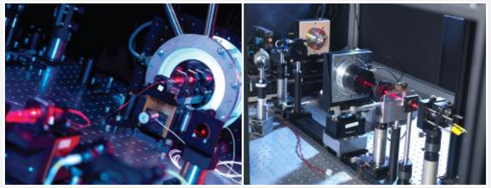
Quantum Photonics in EMN-Q

Christopher Chunnilall (NPL)

About me

NPL: Lead – Quantum Photonics

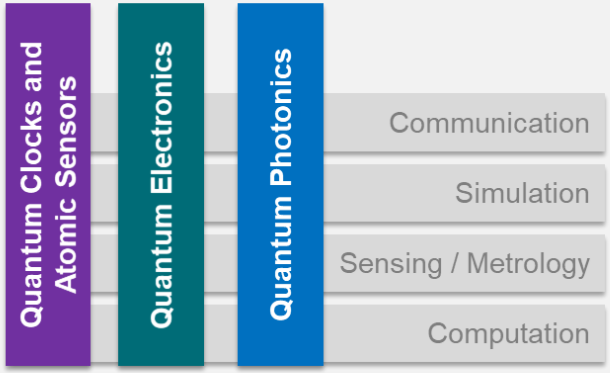


Standards:

In EMN-Q:

Vice-Chair, Section Coordinator “Quantum Photonics”

Supported by two vice-coordinators:
Mikael Lassen (DFM) [Quantum Sensing & Metrology]
Marek Smid (CMI)



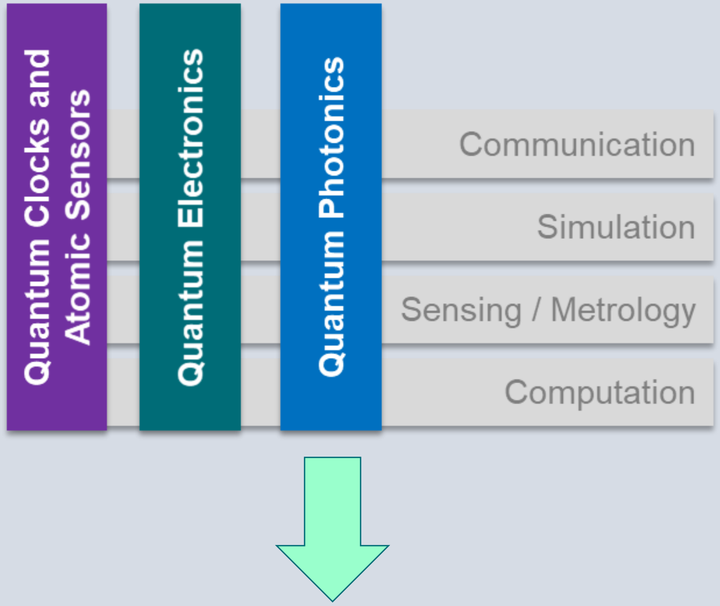
Stakeholders in EMN-Q

Stakeholder involvement is central to EMN-Q!

EMN-Q counts 284 stakeholders

in total, for all three pillars

- Industrial company
- Research organisation
- Academic institute
- Quantum Flagship body/project
- Other type of organisation (e.g. standardisation body, other Consortium)



105 stakeholders in "Quantum Photonics" (87 still unassigned)

46 stakeholders are commercial companies

Industry Stakeholders in EMN-Q "Qu-Photonics"

Single-photon sources
Sparrow Quantum
Quandela

Detectors
ID Quantique
Laser Components
MPD
Redwave
Single Quantum
Femto
etc ...

Lasers

M-Squared
NKT
PicoQuant
Toptica
etc ...

Single-photon LIDAR

QLM Technology

Q Comms – vendors, developers
ID Quantique
Toshiba Europe
Huawei Technologies Duesseldorf
InfiniQuant
KETS
Nu Quantum
etc ...

Q Comms - providers
ArQit
BT
Italtel
DT
Telefonica
etc ...

Underpinning

PicoQuant, Swabian, FastCom (time-taggers)
Microgate (adaptive optics)
Bay Photonics (optical packaging)
Element Six, Qnami (materials - diamond)
Attocube, Entropy, Oxford Instruments (cryogenics)
Covesion (non-linear materials)
Fabrication facilities
etc ...

Large industry (potential users)

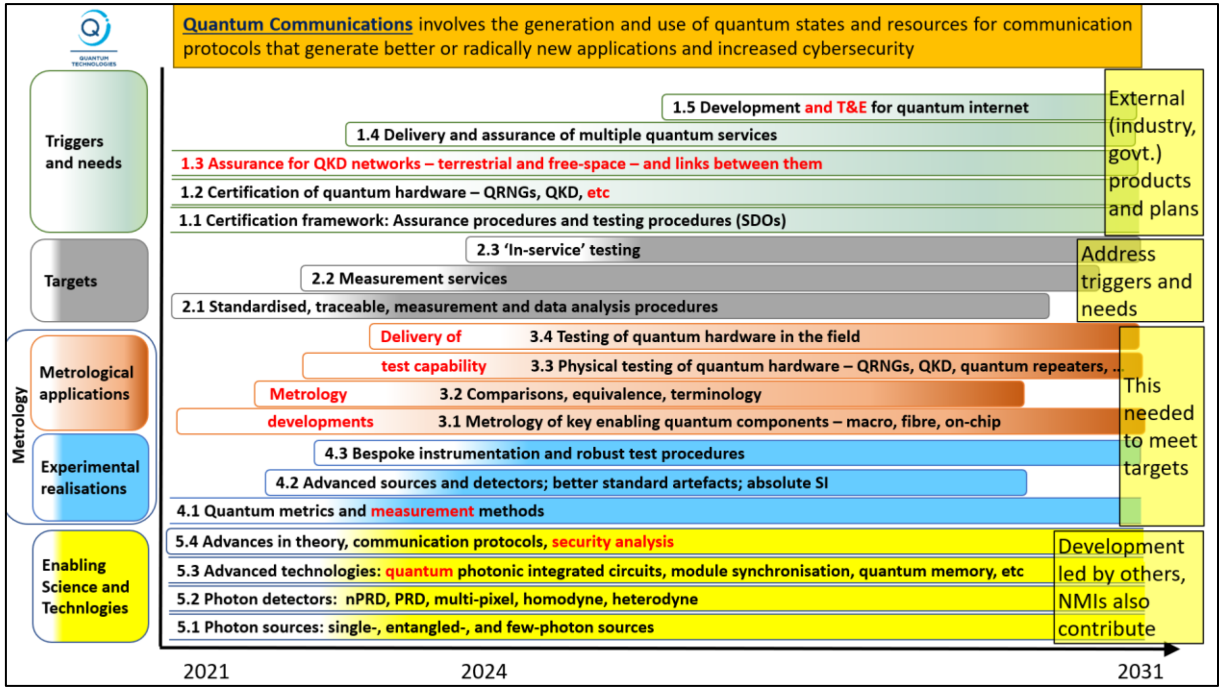
Airbus (all)
Bosch (sensing and metrology)
Thales (sensing and metrology)
etc ...

Quantum Photonics Roadmaps

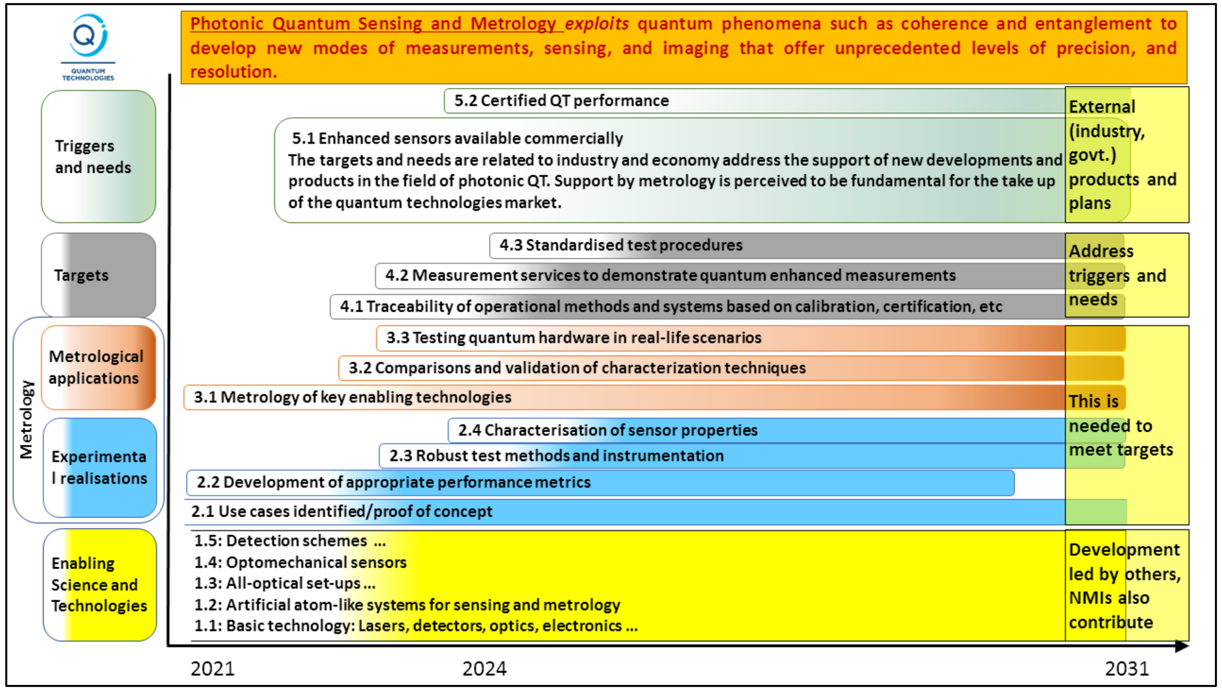
Two sub-fields:

→ two roadmaps in the Strategic Research Agenda (SRA) of EMN-Q:

Quantum Communications



Quantum Sensing & Metrology



Quantum Communications

Aug 2022

Quantum Communications involves the generation and use of quantum states and resources for communication protocols that generate better or radically new applications and increased cybersecurity

QUANTUM TECHNOLOGIES

Triggers and needs

Targets

Metrology

Metrological applications

Experimental realisations

Enabling Science and Technlogies

Quantum communications can be considered to refer to the exploitation of quantum resources for:

- securing the communication of information
- transmitting quantum information
- transmitting information at a higher capacity than possible with purely classical systems

External (industry, govt.) products and plans

Address triggers and needs

This needed to meet targets

Development led by others, NMIs also contribute

2021 2024 2031

Quantum Communications involves the generation and use of quantum states and resources for communication protocols that generate better or radically new applications and increased cybersecurity

Triggers and needs

1.5 Development and T&E for quantum internet

1.4 Delivery and assurance of multiple quantum services

1.3 Assurance for QKD networks – terrestrial and space – and links between them

1.2 Certification of quantum hardware – QRNGs, QKD, etc

1.1 Certification framework: Assurance procedures and testing procedures (SDOs)

External (industry, govt.) products and plans

Targets

E.g. Quality of single- and entangled-photon state distribution

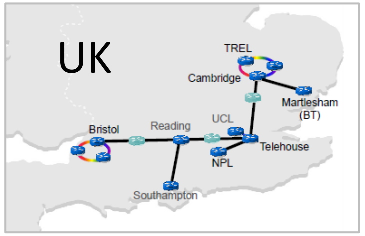
Address triggers and needs

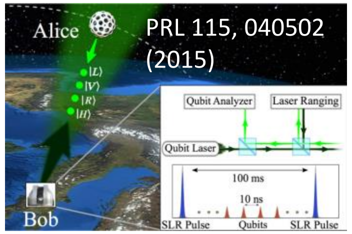
E.g. Time-dissemination and quantum communications over same fibre

Metrology

Metrological applications

Terrestrial – fibre & free-space
Space – satellite-ground, (satellite-satellite)
Test point-to-point links (quantum & classical layers)
Classical testing of network architecture





This needed to meet targets

Experimental realisations

Accredited test laboratories
Standardised test and evaluation methods

Enabling Science and Technlogies

National and pan-national security assurance process
Certification bodies
Formal procedures

Development led by others, NMIs also contribute

2021 2024 2031

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QUANTUM TECHNOLOGIES

Triggers and needs

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Instrumentation compatible with Q Comms hardware
Embed metrology into hardware

External (industry, govt.) products and plans

Targets

2.3 'In-service' testing

2.2 Measurement services

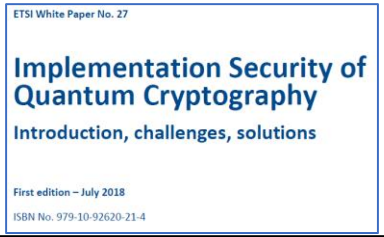
2.1 Standardised, traceable, measurement and data analysis procedures

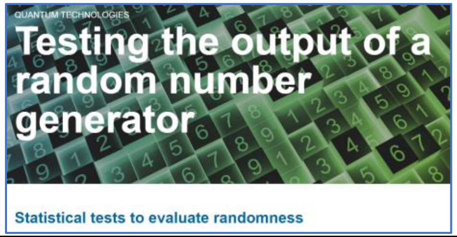
Address triggers and needs

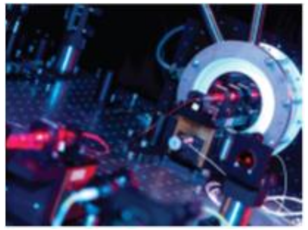
Metrology

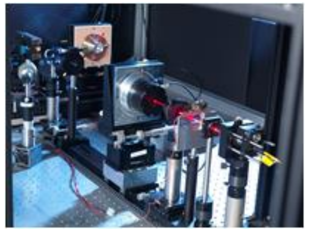
Metrological applications

Experimental realisations









Measure properties required to assess system/security performance
Measurement services to support manufacturing process – on-chip or otherwise

This needed to meet targets

Enabling Science and Technlogies

Identify gaps e.g. CEN/CENELEC FGQT

Input into work SDOs to ensure globally-accepted standards

CEN CENELEC Focus Group on Quantum Technologies

ISO IEC ITU ETSI

Development led by others, NMIs also contribute

2021 2024 2031

Quantum Communications involves the generation and use of quantum states and resources for communication protocols that generate better or radically new applications and increased cybersecurity

QUANTUM TECHNOLOGIES

Triggers and needs

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- **1.2 Certification of quantum hardware – QRNGs, QKD, etc**
- **1.1 Certification framework: Assurance procedures and testing procedures (SDOs)**

External (industry, govt.) products and plans

Targets

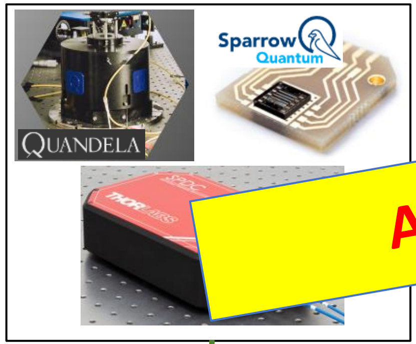
- **2.3 'In-service' testing**
- **2.2 Measurement services**
- **2.1 Standardised, traceable, measurement and data analysis procedures**

Address triggers and needs

Metrology

Metrological applications

Experimental realisations



A lot of innovation activity!

New concepts
New protocols
- DI-, MDI-, TF-QKD
- q. signatures
- q. secrets
- q. etc …

Security proofs

This needed to meet targets

Enabling Science and Technlogies

- **5.4 Advances in theory, communication protocols, security analysis**
- **5.3 Advanced technologies: quantum photonic integrated circuits, module synchronisation, quantum memory, etc**
- **5.2 Photon detectors: non-PRD, PRD, multi-pixel, homodyne, heterodyne**
- **5.1 Photon sources: single-, entangled-, and few-photon sources**

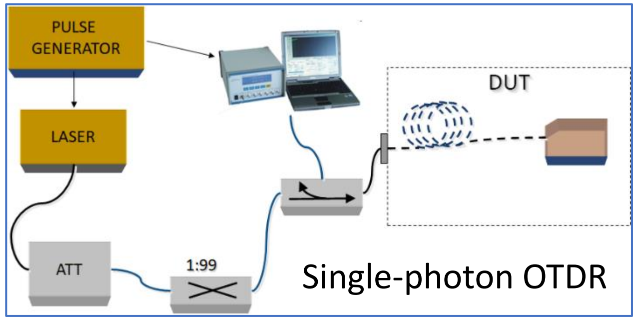
Development led by others, NMIs also contribute

2021 2024 2031

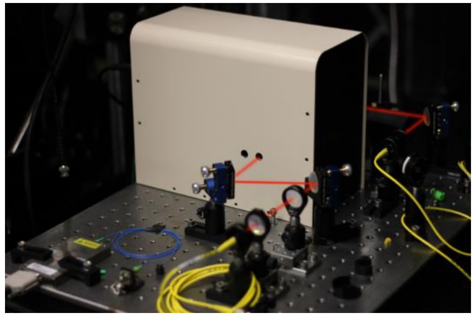
QUANTUM TECHNOLOGIES

Quantum Communications involves the generation and use of quantum states and resources for communication protocols that generate better or radically new applications and increased cybersecurity

Triggers and needs	1.4 Delivery and ass…
	1.3 Assurance for QKD networks – terrestria…
	1.2 Certification of quantum hardware – QR…
	1.1 Certification framework: Assurance proc…
Targets	2.3 In-service testing
Metrology: Metrological applications	
Metrology: Experimental realisations	4.3 Bespoke instrumentation and robust test procedures
	4.2 Advanced sources and detectors; better standard artefacts; absolute SI
	4.1 Quantum metrics and measurement methods
Enabling Science and Technlogies	5.4 Advances in theory, communication protocols, security analysis
	5.3 Advanced technologies: quantum photonic integrated circuits, module synchronisation, quantum memory, etc
	5.2 Photon detectors: non-PRD, PRD, multi-pixel, homodyne, heterodyne
	5.1 Photon sources: single-, entangled-, and few-photon sources



Single-photon OTDR



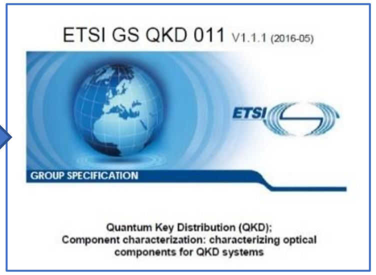

IND06 MIQC

Best-practice guide

Characterisation of optical components of weak-coherent-pulse Quantum Key Distribution systems

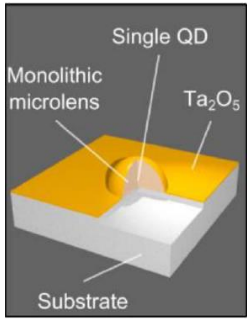
v1.0

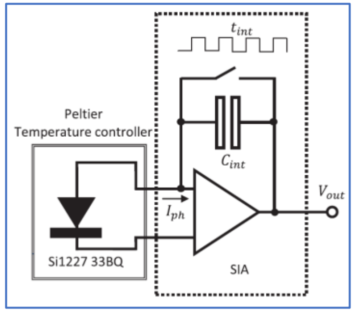
September 2014

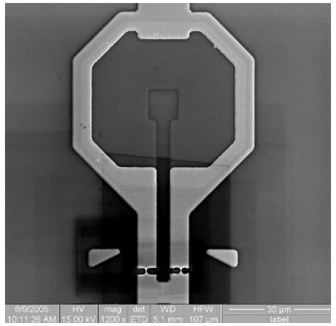

ETSI GS QKD 011 V1.1.1 (2016-05)

GROUP SPECIFICATION

Quantum Key Distribution (QKD); Component characterization: characterizing optical components for QKD systems







External (industry, govt.) products and plans

Address triggers and needs

This needed to meet targets

Development led by others, NMIs also contribute

2021 2024 2031

QUANTUM TECHNOLOGIES

Quantum Communications involves the generation and use of quantum states and resources for communication protocols that generate better or radically new applications and increased cybersecurity

Triggers and needs

Targets

Metrology

Metrological applications

Experimental realisations

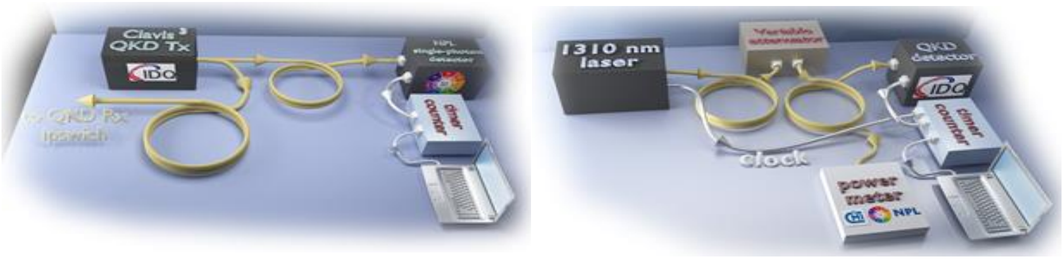
Enabling Science and Technlogies

Study comparisons

- single-photon source $g^{(2)}$
  - Moreva *et al.* 2019 *Metrologia* **56** 015016 (vis/NIR λ)
  - Rebufello *et al.* 2019 *Metrologia* **56** 025004 (telecom λ)
- single-photon detector DE
  - CCPR - ongoing (vis/NIR λ)
  - López et al., 2020 *EPJ Q.Tech* **7** 14 (telecom λ)

Terminology for single-photon sources and detectors

- many NMIs – to harmonise other standards



External (industry, govt.) products and plans

d testing procedures (SDOs)

' testing

Address triggers and needs

nalysis procedures

Delivery of test capability — **Metrology developments**

3.4 Testing of quantum hardware in the field

3.3 Physical testing of quantum hardware – QRNGs, QKD, quantum repeaters, …

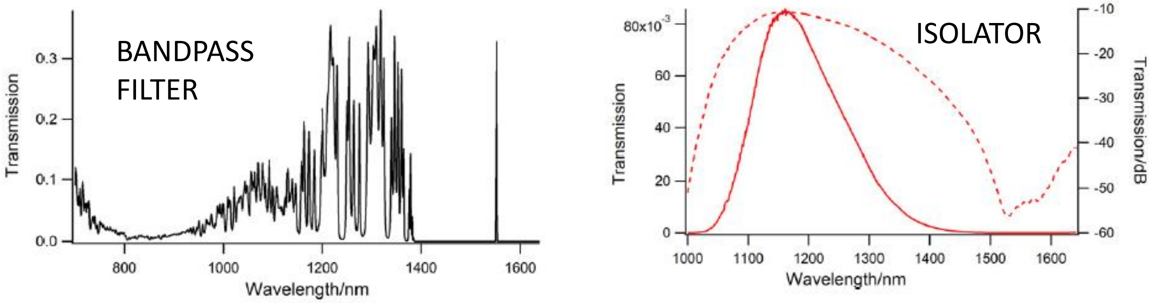
3.2 Comparisons, equivalence, terminology

3.1 Metrology of key enabling quantum components – macro, fibre, on-chip

This needed to meet targets

4.3 Bespoke instrumentation and robust test procedures

and classical! e.g. Castagna and Morel 2022 *Metrologia* **59** 035005



lute SI

onisation, quantum memory, etc

Development led by others, NMIs also contribute

2021 2024 2031

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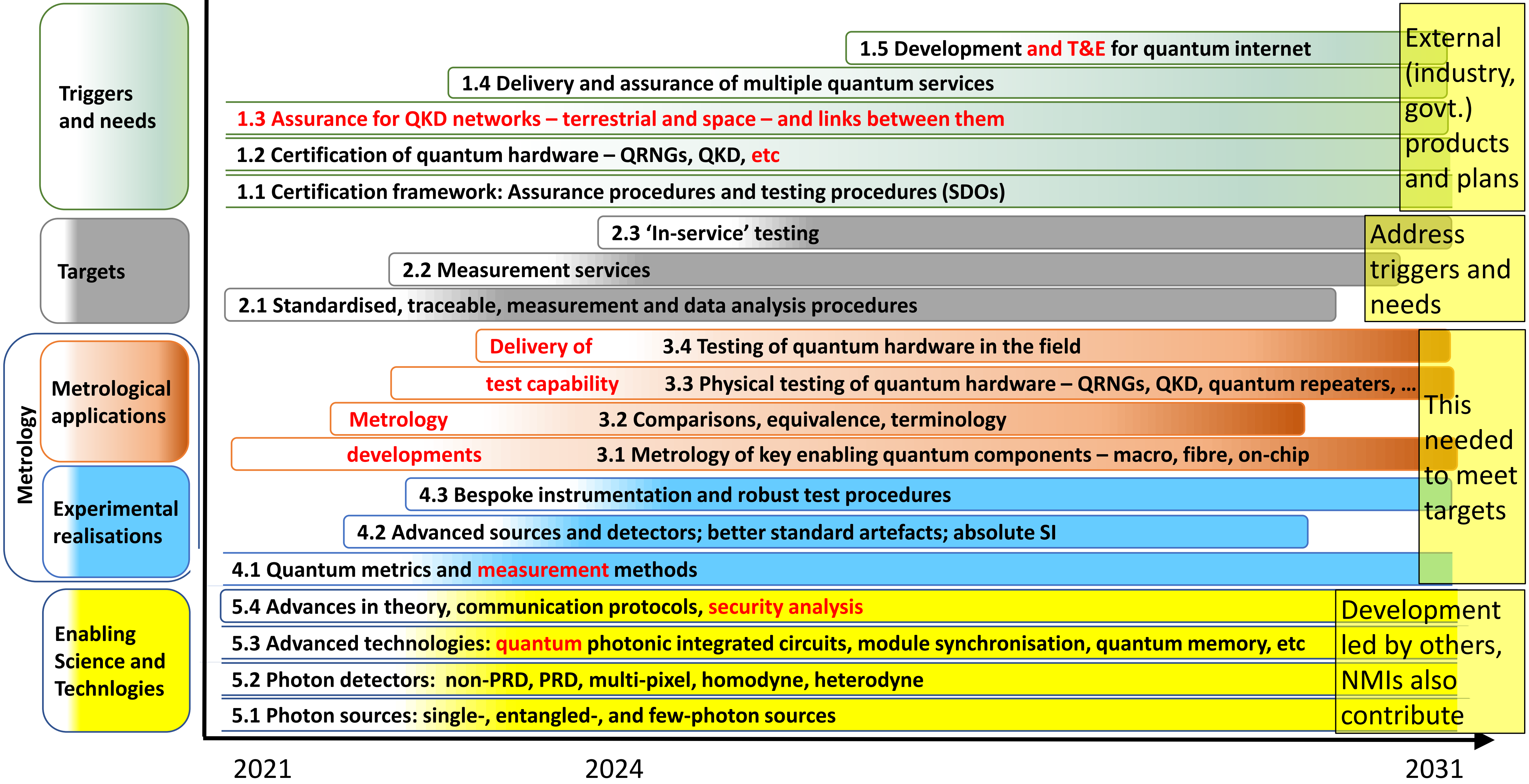


Quantum Sensing and Metrology

Aug 2022

QUANTUM TECHNOLOGIES

Quantum Sensing and Metrology *exploits* quantum phenomena such as coherence and entanglement to develop new modes of measurements, sensing, and imaging that offer unprecedented levels of precision, and resolution.

Triggers and needs

Targets

Metrology

Metrological applications

Experimental realisations

Enabling Science and Technlogies

Photonic Sensing and Metrology exploits quantum phenomena, such as **coherence** and **entanglement**, to develop novel methods of measurement, sensing, and imaging which significantly improve the precision of parameters of a wide range of systems.

Also:

Beat the standard quantum limit (SQL, precision $1/\sqrt{N}$)

↓

Heisenberg limit (precision $\propto 1/N$)

External (industry, govt.) products and plans

Address triggers and needs

This is needed to meet targets

Development led by others, NMIs also contribute

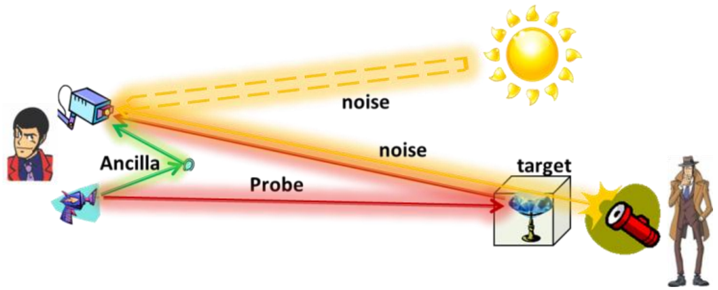
2021

2024

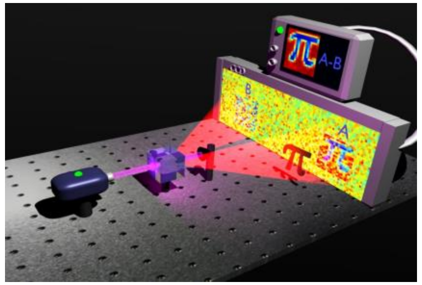
Quantum Sensing and Imaging

Some photonics applications (also, recall presentation by Thierry Debuisschert)

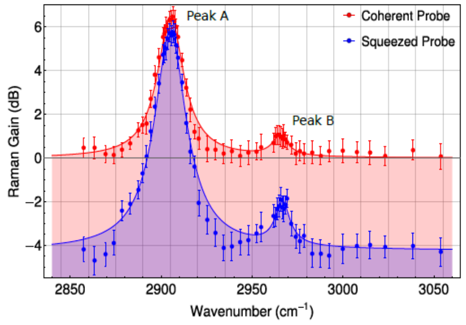
Single-photon LIDAR



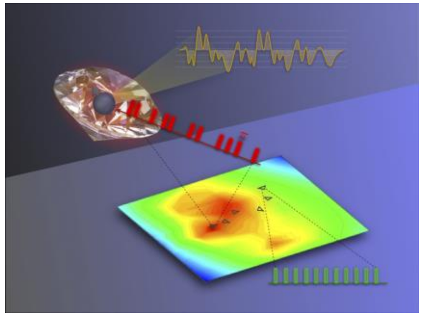
Quantum illumination



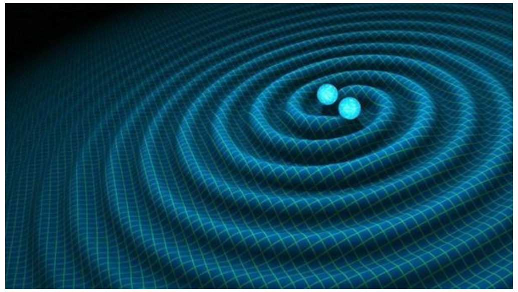
Sub-shot-noise imaging



Amplitude-squeezed spectroscopy



NV- centre sensing



Squeezing and entanglement for gravity wave detectors

<u>Quantum Sensing and Metrology</u> *exploits* quantum phenomena such as coherence and entanglement to develop new modes of measurements, sensing, and imaging that offer unprecedented levels of precision, and resolution.

QUANTUM TECHNOLOGIES

Triggers and needs

5.2 Certified sensor performance

5.1 Enhanced sensors available commercially
The targets and metrics are related to industry and the economy to support new developments and products in the field of photonic QT. Support by metrology is perceived to be fundamental to the take-up of the quantum technologies market

External (industry, govt.) products and plans

Targets

4.3 Standardised test procedures

4.2 Measurement services to demonstrate quantum enhanced measurements

4.1 Traceability of operational methods and systems based on calibration, certification, etc

Address triggers and needs

Metrology

Metrological applications

3.3 Testing quantum hardware in real-life scenarios

3.2 Comparisons and validation of characterization techniques

3.1 Metrology of key enabling technologies

Experimental realisations

2.5 Characterisation of sensor properties

2.4 Robust test methods and instrumentation

2.3 Traceability

2.2 Development of appropriate performance metrics

2.1 Use cases identified/proof of concept

This is needed to meet targets

Enabling Science and Technlogies

1.5: Detection schemes …
1.4: Optomechanical sensors
1.3: All-optical set-ups …
1.2: Artificial atom-like systems for sensing and metrology
1.1: Basic technology: Lasers, detectors, optics, electronics …

Development led by others, NMIs also contribute

2021 2024

EMN-Q in “Framework Partnership Agreement” (FPA)

FPA for “open testing and experimentation for quantum technologies”: ‘Qu-Test’

Call: HORIZON-CL4-2021-DIGITAL-EMERGING-02

Topic: HORIZON-CL4-2021-DIGITAL-EMERGING-02-22

- Partnership of European testbeds for quantum technology, coordinated by TNO (NL)
- Composed of distributed infrastructures with globally unique equipment and competencies across Europe.

Goal: To provide European industry with the necessary support in terms of infrastructure and know-how to move faster to the market and create a robust supply chain for the quantum technology market.

EMN-Q members:

EMN-Q in “Framework Partnership Agreement” (FPA)

EURAMET European Commission

FPA for “open testing and experimentation for quantum technologies”: ‘Qu-Test’

“Qu-Photonics” in red

Testbed 1	**Quantum Computing** VTT INRiM PTB LNE	Cryogenic quantum devices, cryogenic qubits (superconducting and semiconducting, photonic) and ion traps.
Testbed 2	**Quantum Communication** VTT INRiM PTB	Devices for Quantum Key Distribution (QKD) and Quantum Random Number Generation (QRNG).
Testbed 3	**Quantum Sensing** VTT INRiM PTB LNE SYRTE Observatoire PSL	Sensing and metrology instruments provided by industry, and quantum sensors (e.g. based on colour centres).

EMN-Q Infrastructure in FPA ‘Qu-Test’

EMN-Q services and facilities *“Quantum-Photonics”*

Service: Characterisation of single-photon detectors	INRIM
Facility: Trusted node for QKD	
Facility: PIQUET Nanofacility (Nanofabrication)	
Facility: Italian Quantum Backbone	
Facility: (Portable) single-photon OTDR [Optical time domain reflectometer]	
Service: Characterisation of single-photon detectors	PTB
Service: Characterisation of single-photon sources	
Facility: Niedersachsen Quantum Link	

Other significant EMN-Q infrastructure: NPL, CMI, DFM, METAS

EMN-Q in Standardisation (Quantum Photonics)

CEN CENELEC

FGQT roadmap released on 18 Nov for comments by contributors and liaising committees
Relevant topics – Single-photon sources and detectors, quantum communications

ISO IEC

Draft standard for testing QKD systems
Revision of standard 18031 on random bit generation

ETSI

QKD – Common Criteria protection profile, test standards, security proofs, terminology

ITU

Standards for QKD networks

CCPR

Terminology for single-photon metrology

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Mikael Lassen *(EMN-Q vice-Coordinator, quantum photonics, DFM)*