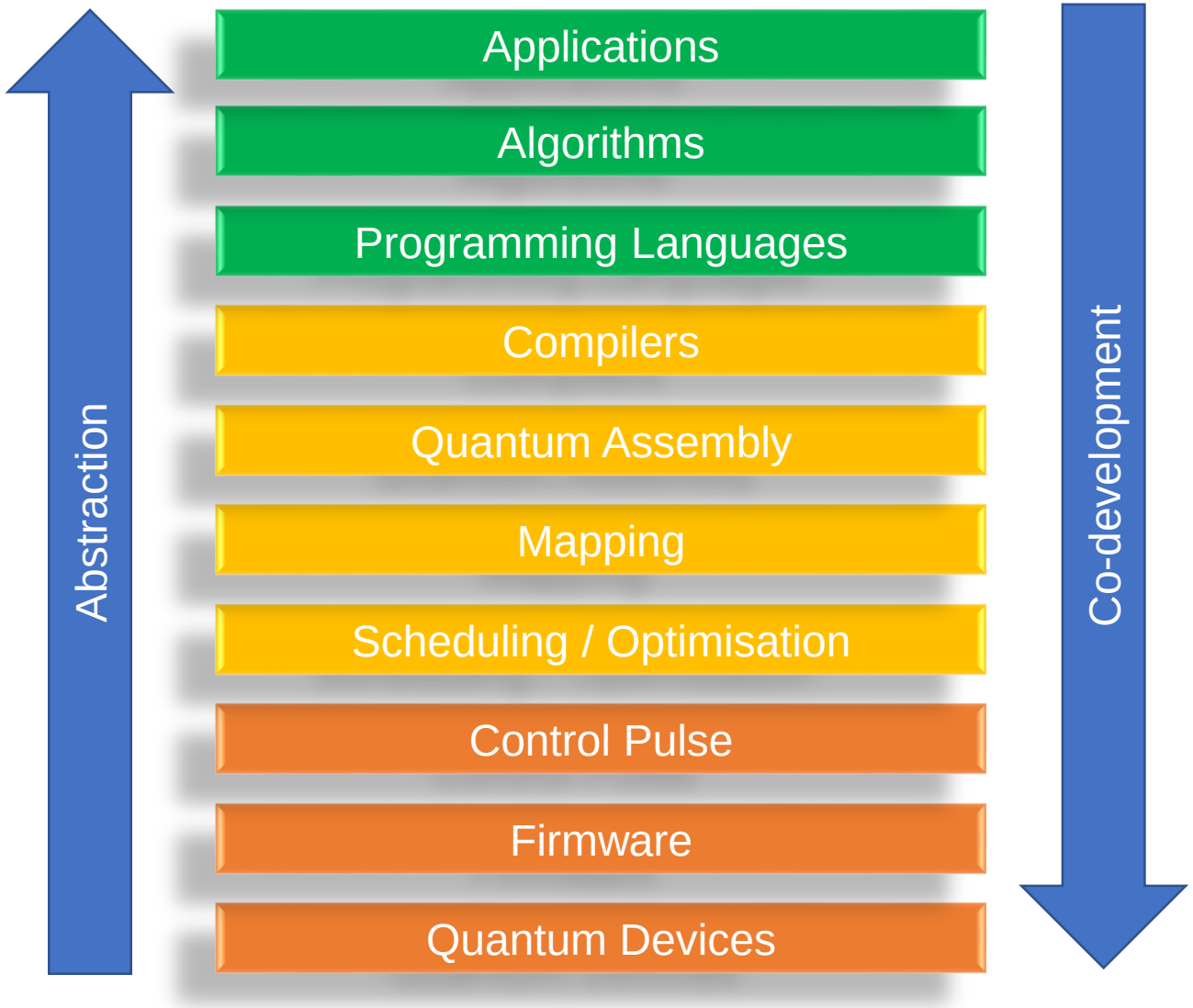


The Quantumacy Platform



Jose Cabrero-Holgueras & Gabriele Morello

Algorithms and Full-Stack Quantum Computers



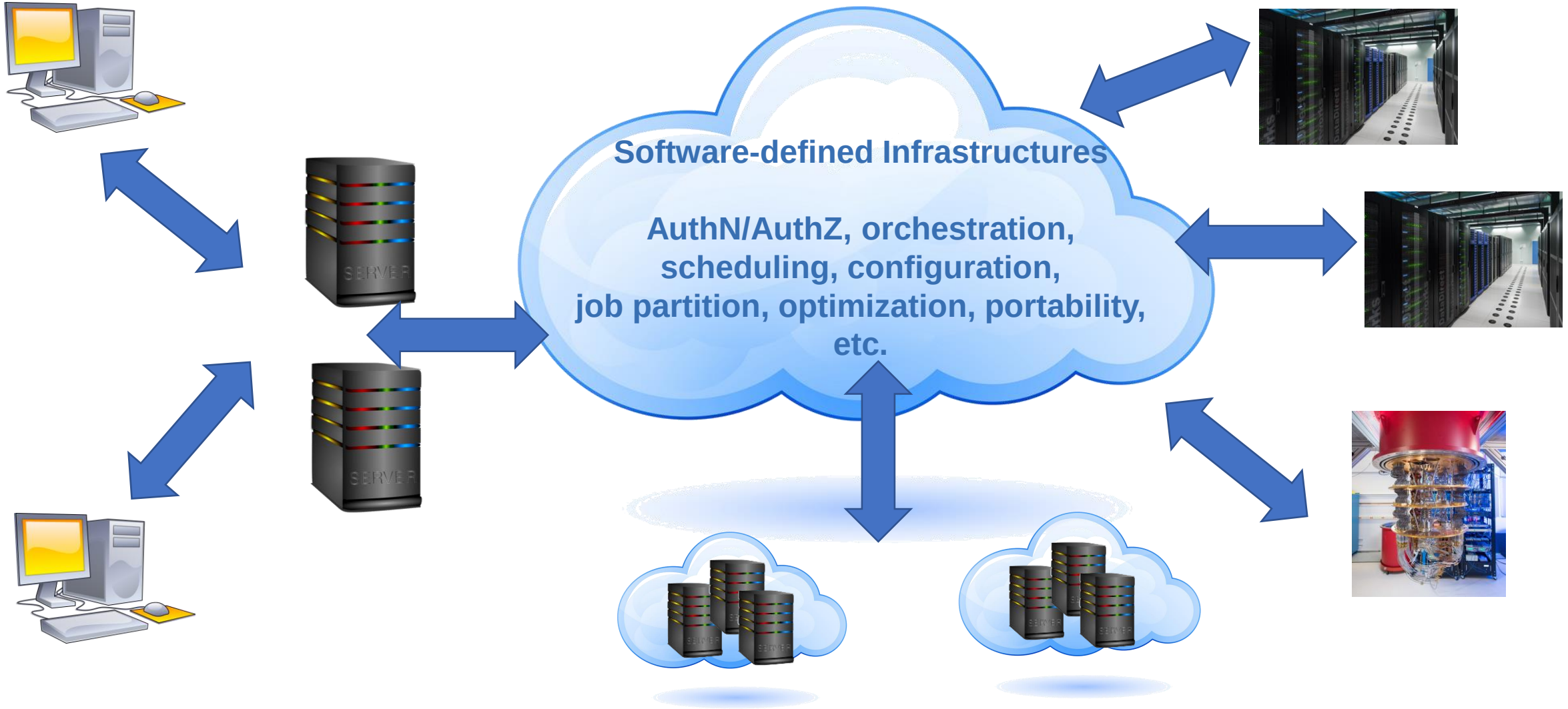
The abstraction we expect from computing platforms is not as mature yet as for classic platforms

Today quantum companies pride themselves to be “full-stack companies” because applications and algorithms have to be developed and optimised for specific hardware

- Today: need for co-development
- Tomorrow: better abstraction

Quantum algorithms
Quantum Machine Learning
Noise characterisation, mitigation, correction
Hybrid Classic-Quantum Algorithms and applications

Hybrid Classic-Quantum Computing Infrastructures



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

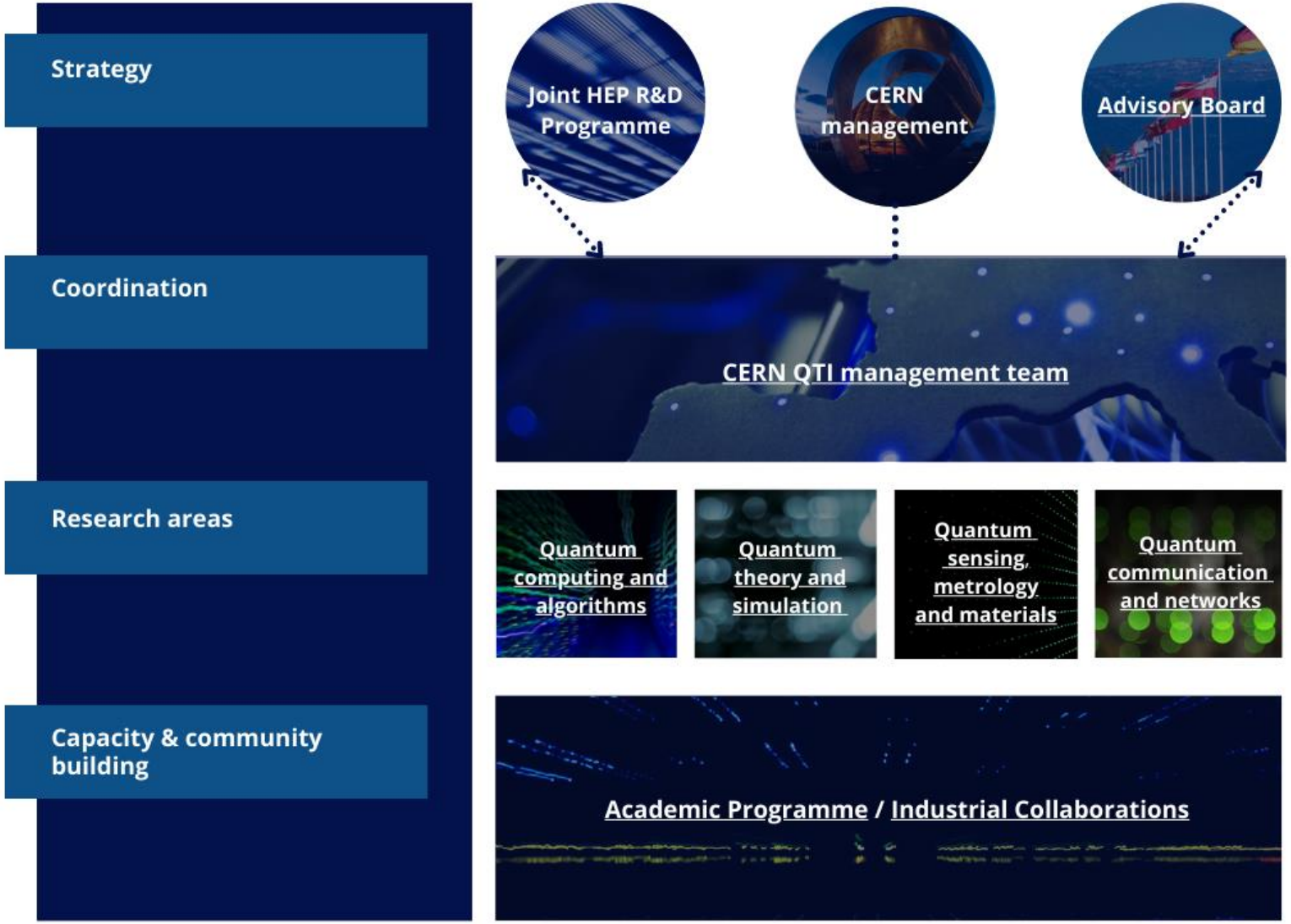
T1 - Scientific and Technical Development and Capacity Building

T3 - Community Building

T2 - Co-development

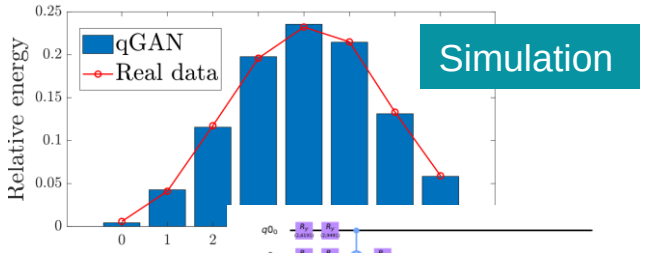
T4 - Integration with national and international initiatives and programmes

CERN Quantum Technology Initiative

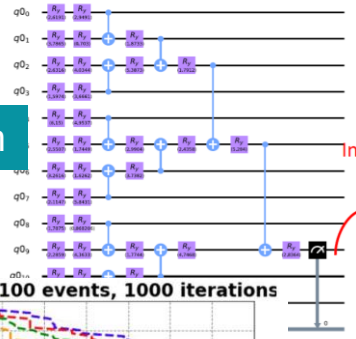


Areas of Research

Computing

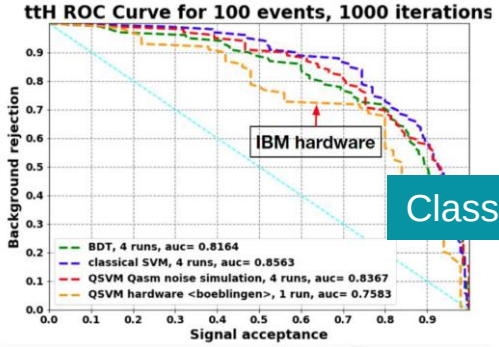


Simulation



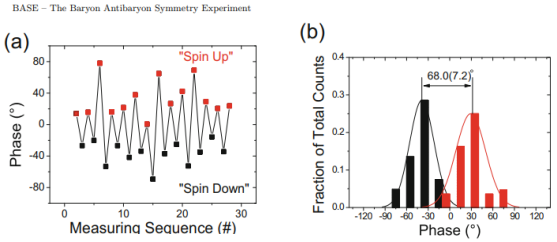
Reconstruction

Node Information



Classification

Sensing

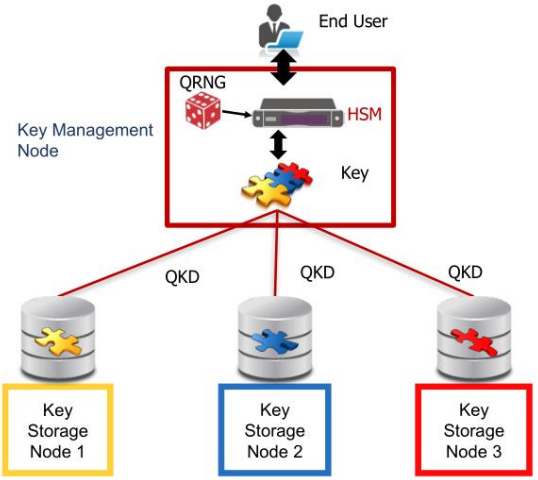


https://doi.org/10.1140/epjst/e2015-02607-4

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

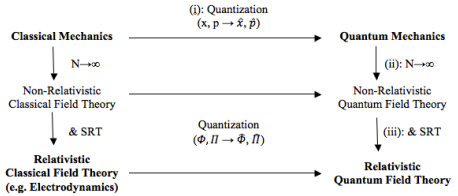
Future HEP Detectors

Communications

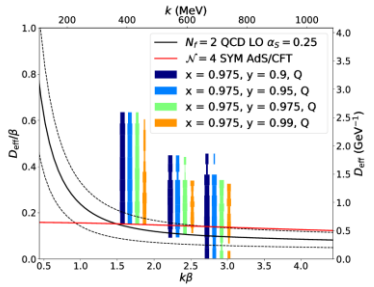


QKD infrastructures Quantum Internet

Theory



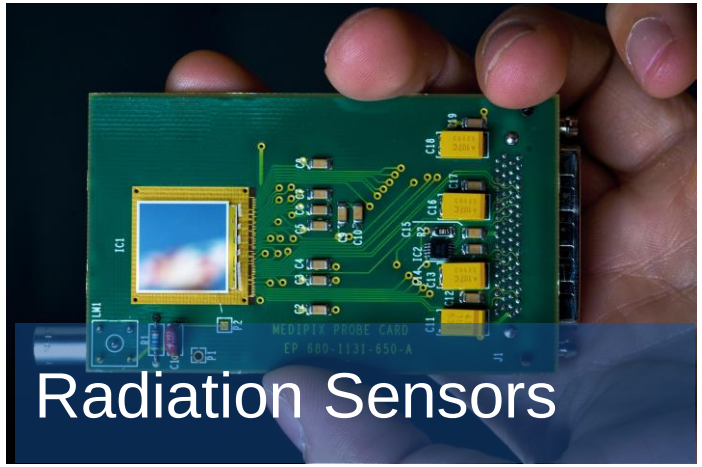
Quantum Field Theory

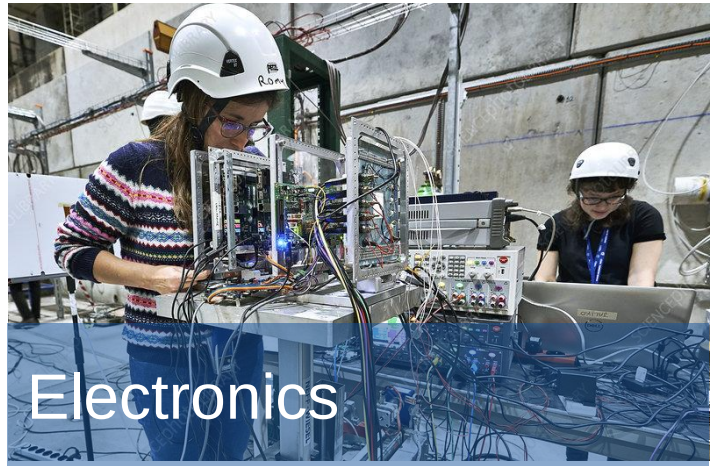


https://cds.cern.ch/record/2703396

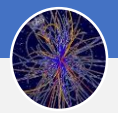
Lattice QCD

Enabling Technologies





Scientific and Technological Objectives

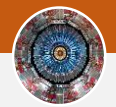


- Assess the **areas of potential quantum advantage** in HEP applications (QML, classification, anomaly detection, tracking)
- Develop **common libraries of algorithms, methods, tools**; benchmark as technology evolves
- Collaborate to the development of shared, **hybrid classic-quantum infrastructures**

Computing & Algorithms

- Identify and develop techniques for **quantum simulation** in collider physics, QCD, cosmology within and beyond the SM
- Co-develop quantum computing and sensing approaches by providing **theoretical foundations** to the identifications of the areas of interest

Simulation & Theory



- Develop and promote **expertise in quantum sensing** in low- and high-energy physics applications
- Develop quantum sensing approaches with emphasis on **low-energy particle physics measurements**
- Assess **novel technologies and materials** for HEP applications

Sensing, Metrology & Materials

- **Co-develop CERN technologies relevant to quantum infrastructures** (time synch, frequency distribution, lasers)
- Contribute to the **deployment and validation of quantum infrastructures**
- Assess requirements and **impact of quantum communication on computing applications** (security, privacy)

Communications & Networks

R&D Collaborations and Partnerships

Organizations and Projects

Industry

IBM Q-Net

Xanadu

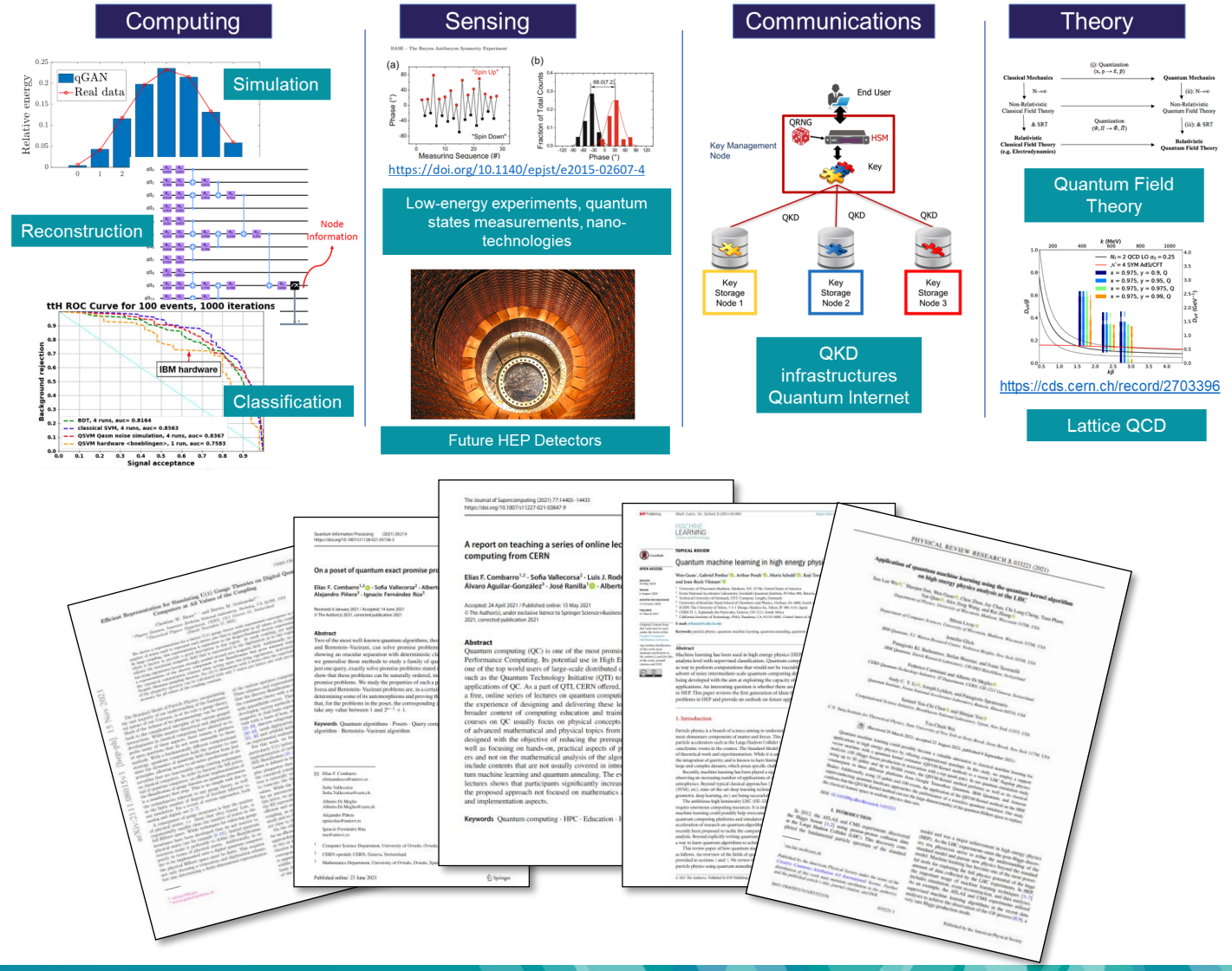
Cambridge
Quantum
Computing

Universidad de Oviedo

Academia, Research Labs and Agencies

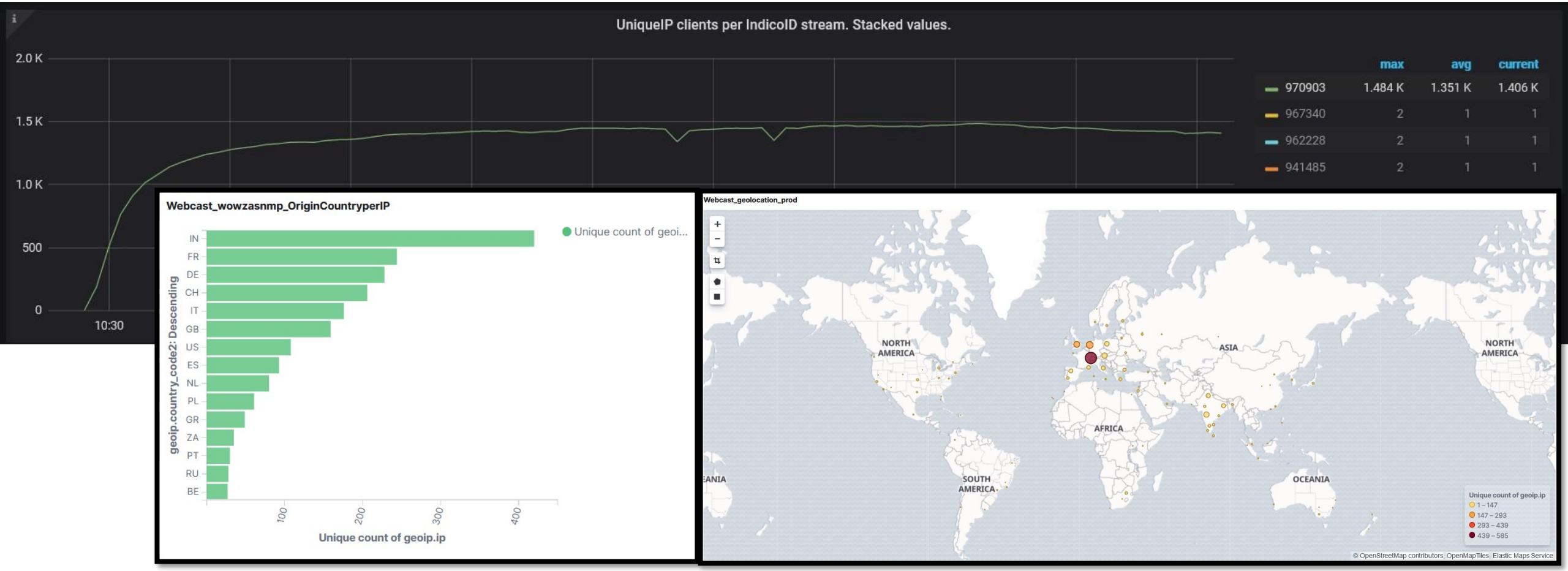
Scientific Publications (2021)

- **More than 20 projects in all four quantum areas**
- **18 papers**
  - 8 on peer-reviewed journals
- **More than 20 talks and presentations at conferences and workshops**



“A Practical Introduction to Quantum Computing”

A 7-part lecture series by Prof. Elias Combarro, University of Oviedo, CERN Scientific Associate



CERN QTI Colloquia

High-level discussions on large-scope quantum research contributions

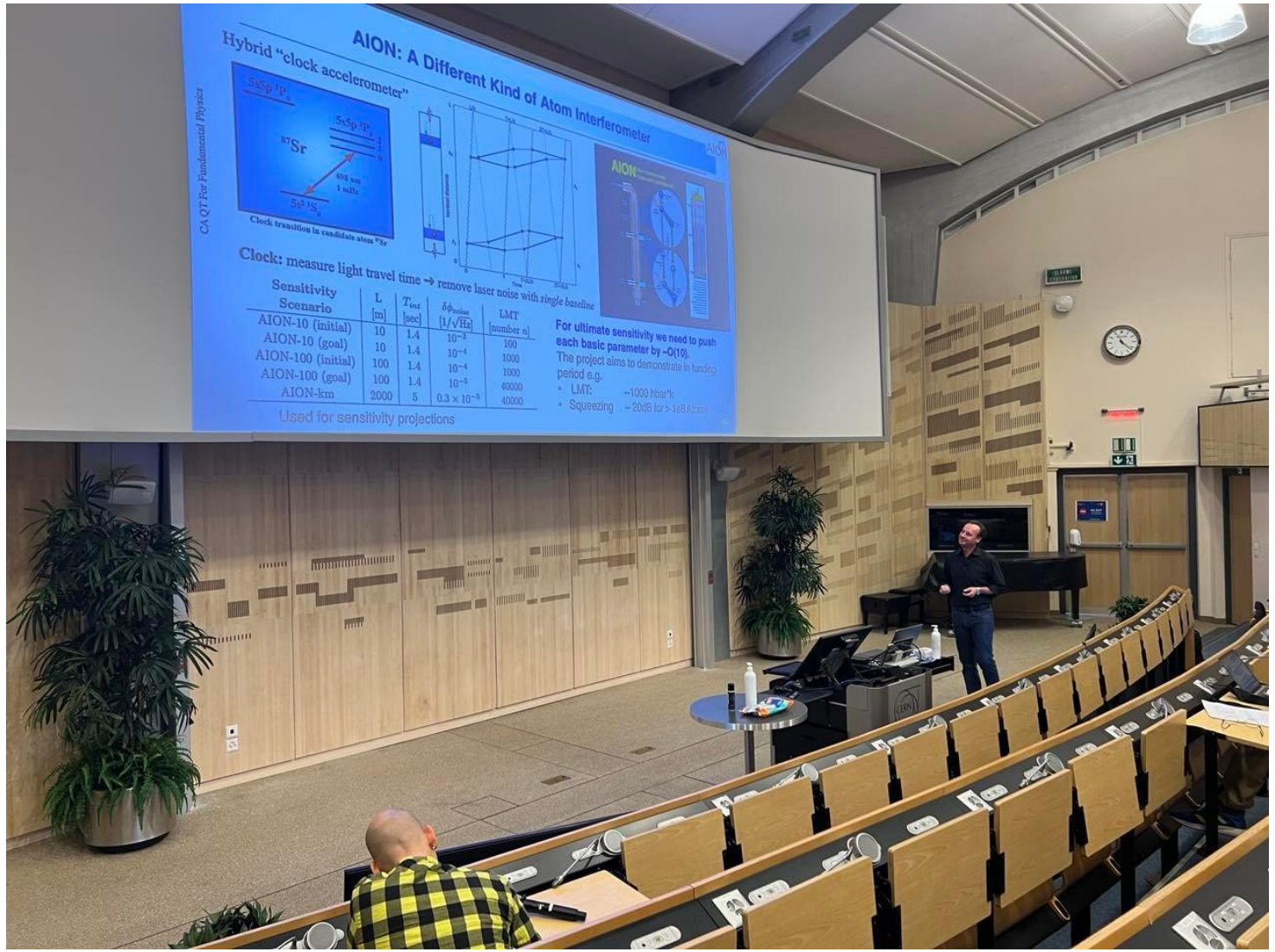
Launched on **6 April**

First colloquium given by Oliver Buchmüller on "Quantum sensors for the AION experiment"

Next date (planned): **4 May.**

Speaker: Noah Kurinsky

Topic: "Quantum Sensors for Direct Detection of Sub-GeV Dark Matter"



Quantum technology is an emerging field of physics and engineering that have the potential to revolutionise science and society in the next five to ten years. Knowledge in this rapidly evolving field has advanced considerably, yet still there are resources required that are not a mainstream today.

CERN can be at the forefront of this revolution. Given the broad range of specialised technical expertise found at CERN, the Laboratory is in a unique position today to take a leading role in the development of quantum technologies not only for its own programmes, but also as a general contribution to the advancement of science and technology.

The CERN Quantum Technology Initiative (QTI) will define a three-year roadmap and research programme in collaboration with the HEP and quantum-technology research communities. Together, we will establish joint research, educational and training activities, set up the supporting computing infrastructure, and provide dedicated mechanisms for exchange of both knowledge and technology.

LATEST NEWS

https:worldquantumday.org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