



Network eAcademy:

Training for Quantum and Time & Frequency Networks

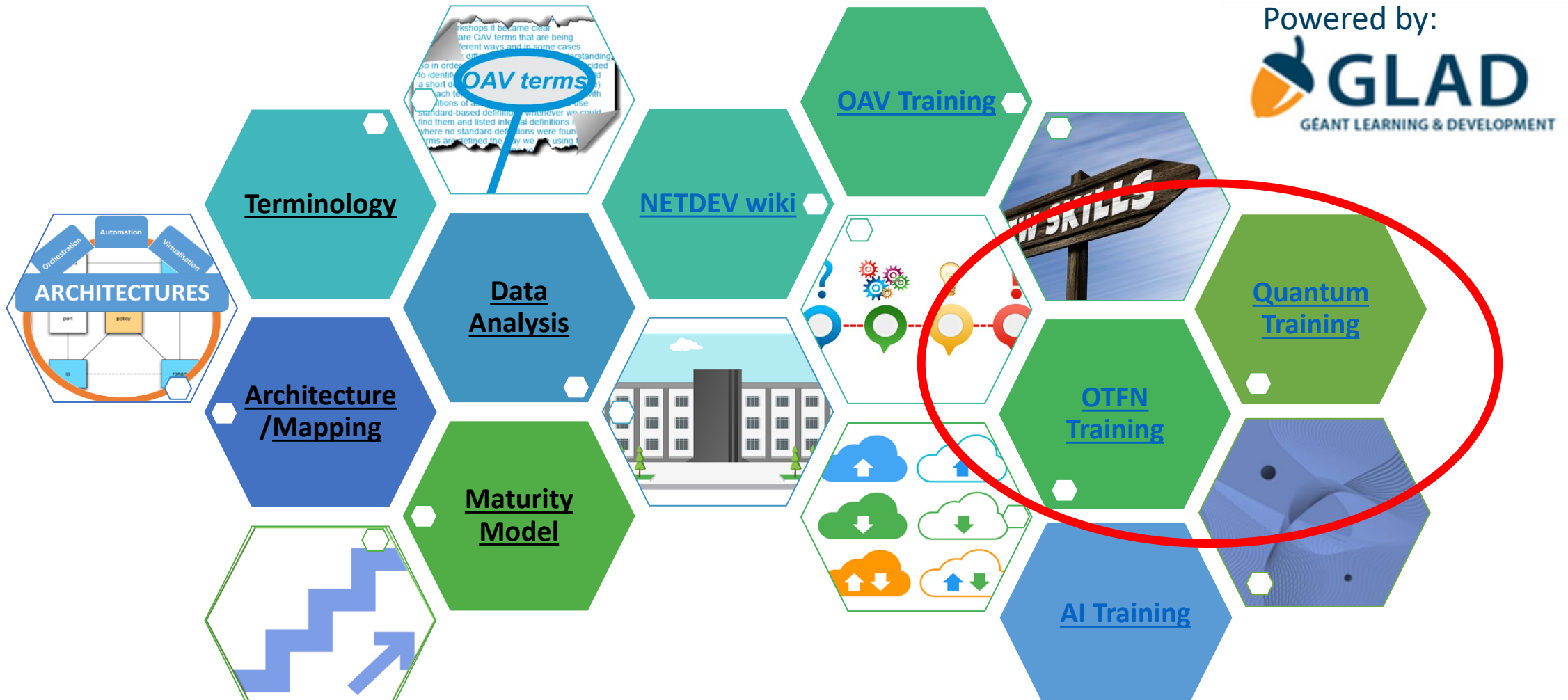
Susanne Naegele-Jackson, FAU

GNA-G Network eAcademy Working Group - Fourth Open Monthly Meeting

February 11, 2026, <https://events.geant.org/event/2019/>

Network eAcademy, as a Service in GÉANT

To help and support organisations in human capital development in Network-development-related domains, as an umbrella covering several activities



Network e-Academy

Community-driven training platform for advanced networking

- It offers free courses and learning materials on emerging network technologies
- Intended for NRENs and for the research and education community at large - engineers, managers, researchers, and students
- Mostly short learning units that can be consumed quickly and on-demand
- More than 50 learning units across 3 tracks



Why have different eAcademy areas?

- To cover new emerging technologies that NRENs are exploring
- To upskill existing professionals
- To identify relevant use cases
- For Quantum eAcademy:
 - to raise awareness about Quantum computing potentially threatening to break much of the cryptography we currently use and what to do about it
- For Time & Frequency Networks:
 - To understand network synchronisation which is essential to ensure that distributed network components operate in unison, maintaining precise frequency and time references for reliable, secure, and efficient operations as is needed for many applications

Where Do We Need Precise Time?



Many applications require precise time in everyday life: These applications can be found in different areas ranging from transport and navigation, to defence and security, but are also necessary in sciences, power grids and distributed installations, in telecommunications and - last but not least - in the financial sector. We will look at some of these use cases in more detail later in this learning unit.

Some of these sectors have very high values in terms of assets, people employed and people served.

Financial	Defence	Transport	ICT
<p>Financial sector:</p> <ul style="list-style-type: none"> According to the "Report on financial structures"¹ from European Central Bank at the end of 2015, the size of the overall euro area financial sector (assets held by MFIs. 	<p>Defence sector:</p> <ul style="list-style-type: none"> Estimates suggest that the defence sector could indirectly support another 1.2 million to 2 million jobs across the EU. According to the "The European defence 	<p>Transport sector:</p> <ul style="list-style-type: none"> There were about 1.4 mln enterprises in EU in 2021. Employed 10.2 million persons. The transportation and storage services' value added accounted for €527.5 billion in 2021.³ 	<p>ICT sector:</p> <ul style="list-style-type: none"> The EU ICT sector value added was over €718 billion in 2021. The ICT sector employed 6.7 million people in 2021.⁴

Access to courses through wiki (I)

- <https://wiki.geant.org/display/NETDEV/Network+eAcademy>

The screenshot displays the Network eAcademy wiki page. The left sidebar contains navigation options: Pages, Blog, Calendars, Analytics, and SPACE SHORTCUTS. The main content area is titled "Network eAcademy" and includes a description of the platform's purpose. Below the description are several key sections:

- Network eAcademy Training Portal:** A section with three sub-panels: Network Automation, Quantum Technology, and Time & Frequency Networks.
- OAV Maturity Model:** A section explaining the model's four main dimensions and their subdimensions.
- OAV Architectures:** A section describing the high-level architectural blueprint (ODA) for Network Management, Operations, and Business Support Systems.
- OAV Terminology:** A section discussing the need for a common basis for OAV terms used in different contexts.
- OAV Community Portal:** A section encouraging users to follow OAV examples by country.

On the right side of the page, there is a word cloud and a section titled "Infoshares ++ Events" listing various events and presentations, including the CARNET Conference and the JISC Networkshow.

This section provides a detailed view of the "Network eAcademy Training Portal". It features a large image of hands interacting with a laptop. Below the image, the title "Network eAcademy Training Portal" is prominently displayed. Underneath, there are three distinct panels, each with a title and a corresponding diagram or chart:

- Network Automation:** Includes a diagram showing various automation components and their interactions.
- Quantum Technology:** Includes a diagram illustrating quantum technology applications in networking.
- Time & Frequency Networks:** Includes a diagram showing the structure and components of time and frequency networks.

Access to courses through wiki (II)

- <https://wiki.geant.org/display/NETDEV/Network+eAcademy>

Network eAcademy Training Portal

Created by Susanne Nägele-Jackson, last updated on Oct 17, 2025 • 3 minute read

Network Training

This Training Portal is offering courses focused on the research and education external references that can be useful for us and examples that can be closer training by the community for the community. We will be publishing new classes are online courses that you can follow and complete at your own pace.

Network Automation

Take network automation classes to learn about orchestration, automation and virtualisation of networks with network architecture, data modeling, data formats and protocols and CI/CD and then move networks using data analytics and AI.

[Learn more about Network Automation...](#)

Quantum Technology

Follow our Quantum technology track to learn about basics such as Qubits, Qubit Entanglement. Find out about Quantum Key Distribution and quantum simulation. Or learn the latest on standardisation.

[Learn more about Quantum Technology...](#)

Time and Frequency Networks

Follow our track for Time and Frequency Networks to learn about the basic metrology concepts of time and frequency, or find out about working with White Rabbit in networks. Other learning units will offer Optical Carrier Distribution, or the ELSTAB system, which is used for Time and Frequency over optical fibers.

[Learn more about Time and Frequency Networks...](#)

Quantum Technology

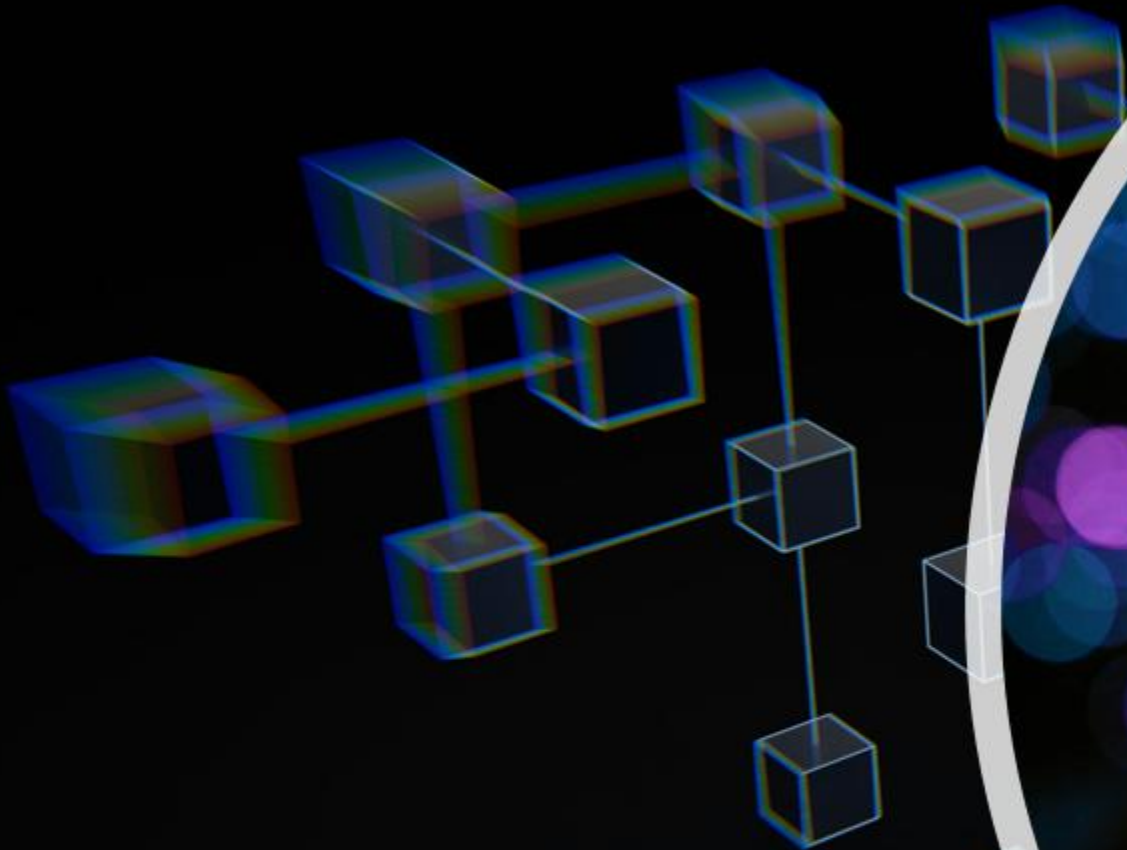
Time and Frequency Networks

Basic Layout

• Similar look and feel as Network Automation eAcademy

The image displays a collage of overlapping screenshots from an e-learning platform, illustrating its basic layout. The screenshots are arranged in a layered fashion, showing different parts of the user interface. Red circles highlight specific elements across the various pages:

- Course Overview:** The 'OVERVIEW' tab is highlighted in red circles on multiple pages, including the 'Why Do We Need Precise Time' and 'Time and Frequency Network' pages. The 'Main Goals' link is also circled in red on the 'Time and Frequency Network' page.
- Navigation and Content:** The 'Existing and Planned T&F Networks' video player and its associated PDF download link are circled in red. The 'Useful Links' menu item is circled in red on the 'Time and Frequency Network' page.
- Quiz and Feedback:** The 'Short Quiz on Time and Frequency Network' page is shown, along with a 'Training Feedback' form where the 'Certificate of completion' checkbox is circled in red.
- Course Structure:** The 'Quantum Algebra: Qubits' page shows a navigation menu with 'What's Next?' circled in red.
- Course Details:** The 'Cable Transmission' page shows a 'Main Goals' section with a typewriter image and a 'Self paced' option.

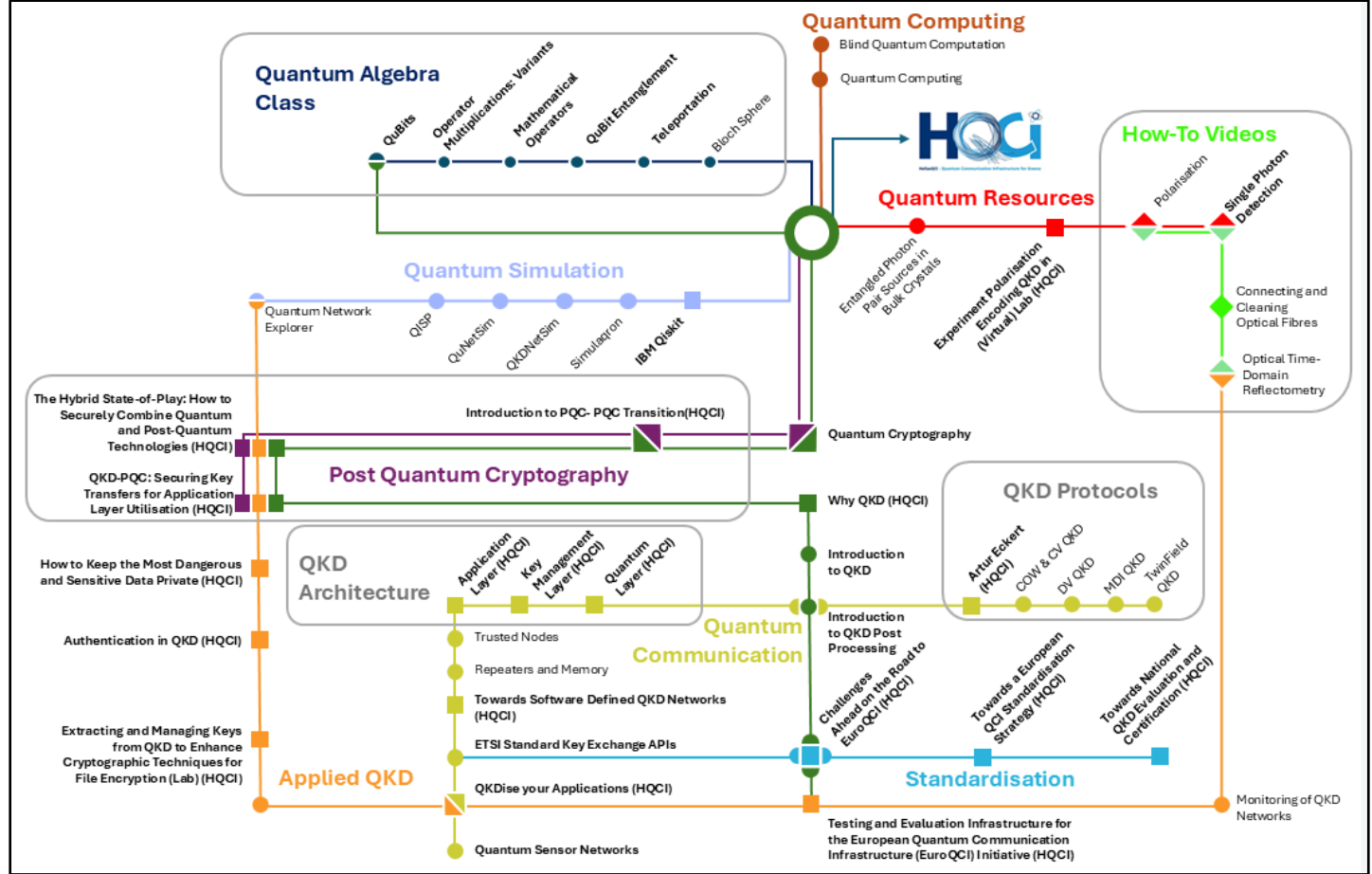


**Quantum
eAcademy**

Quantum eAcademy (I)

- Classes accessible via links
- Classes also accessible via metro map
 - Available classes are clickable on map
 - Circles for classes in Moodle
 - Rectangles for links to documents or external material
 - Various sections and metro lines that cover different topics
 - A green line for introductory courses

Introduction <ul style="list-style-type: none"> Quantum Algebra Class <ul style="list-style-type: none"> Qubits (30) Operator Multiplications: Variants (30) Mathematical Operators (30) Qubit Entanglement (30) Teleportation (30) Why QKD? (HQCI) (20) New Introduction to QKD (120) New Introduction to QKD Post Processing (30) 	Quantum Communication <ul style="list-style-type: none"> QKD Architecture <ul style="list-style-type: none"> Quantum Layer (HQCI) (20) Key Management Layer (HQCI) (25) Application Layer (HQCI) (20) Towards Software-Defined QKD Networks (HQCI) (20) QKD Protocols <ul style="list-style-type: none"> Artur Ekert (HQCI) (30)
Quantum Simulation <ul style="list-style-type: none"> IBM Qiskit (10) 	Quantum Standardisation <ul style="list-style-type: none"> ETSI Standard Key Exchange APIs (30) Challenges Ahead on the Road to EuroQCI (HQCI) (15) Towards a European QCI Standardisation Strategy (HQCI) (15) Towards National QKD Evaluation and Certification (HQCI) (15)



Quantum eAcademy (II)

Available lines

- General Introduction
- Quantum Algebra
- Quantum Communication
- Quantum Simulation
- Quantum Computing
- Post Quantum Cryptography
- Applied QKD
- Standardisation
- Quantum Resources
- How-To Videos



Cooperation with

- Hellas QCI Training Platform
- <https://training.hellasqci.eu/>

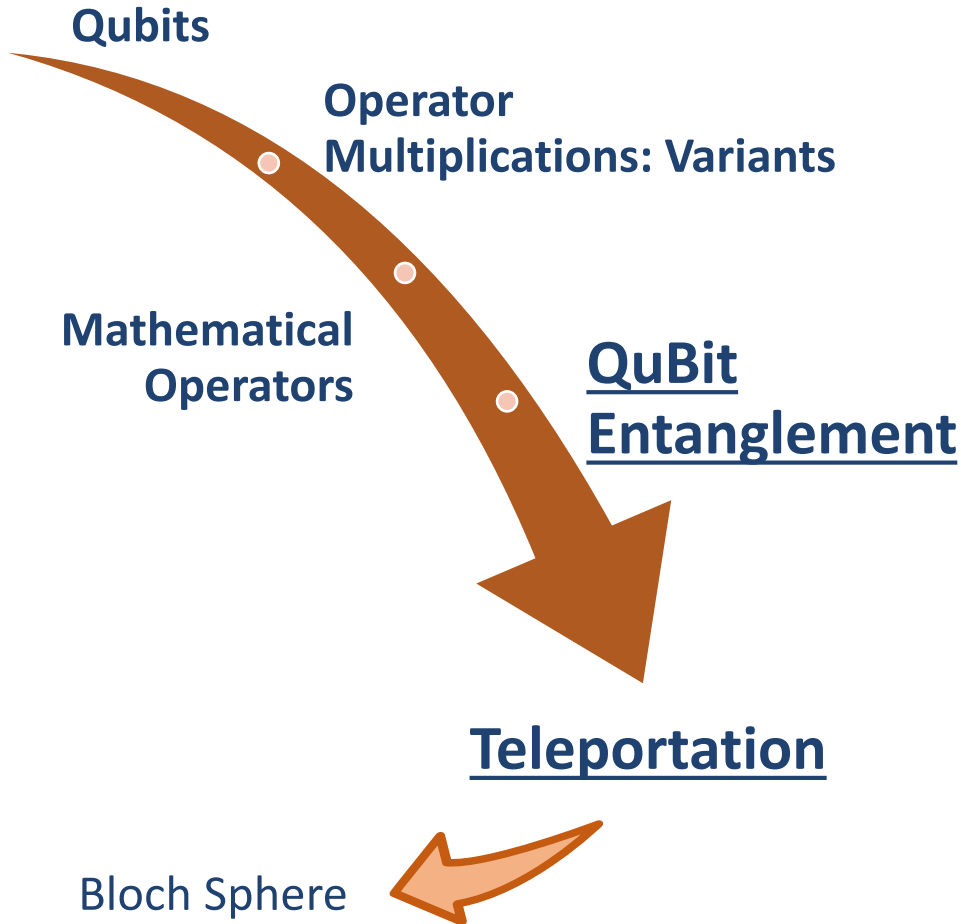


New in Quantum eAcademy

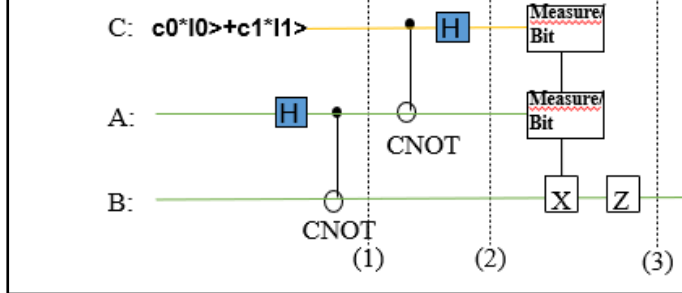
- How-To Videos
- Concept of whole classes
- HellasQCI Training via Zenodo links
- Direct link to HellasQCI training platform (login required)

New Concept: Quantum Algebra Class (I)

- 5 learning units + 1 addendum



At the end, Qubit-B (right side of the marker (3)) is in the starting state
teleportation is finished.



$$\begin{bmatrix} a \\ b \end{bmatrix} \otimes \begin{bmatrix} c \\ d \end{bmatrix} = \begin{bmatrix} a \begin{bmatrix} c \\ d \end{bmatrix} \\ b \begin{bmatrix} c \\ d \end{bmatrix} \end{bmatrix} = \begin{bmatrix} ac \\ ad \\ bc \\ bd \end{bmatrix}$$

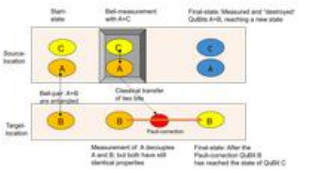
$$\begin{pmatrix} a & b \\ c & d \end{pmatrix} \otimes \begin{pmatrix} e & f \\ g & h \end{pmatrix} = \begin{pmatrix} a \begin{pmatrix} e & f \\ g & h \end{pmatrix} & b \begin{pmatrix} e & f \\ g & h \end{pmatrix} \\ c \begin{pmatrix} e & f \\ g & h \end{pmatrix} & d \begin{pmatrix} e & f \\ g & h \end{pmatrix} \end{pmatrix} = \begin{pmatrix} ae & af & be & bf \\ ag & ah & bg & bh \\ ce & cf & de & df \\ cg & ch & dg & dh \end{pmatrix}$$

Wait a minute . . .

Did I get this right?



- Qubit-A and Qubit C *****ARE***** at the source location and they never move to the target location???
- Only two classical bits from the measurement at the source location are moved classically to the target location.



New Concept: Quantum Algebra Class (II)

- Most learning units of the class contain exercises
- Exercises ≠ Quizzes; Results tabs are available

Quantum Algebra: Mathematical Operators

Course Settings Participants Grades Reports More ▾

INTRODUCTION Quantum Algebra Class Identity Operator Hadamard Operator **Exercise 1**

Pauli Operator X Pauli Operator Z Pauli Operator Y Operator Applications **Exercise 2**

Useful Links Quiz Feedback & Certificate What's Next? Results

Let's do more exercises...




Photo by Laura Rivera on Unsplash

Z = ?
 Z ⊗ Z =
 X = ?
 Z * X = ?
 CNOT = ?
 |V4> = ?
 CNOT |V4> = ?

(To check your answers, go to the Results tab.)

INTRODUCTION Quantum Algebra Class Identity Operator Hadamard Operator Exercise 1

Pauli Operator X Pauli Operator Z Pauli Operator Y Operator Applications Exercise 2

Useful Links Quiz Feedback & Certificate What's Next? Results

Need some exercises?

Let's have a look at the **Identity Operator I** again:




Photo by Michal Malton on Unsplash

$$I = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$$

$$I * |0\rangle = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} * \begin{bmatrix} 1 \\ 0 \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$$

How did we get this result?

$$\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} * \begin{bmatrix} 1 \\ 0 \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$$

1 * 1 + 0 * 0 = 1 (upper value)
 and
 0 * 1 + 1 * 0 = 0 (lower value)

Now let's try this for the **Hadamard Operator H**:

$$H = \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}$$

$$H * |0\rangle = \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix} * \begin{bmatrix} 1 \\ 0 \end{bmatrix} = ?$$

$$H * |1\rangle = \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix} * \begin{bmatrix} 0 \\ 1 \end{bmatrix} = ?$$

(To check your answers, go to the Results tab.)

Useful Links Quiz Feedback & Certificate What's Next? **Results**

Exercise 1:

$$H * |0\rangle = \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix} * \begin{bmatrix} 1 \\ 0 \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \end{bmatrix}$$

$$H * |1\rangle = \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix} * \begin{bmatrix} 0 \\ 1 \end{bmatrix} = \begin{bmatrix} 1 \\ -1 \end{bmatrix}$$

Exercise 2:

$$Z = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

$$Z \otimes Z = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \otimes \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} = \begin{pmatrix} 1 \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} 0 \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \\ 0 \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} -1 \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$$X = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$$

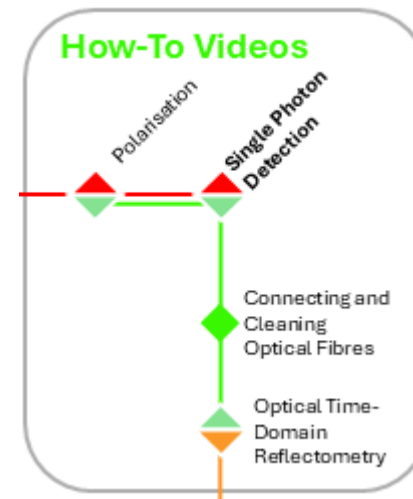
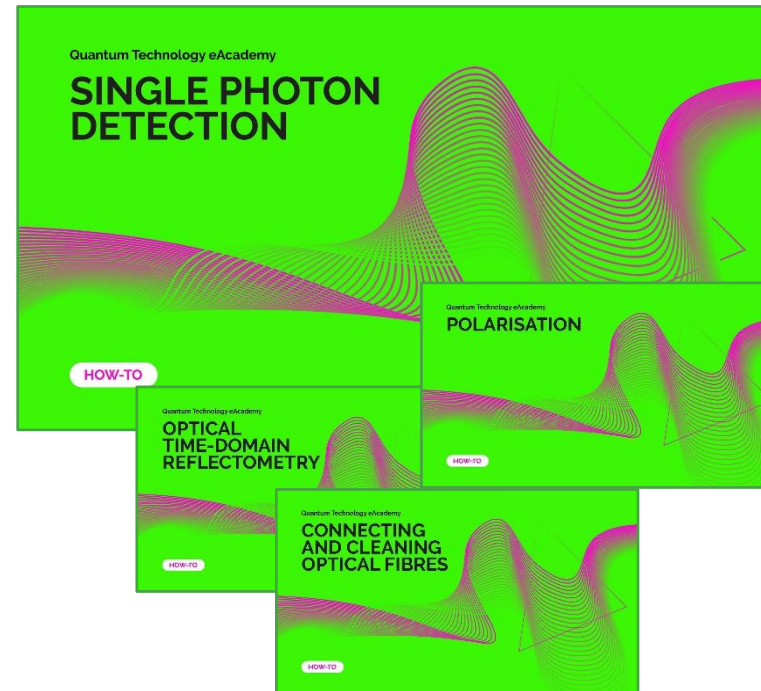
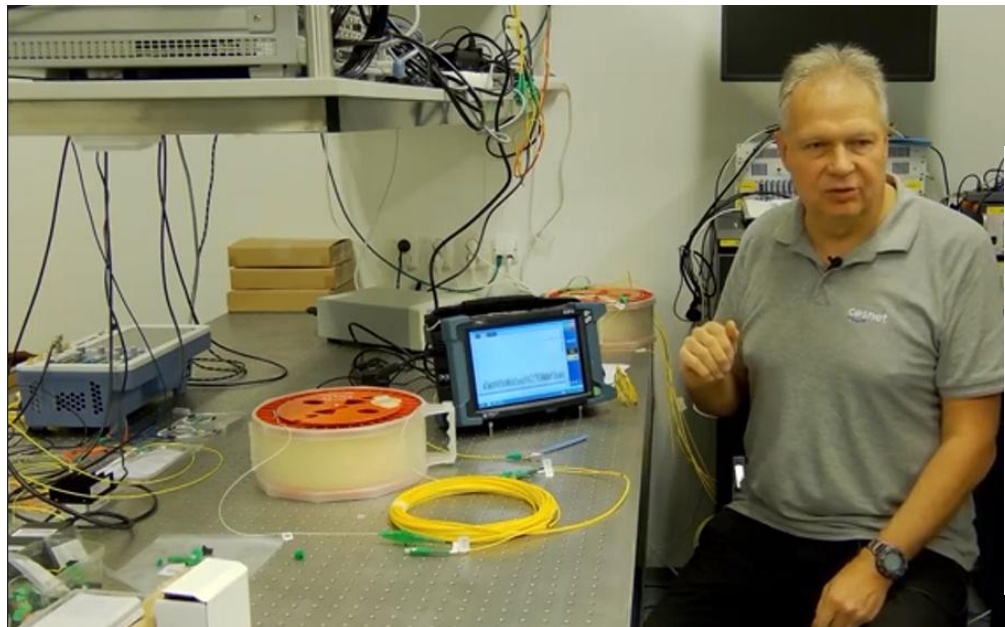
$$Z * X = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} * \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} = \begin{pmatrix} (1*0+0*1) & (1*1+0*0) \\ (0*0-1*1) & (0*1-1*0) \end{pmatrix} = \begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}$$

$$|V4\rangle = \begin{bmatrix} v00 \\ v01 \\ v10 \\ v11 \end{bmatrix}$$

$$CNOT |V4\rangle = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} |V4\rangle = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{bmatrix} v00 \\ v01 \\ v10 \\ v11 \end{bmatrix} = \begin{bmatrix} 1*v00 + 0*v01 + 0*v10 + 0*v11 \\ 0*v00 + 1*v01 + 0*v10 + 0*v11 \\ 0*v00 + 0*v01 + 0*v10 + 1*v11 \\ 0*v00 + 0*v01 + 1*v10 + 0*v11 \end{bmatrix} = \begin{bmatrix} v00 \\ v01 \\ v11 \\ v10 \end{bmatrix}$$

New Concept: Hands-on Videos

- Short demonstrations
- Includes script with screenshots and timestamps
- Includes useful links, but no quiz



Measurement
Measuring Problems

02:29.000 → 02:51.000:
We can find out whether there are any nonlinearities, whether we have any increased attenuation, whether we have any optical connector joints, whether there are any welds, how a large bend may have occurred, and additional attenuation is occurring, so is there a problem somewhere?

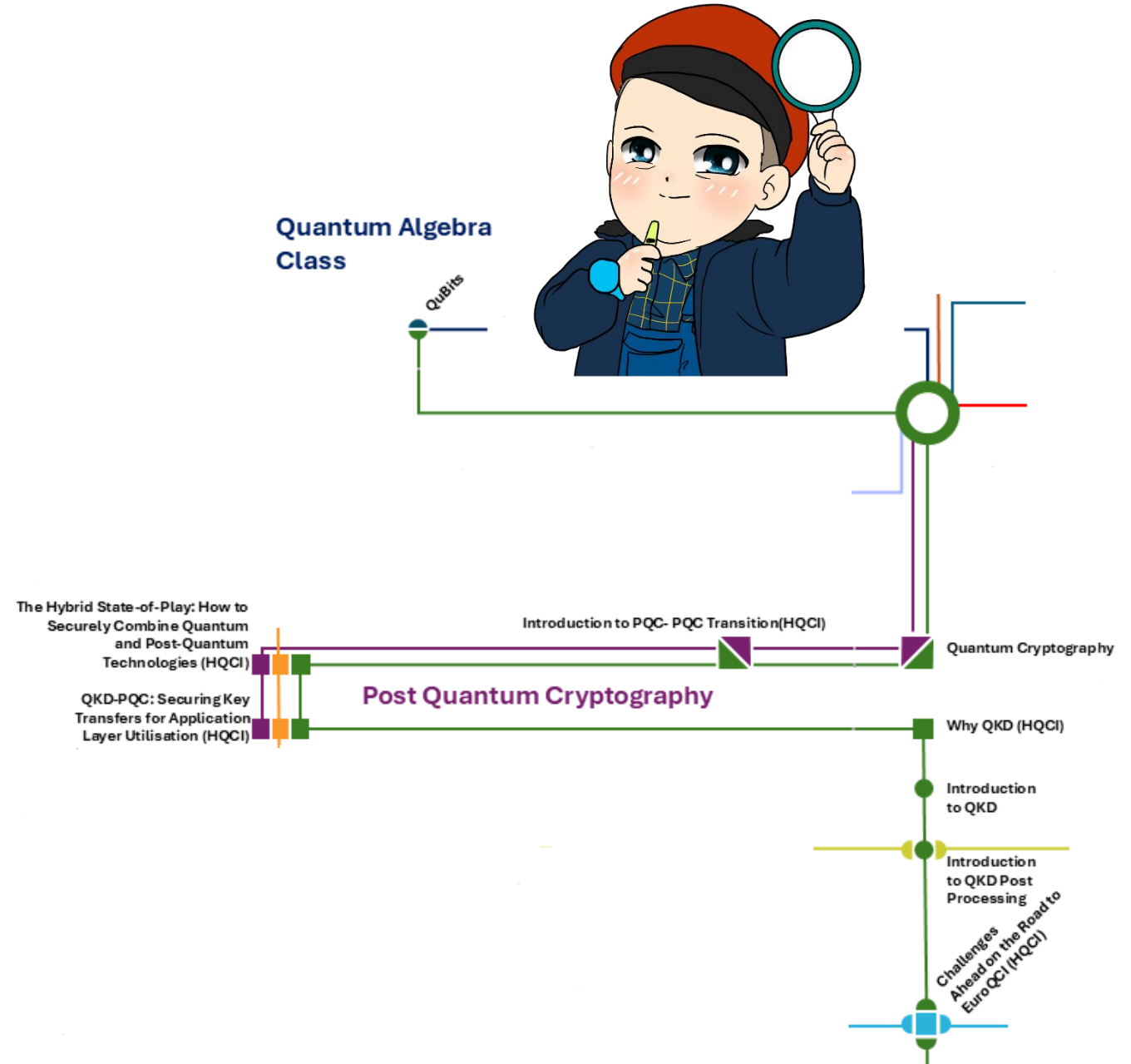
02:51.000 → 03:19.000:
Alternatively, we are actually able, because the time is converted to distance based on the speed of light in the fibre, so we are able to determine with some accuracy the place where the problem arose and perhaps we can find out on the optical path: "Aha, there was an excavation here", "someone cut the cable here", "there's a problem in the fibre or cable". And we are actually able to detect this on one side and at the same time measure some other parameters: weld attenuation, connector attenuation.

Measurement
Actual Measurement

03:19.000 → 03:52.000:
So now let's see what the ODR optical device actually shows us. Currently, we have one input/output connector here, we still have a 1 km fibre coil stored in the device, and this route continues here with an unconnected patch cord. This means that here, when we are actually in real-time mode, where there is no averaging and noise reduction that is coming back to us from that route. Here you can see how the noise is running and here is the beginning of the route. So when we zoom in...

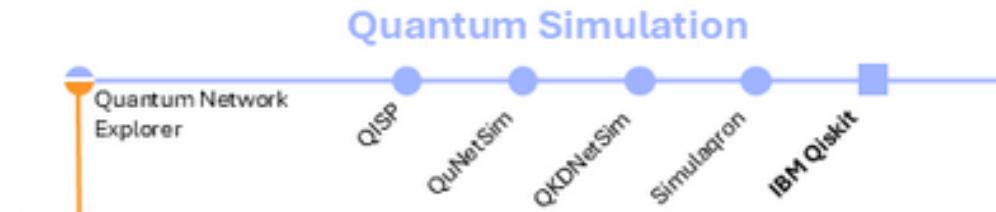
The green metro line: Introduction

- QuBits (30')
- Quantum Cryptography (HQCI) (45')
- Introduction to PQC - PQC transition (HQCI) (30')
- The Hybrid State-of-Play: How to Securely Combine Quantum and Post-Quantum Technologies (HQCI) (15')
- QKD-PQC: Securing Key Transfers for Application Layer Utilisation (HQCI) (35')
- Why QKD? (HQCI) (20')
- Introduction to QKD (120')
- Introduction to QKD Post Processing (30')
- Challenges Ahead on the Road to EuroQCI (HQCI) (15')



The lavender metro line: Quantum simulation

- Available learning units
 - IBM Qiskit (wiki)
- In preparation
 - Simulaqron
 - QKDNetSim



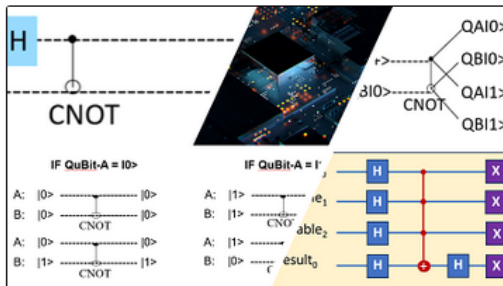
Qiskit

Created by Susanne Nägele-Jackson, last updated on Feb 06, 2026 • 1 minute read



IBM Qiskit is an open-source toolkit that helps users schedule and run quantum programs either in the cloud on a variety of simulators and quantum processors or in their local Python environment. Users have the option to build their own circuits or select some pre-built circuits from an extensive circuit library. More information including tutorials, Youtube videos and user exchange platforms are available under the following links:

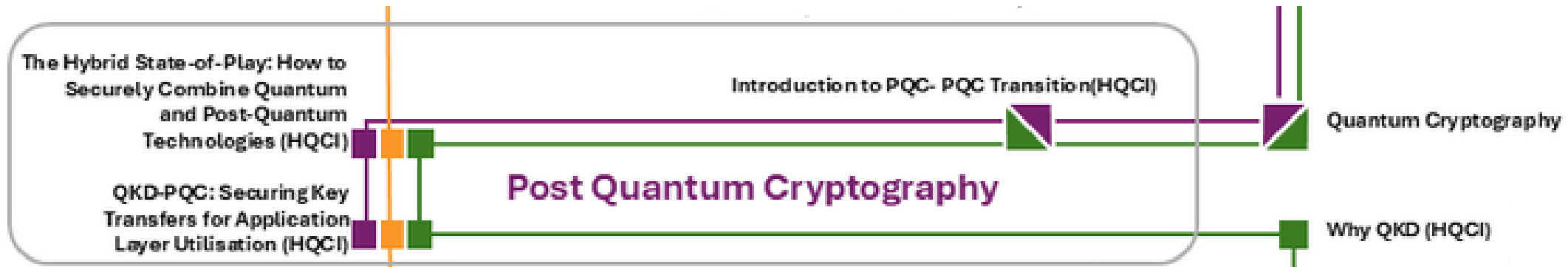
- <https://qiskit.org/>
- <http://qiskit.slack.com/>
- <https://www.youtube.com/@qiskit>
- <https://qiskit.org/documentation/>
- <https://github.com/Qiskit>
- Qiskit Foundations - Coding with Qiskit Season 1, https://www.youtube.com/playlist?list=PLOFEBzvs-VvrgHZT3exM_NNINKtZIHvZI
- Qiskit Textbook, <https://qiskit.org/learn/>
- Qiskit Runtime Service, <https://www.ibm.com/quantum/qiskit-runtime>
- <https://medium.com/qiskit>
- Microsoft Quickstart: Submit a circuit with Qiskit to Azure Quantum, <https://learn.microsoft.com/en-us/azure/quantum/quickstart-microsoft-qiskit?pivot=platform-ionq>
- James L. Weaver, Frank J. Harkins, Qiskit Pocket Guide, Released June 2022, Publisher(s): O'Reilly Media, Inc., ISBN: 9781098112479
- Marouen Helali, Introduction to Quantum Computing using Qiskit and IBM Q, March 31, 2019
- qiskit Discord Servers, <https://discords.com/servers/tags/qiskit>



[Back to top](#)

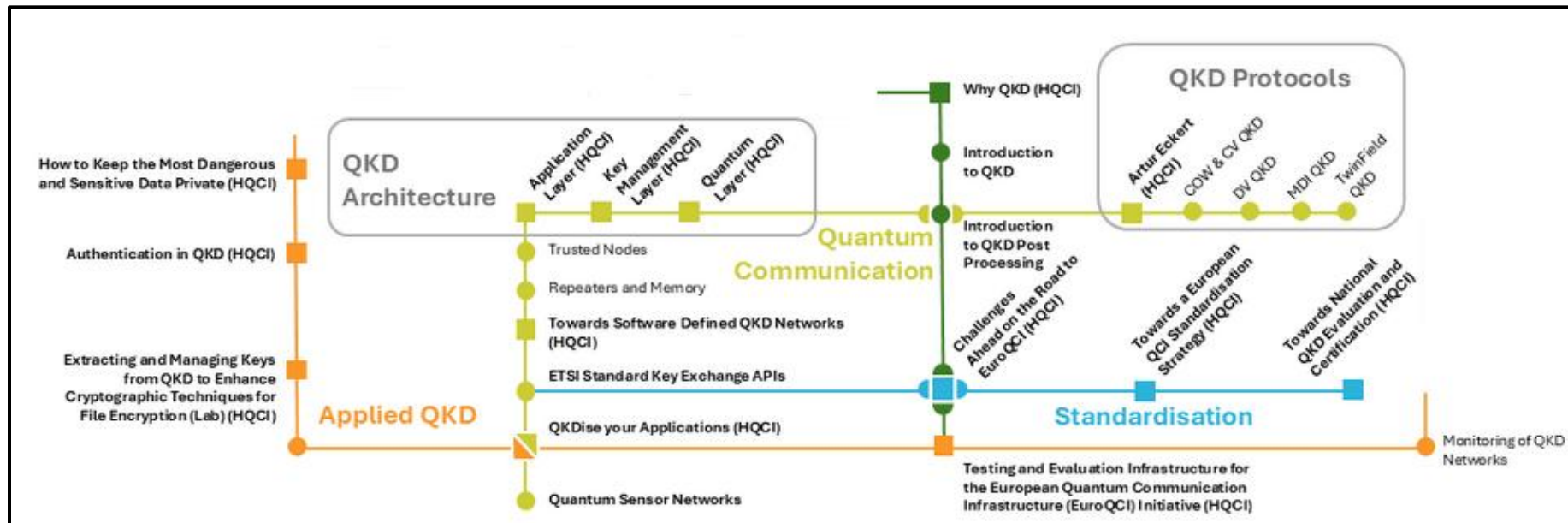
The dark purple metro line: Post Quantum Cryptography (PQC)

- Available learning units
 - Quantum Cryptography (HQCI) (45')
 - Introduction to PQC - PQC transition (HQCI) (30')
 - The Hybrid State-of-Play: How to Securely Combine Quantum and Post-Quantum Technologies (HQCI) (15')
 - QKD-PQC: Securing Key Transfers for Application Layer Utilisation (HQCI) (35')



The **dark yellow** and **orange** metro lines: QKD and Applied QKD

- Available **dark yellow** learning units
 - About QKD technology
 - QKD Protocols
 - QKD Architecture
 - Coming soon: Trusted Nodes
- Available **orange** learning units
 - Dealing with use cases, tests

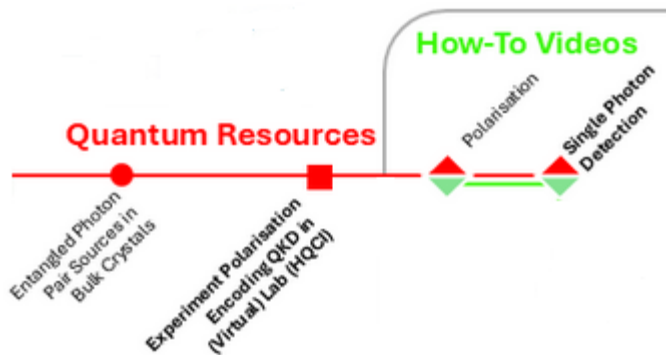


Other Quantum metro lines

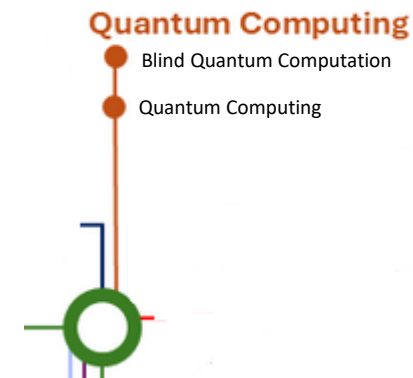
- The **light blue** metro line: Standardisation



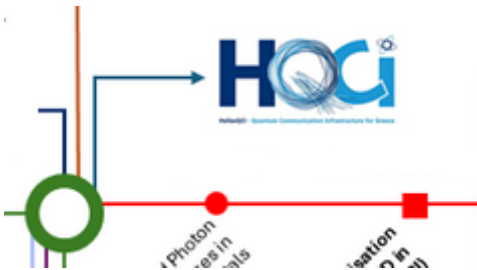
- The **red** metro line: Quantum Resources



- The **brown** metro line: Quantum Computing



The HellasQCI Training Platform



- Classes marked with “HQCI” were made available by the HellasQCI Training Platform
- Also marked with rectangle for station icon on map
- Video and accompanying pdf available via zenodo

The screenshot shows the Zenodo interface for the publication 'Towards Software-Defined QKD Networks'. It includes the title, author name (Gardikis, Georgios), a 'Show affiliations' button, a description of the presentation, and a link to the related video. The right sidebar shows statistics (20 views, 28 downloads), version information, external resources, and communities.

Towards Software-Defined QKD Networks

Gardikis, Georgios¹

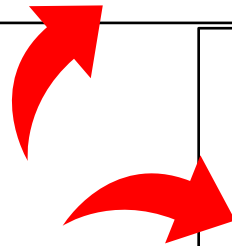
[Show affiliations](#)

This presentation describes solutions for integrated systems (monotoring, observability, security and management), as well as what Software-Defined QKD Network are.

It was used during the HellasQCI Training Event in Crete 2024 - Axis 2 QKD & PQC for Cybersecurity (05/09/2024).

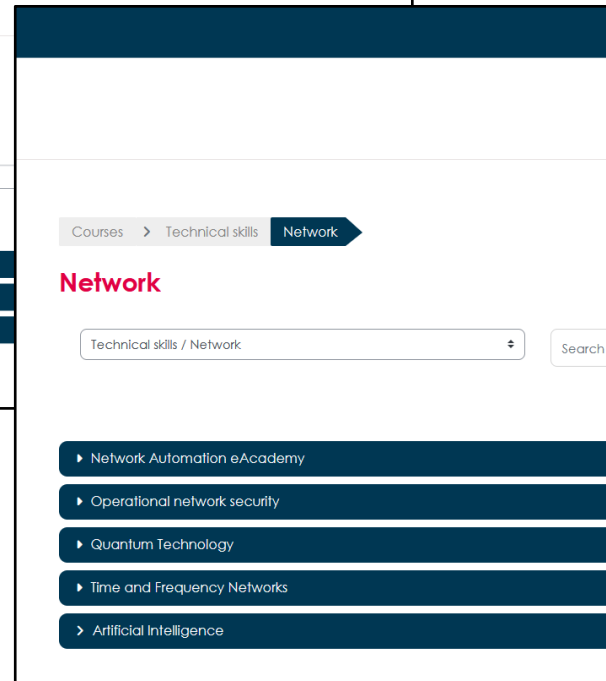
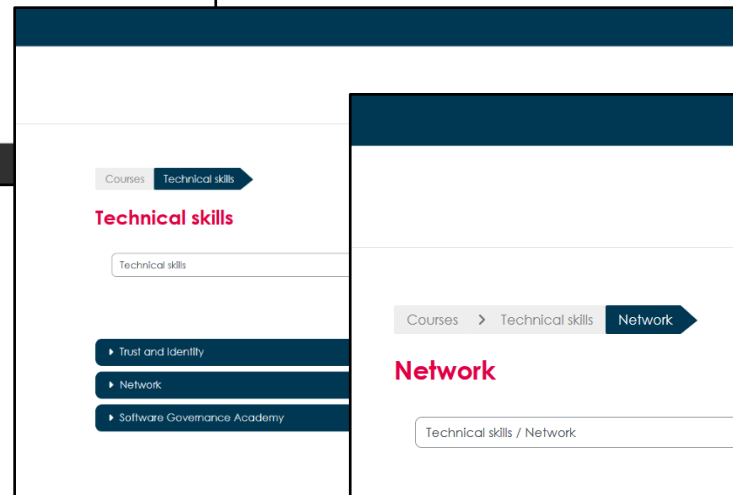
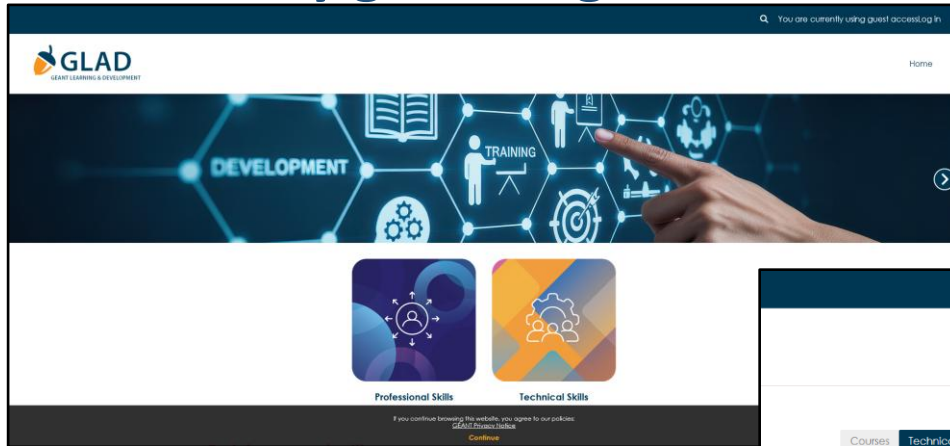
The related video is available here: [Towards Software-Defined QKD Networks](#)

The screenshot shows a file listing in Zenodo. It contains one file: 'Towards Software-Defined QKD Networks.pdf' with a size of 2.4 MB. The file has a unique identifier (md5:7355d3f92d0159c4e259d2081732b90e) and options for 'Preview' and 'Download'.



Access to courses via GÉANT Moodle platform

- e-academy.geant.org



- No access to HQCI through Moodle

**Time &
Frequency
Networks**

**T&F
eAcademy**



T&F eAcademy

Introduction

- **Why Do We Need Precise Time?** (30')
- **Introduction to Time & Frequency** (30')
- **Metrology Concepts for Time & Frequency** (30')
- **Time and Frequency Network** (30')
- **Introduction to Fibre** (30')
- Network Time Services

White Rabbit (WR)

- Network Time Services
- **Introduction to White Rabbit** (50') - From CERN White Rabbit training
- **Experiences with Setting Up a WR Network** (30')
- Monitoring of White Rabbit Networks (30')
- Follow **CERN's White Rabbit Project training**
- And read more on **CERN's official White Rabbit website**

Advanced Level

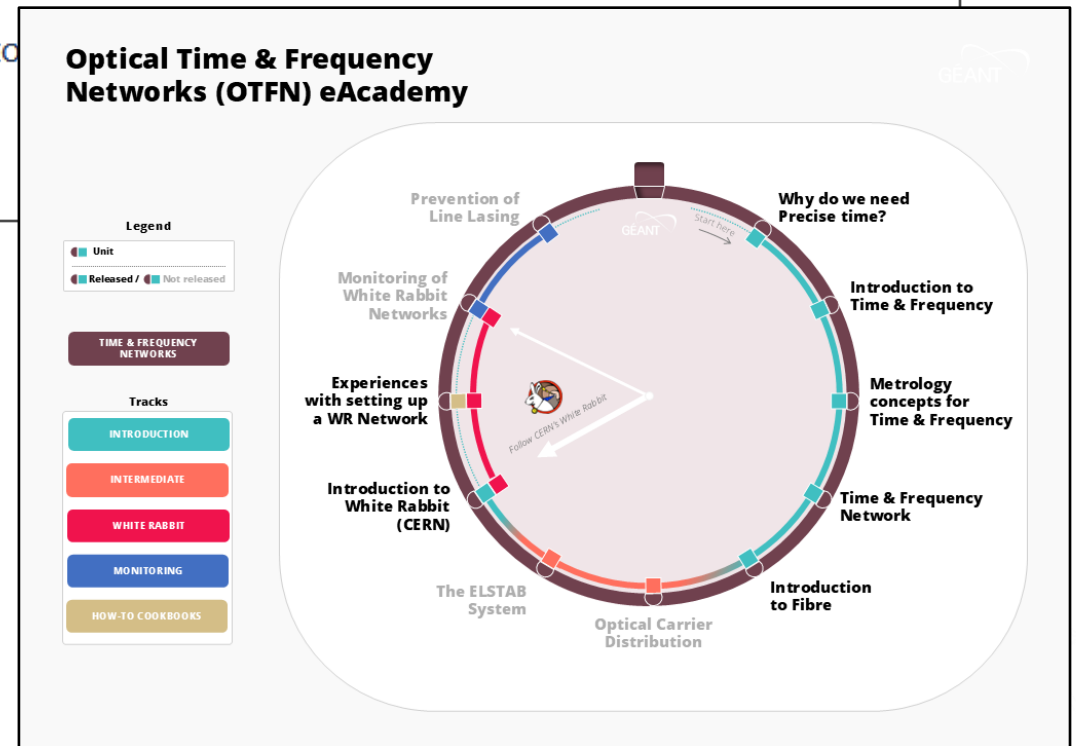
- Optical Carrier Distribution (30')
- The ELSTAB System (30')

Monitoring

- Five metro lines:

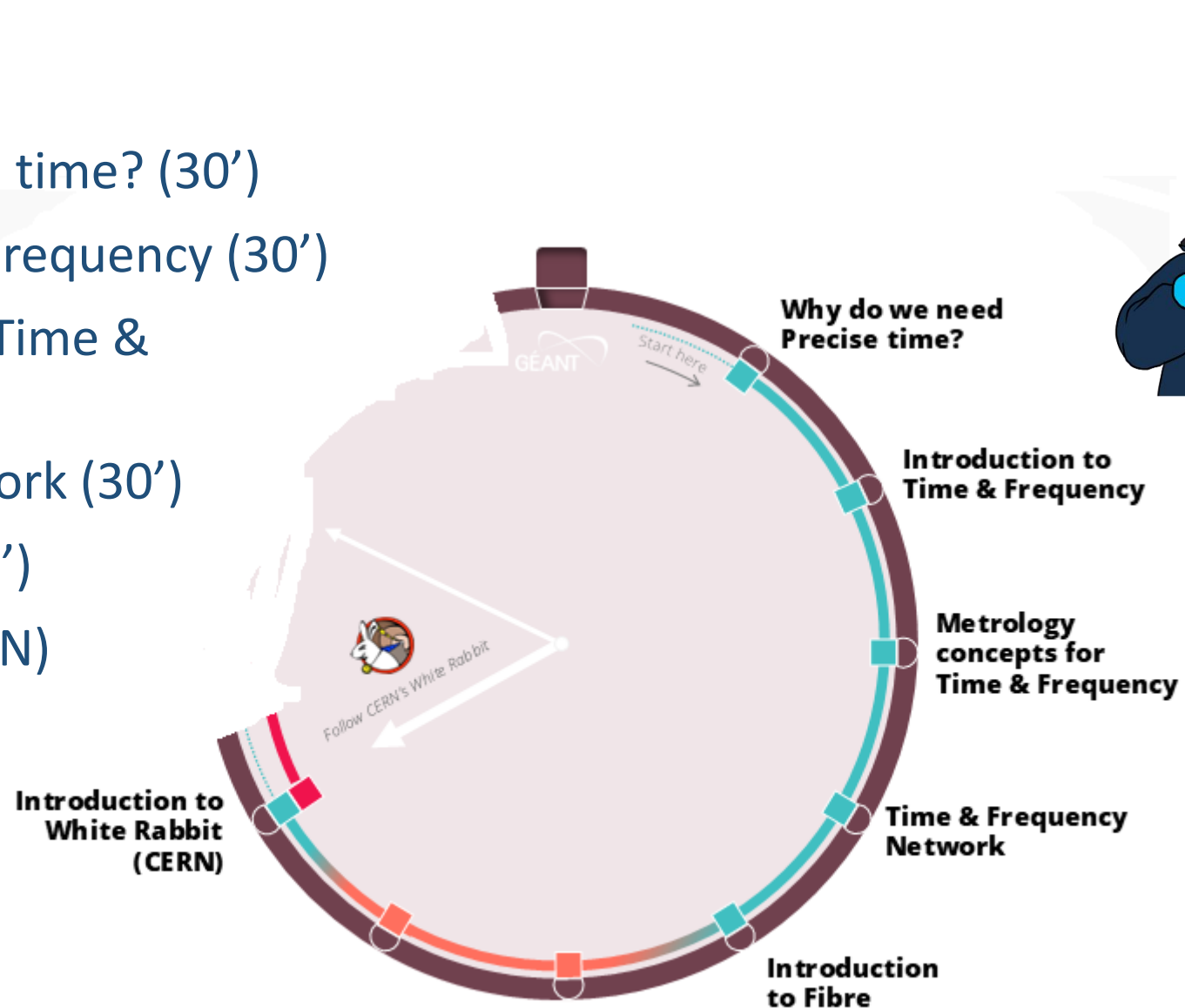
- Introduction
- Intermediate Level
- White Rabbit (WR)
- How-to Cookbooks
- Monitoring

- No circle stations, all access is denoted by rectangles



The green metro line: Introduction

- Why do we need precise time? (30')
- Introduction to Time & Frequency (30')
- Metrology concepts for Time & Frequency (30')
- Time & Frequency Network (30')
- Introduction to Fibre (30')
- Introduction to WR (CERN)



Collaboration with CERN

- Introduction to WR
- White Rabbit Switch - The Basics
- White Rabbit Switch - Advanced Topics
- White Rabbit Node (WR PTP Core)
- White Rabbit PTP Core Integration into a White Rabbit Node
- White Rabbit Calibration
- Oscillators - An Introduction



CERN | Accelerating science
Sign In Directory

White Rabbit
The Collaboration The Technology Qualified Products Forum

Training

Below you will find a series of presentations covering key elements of the White Rabbit Technology.

This training material was made for a training session delivered at CERN for members of the White Rabbit Collaboration.

Click to hear audio

Introduction to White Rabbit

Comprehensive introduction to WR

Maciej Lipinski
WR Collaboration / CERN

Training material

▶ ◂ ▢ ⏮ ⏭

0:00 / 51:56

🔊
⌵

Click to hear audio

Orange, gold and blue metro lines

- **Intermediate Level**

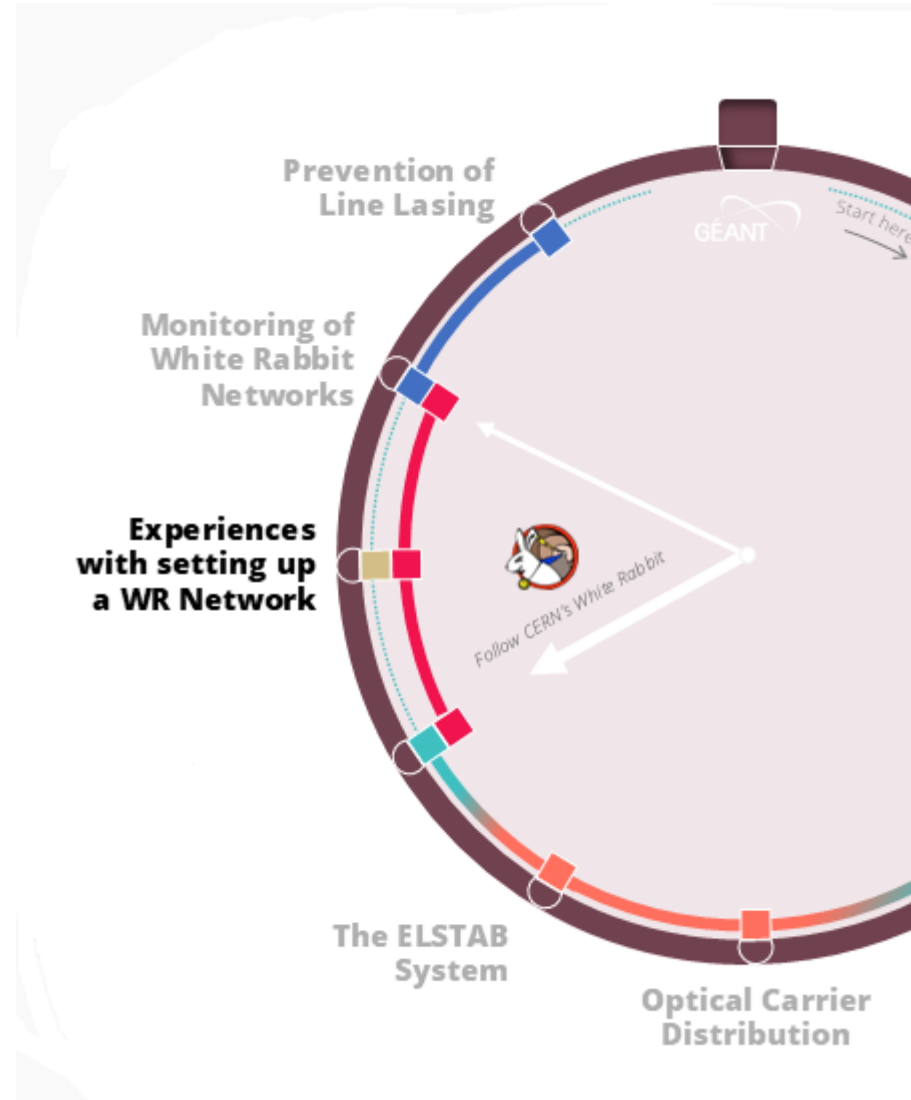
- Optical Carrier Distribution (30')
- The ELSTAB System (30')

- **How-to Cookbooks**

- Experiences with Setting Up a WR Network (30')

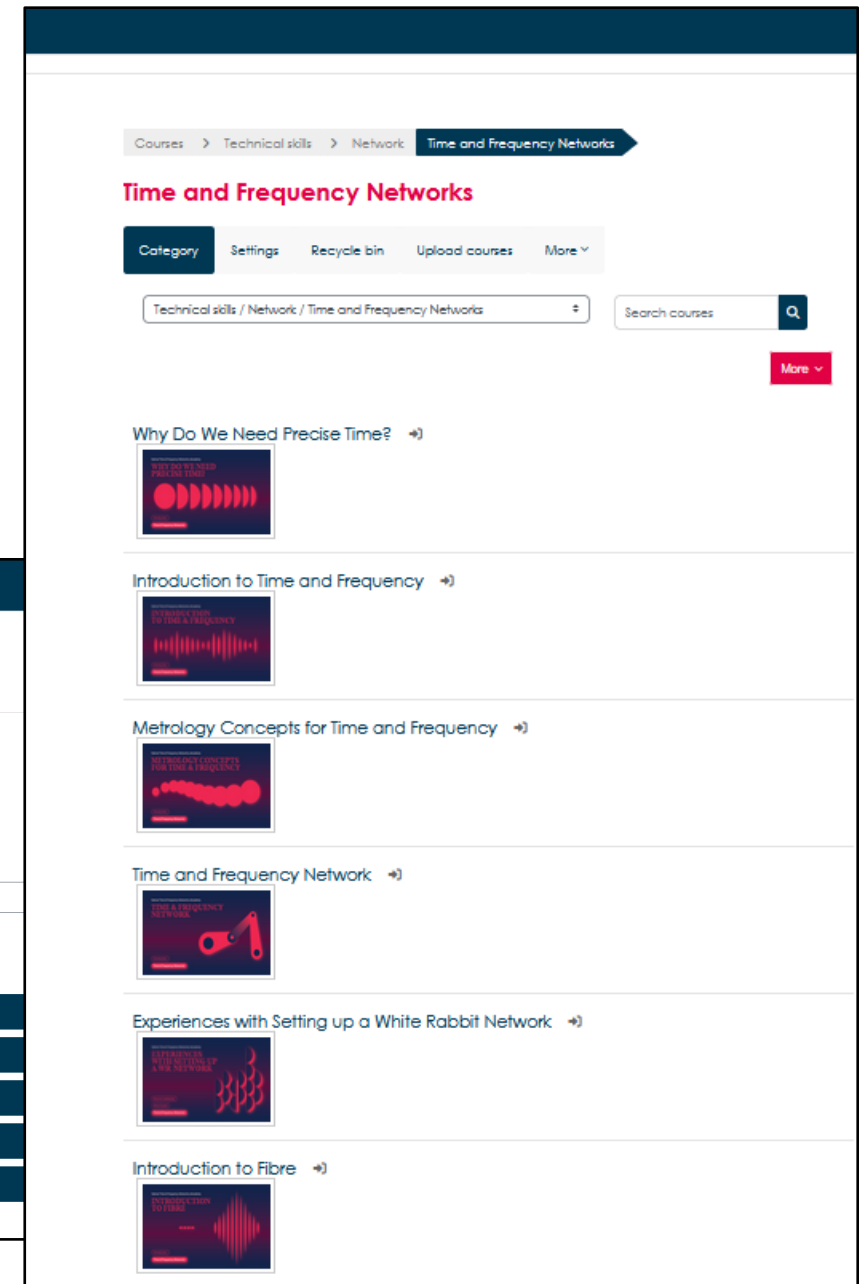
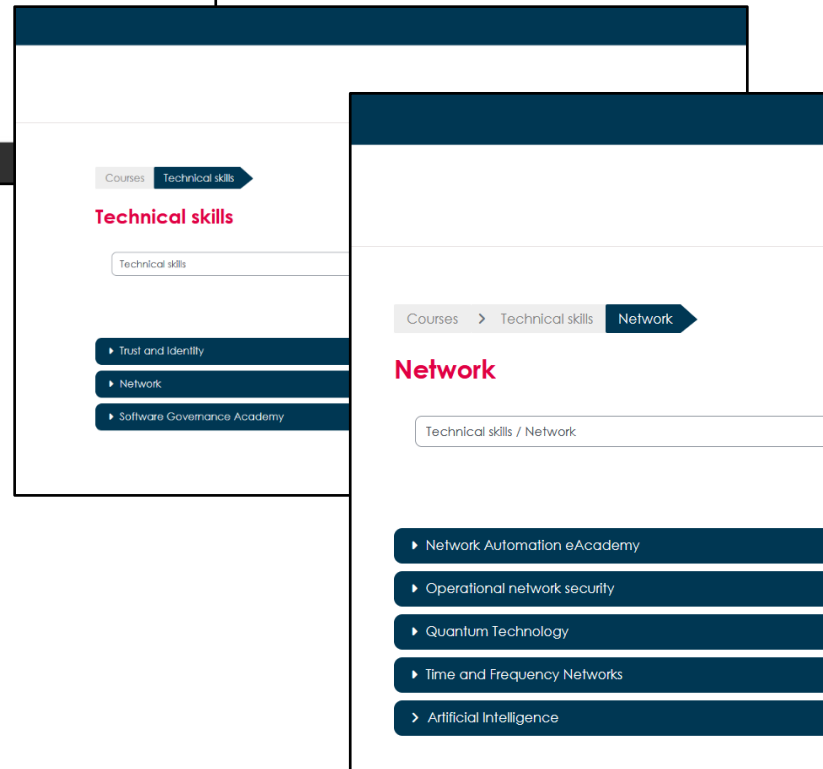
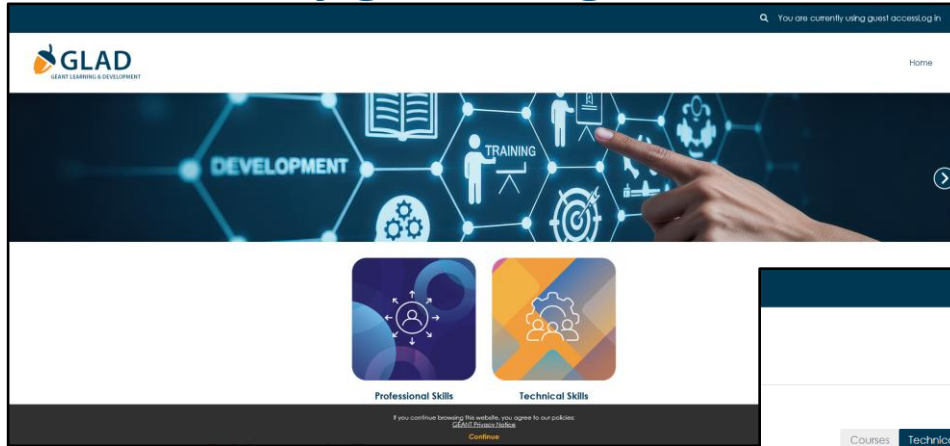
- **Monitoring**

- Monitoring of WR Networks
- Prevention of Line Lasing



Access to courses via GÉANT Moodle platform

- e-academy.geant.org

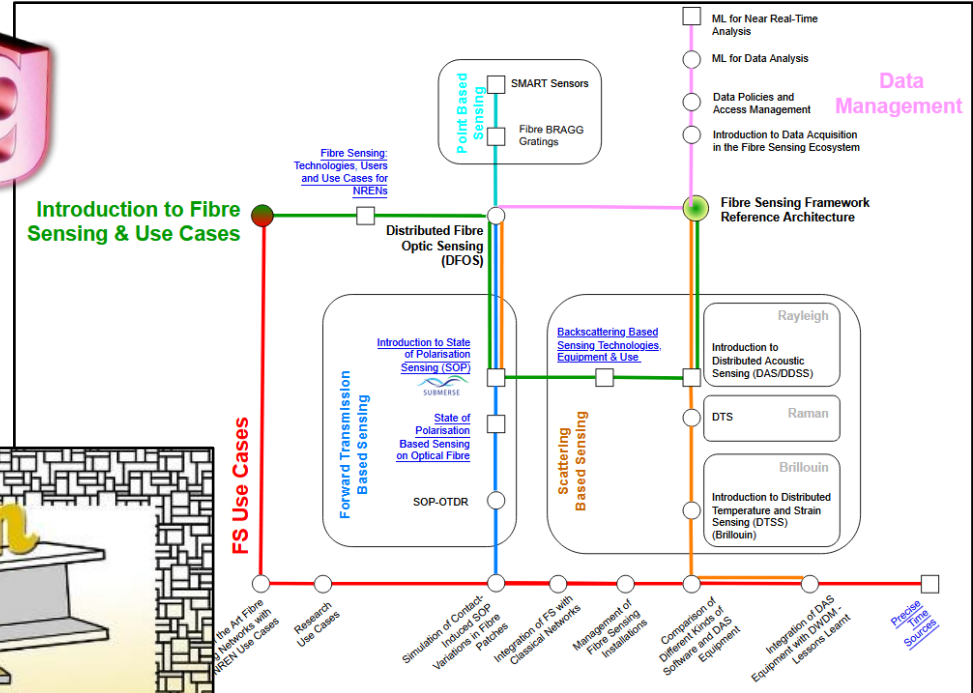
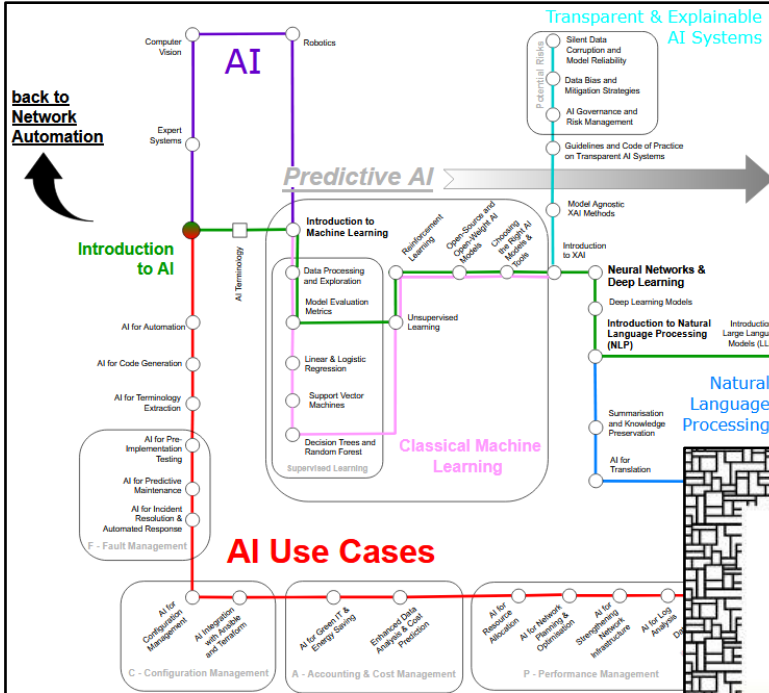


- No access to CERN through Moodle

Coming Soon: AI and Fibre Sensing Metro Maps

Coming Soon

Under Construction



back to Network Automation

Data Management



Thank You

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Co-funded by
the European Union