Discussion Forum on Few-Photon Metrology (CCPR-WG-SP-TG7)

Activity Report to CCPR WG-SP meeting June 2024

Angela Gamouras (NRC)

Report Outline

- TG Terms of reference & membership
- Activities summary
  - Meetings
  - Terminology document updates
    - CIE DR 2-87 (Dong-Hoon Lee, KRISS)
    - Next steps of the NIST Single-Photon Sources & Detectors Dictionary (Josh Bienfang, NIST)
- BIPM Workshop on Accelerating the adoption of Quantum Technologies through Measurements and Standards (21-22 Mar-2024)
  - NMI Collaborations in Quantum Photonics Standards Development

  (John Lehman (NIST), Angela Gamouras (NRC))
- Outlook

Terms of Reference

The objectives of the CCPR-WG-SP Task Group 7 are:

1. to discuss the outstanding issues in the field of few photon metrology;
2. to monitor the advances and demands in the field of few photon metrology;
3. to monitor and report on needs for SI traceability in the field of few photon metrology.

- Members: 46 members from 14 countries (NMIs, Academia, Industry)

Main activities since September 2023

September 8, 2023:

- A. Gamouras (NRC) Chair of TG7 – Thank you to previous Chair D-H. Lee (KRISS)

February 21,2024:

- Virtual TG7 meeting (16 participants, 9 institutes)

March 22, 2024:

- Presentation at BIPM Workshop on Accelerating the adoption of Quantum Technologies through Measurements and Standards

Terms of Reference #1: To discuss the outstanding issues in the field of few photon metrology

- Maintain and update the list of technical issues with the DF members
- If possible, required actions can be initiated by (for example):
  - Organizing a comparison (Single-Photon Radiometry CCPR-WG-SP-TG11)
  - Organizing a workshop or a conference session
  - Cooperating with other international standard organizations
  - Forming a group for publication
    - CIE Reportership DR 2-87 Terminology in single/few photon metrology, Dong-Hoon Lee (KRISS)
    - NIST Single-Photon Sources & Detectors Dictionary

Terminology document updates:

CIE DR 2-87 Terminology in single/few photon metrology

Summary of report from Dong-Hoon Lee (Feb. 2024):

- Aug 2020. Goal: publish an open-access Technical Note (TN) on the terminology issues that can be referenced by other publications in the field.
- Delayed & further revision considering

  Comments from NIST dictionary
- The second draft of the TN was distributed

  17-Feb-2024
- Feedbacks collected by 4-Mar-2024
- Submission of the WD to D2MT in March 2024

  proposed.

Name	Affiliation	Country
Bienfang, Joshua	NIST	USA
Borbely, Joseph	MSL	New Zealand
Cheung, Jessica	NPL	UK
Chunnilall, Christopher	NPL	UK
Degiovanni, Ivo	INRIM	Italy
Gamouras, Angela	NRC	Canada
Jin, Jeongwan	NRC	Canada
Kück, Stefan	PTB	Germany
Lee, Dong-Hoon	KRISS	Korea
Nam, Sae-Woo	NIST	USA
Polyakov, Sergey	NIST	USA
You, Lixing	SIMIT-CAS	China

Embedded Word document from D-H. Lee:

DR 2-87 Terminology in Single/Few Photon Metrology

Status Report, 19 September 2023, Dong-Hoon Lee

Terms of Reference

To review the existing international standards for terminology in single/few photon metrology, to survey the current status of the terms used in the practice, and to publish an open-access Technical Note (TN) on the terminology issues that can be referenced by other publications in the field.

Activity Updates

The contents to be included in TN are collected and reviewed from the following experts:

Name	Affiliation	Country
Bienfang, Joshua	NIST	USA
Borbely, Joseph	MSL	New Zealand
Cheung, Jessica	NPL	UK
Chunnilall, Christopher	NPL	UK
Degiovanni, Ivo	INRIM	Italy
Gamouras, Angela	NRC	Canada
Jin, Jeongwan	NRC	Canada
Kück, Stefan	PTB	Germany
Lee, Dong-Hoon	KRISS	Korea
Nam, Sae-Woo	NIST	USA
Polyakov, Sergey	NIST	USA
You, Lixing	CAS CENSE	China

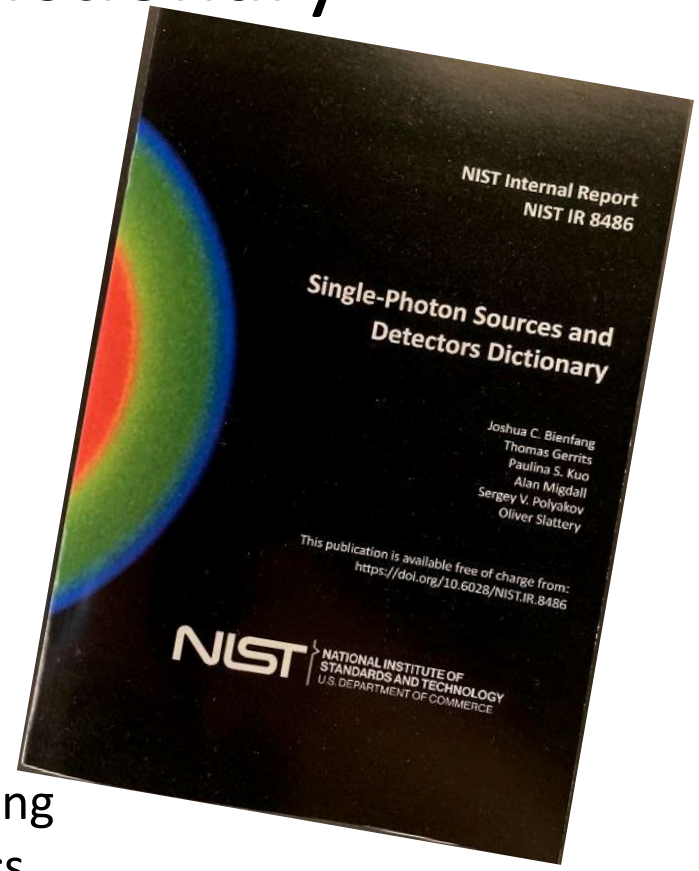
The first draft of the TN is distributed to the experts on 8 June 2022 for review. Review comments are collected.

There was an issue that the experts from NIST have independently drafted a "Single-photon dictionary" document, which is a collection of terms and metrics in a wider scope than the TN. The reporter and the NIST experts had a teleconference on 10 August 2022 to discuss how these two documents can be arranged. The following actions were agreed in the meeting:

This document will be publicly available on the CIE website

Terminology document updates:
NIST Single-Photon Sources & Detectors Dictionary

- Available now at
  https://www.nist.gov/itl/single-photon-sources-and-detectors-dictionary
- Printed as NIST Internal Report 8486
- Continuing to welcome feedback, additions, and comments
  from the community
- Starting work on memories, will lead, inevitably, to entanglement
  - singlephotondictionary@nist.gov
- Seeking funding for an effort to develop recommended practices for characterization measurements
- Seeking funding to connect with ISO/IEC JTC-Q to form an international working group (NMIs) to develop a documentary standard on terms in single photonics



Update from J. Bienfang Feb. 2024

BIPM Workshop: Accelerating the adoption of Quantum Technologies through Measurements & Standards

The workshop will provide an opportunity for strategic leaders from NMIs and DIs to:

- Share information on priority activities to support quantum technology development and adoption.
- Agree on an initial strategy and framework for an ongoing quantum initiative, including industry engagement.
- Establish potential task groups in quantum technology areas where NMIs and DIs are willing to collaborate to accelerate the development of best measurement practices.

https://www.bipm.org/en/bipm-workshops/quantum-tech

BIPM Workshop: Accelerating the adoption of Quantum Technologies through Measurements & Standards

Few-photon metrology is quite advanced in these areas

- Sharing info, measurement and terminology activities, etc.
- Other areas may look to few-photon metrology as an example

Workshop session: NMI Collaborations in Quantum

- EMN-Q, Qu-Test - Ivo Degiovanni (INRIM)
- Quantum photonics - Angela Gamouras (NRC) and John Lehman (NIST)

Input to Quantum Photonics presentation from TG7 virtual meeting Feb-2024

NMI Collaborations in Quantum Photonics Standards Development

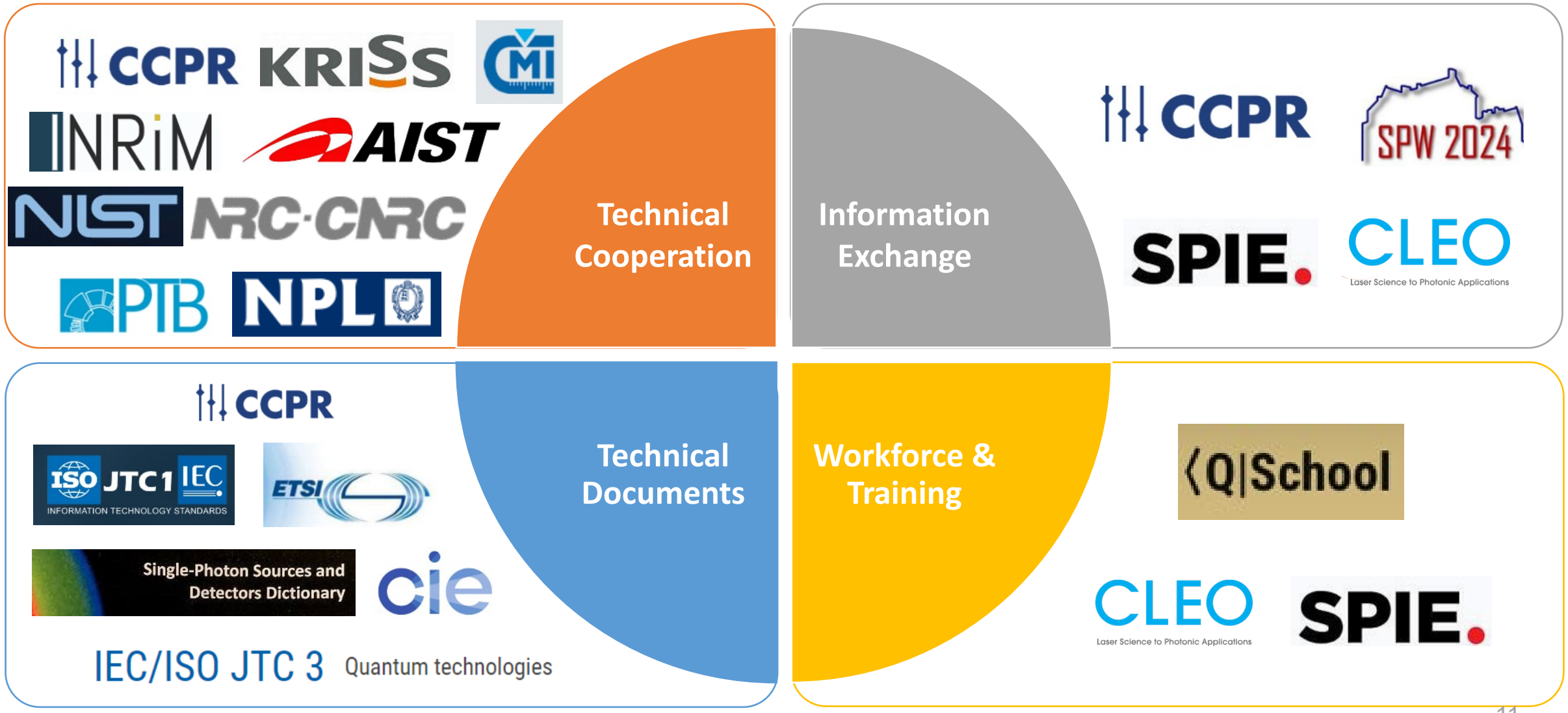
John Lehman & Angela Gamouras

https://www.bipm.org/documents/20126/228569750/Quantum-BIPM-Workshop-2024/283dd72c-c6b0-1be5-da3f-db8a6c1bbfa4

National Institute of Standards and Technology
U.S. Department of Commerce

National Research Council Canada
Conseil national de recherches Canada

Outline and Framework



Timeline 2003 - 2018

2003 Single Photon Workshop (Alan Migdall et al.)

2006 The “last” Symposium on Optical Fiber Measurements (SOFM)

2015 CCPR TG-7 questionnaire & pilot study single-photon detector (SPD) detection efficiency

2016 CCPR TG-7 pilot study, 11 participants, free space SPD (ongoing)

2016 NIST/PTB synchrotron based single photon detector calibration

2017 NIST/PTB Verification of calibration methods

2017 NIST special test SPD calibration

2018 NRC/NIST free space SPD comparison began

Timeline 2019 - 2021

2017 BIPM Workshop "The Quantum Revolution in Metrology" 28-29 September 2017

2018 NPL/NRC/NIST Quantum Standards Meeting NIST Gaithersburg

2019 NPL/NRC/NIST Quantum SI Workshop NIST Boulder

2019 NIST/PTB MOU for faint light radiometry/radiometers (Beyer/Lehman)

2019 3rd Germany-USA-DE Joint Meeting, Federal Ministry of Education and Research, Berlin

2021 QED-C Workshop Single-photon measurement infrastructure: Needs and priorities

2021 National Quantum Initiative Funding to NIST

2021 New Developments and Applications in Optical Radiometry (NEWRAD)

Timeline 2022 - 2024

2022 NIST/NRC/CU Quantum dot source & faint light radiometry

2022 NIST/NRC Calibration and comparison of detection efficiency

2023 NIST Detector Calibration for Customers ISO17025

2023 NIST/NPL single photon detector comparison (APD)

2023 NIST Single Photon Dictionary

2023 NEWRAD Teddington

2023 Single Photon Short Course (INRIM, NIST, NRC, NPL)

2024 Single Photonics Short Course

2024 Single Photon Workshop

Directions: NMI Collaboration

Quantum SI workshop for single-photon metrology

NIST, Boulder, Colorado

February 28, March 1, 2019

Purpose:

The purpose of the workshop is to bring together subject matter experts in single photon science and engineering from the national metrology institutes, NPL, NRC, and NIST, to engage in development, metrology, standardization, and dissemination of scales.

Directions: International Engagement

3rd Germany – United States Science and Technology Joint Meeting Commission

November 5 & 6, 2019, Federal Ministry of Education and Research (BMBF), Berlin

Workshop on Quantum Information Sciences

Highlighted the longstanding cooperation with PTB

Additional State Dept meetings were planned before Covid

Directions: Workforce Development

https://www.colorado.edu/initiative/cubit/single-photonics-and-quantum-radiometry-short-course

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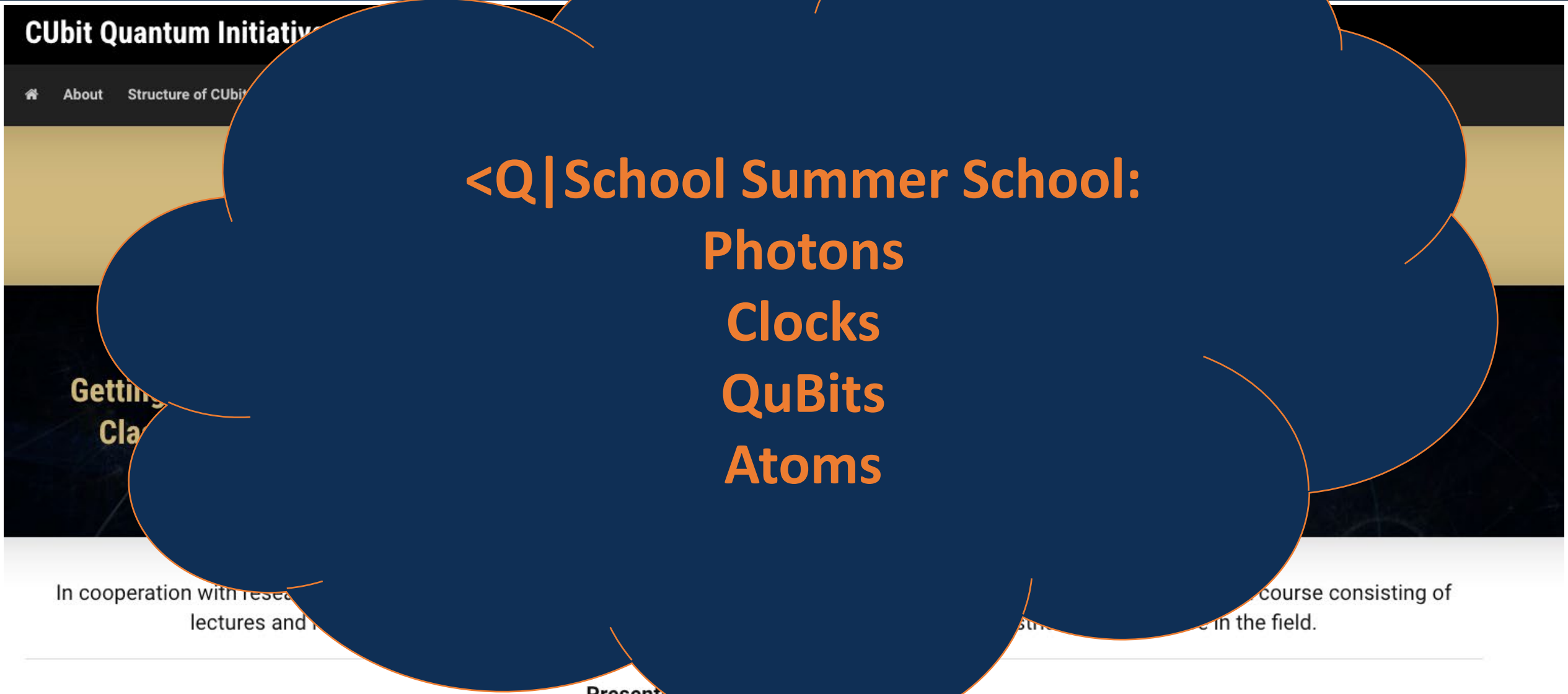
Directions: Workforce Development



<Q|School Summer School:

Photons

Clocks

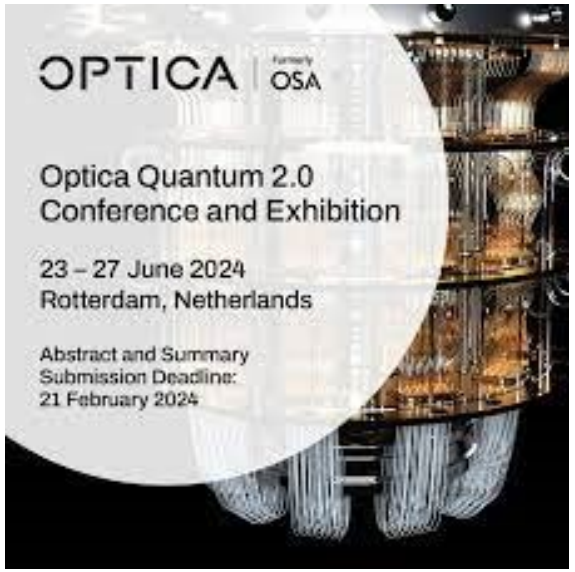
QuBits

Atoms

https://www.colorado.edu/initiative/cubit/single-photonics
-radiometry-short-course

Directions and Opportunities

SPIE Photonics west 2024 (893 presentations)
SPIE Photonics Europe (300 presentations)



Laser Science to Photonic Applications

Directions and Opportunities

1986 -2006

"The first transatlantic telephone cable to use optical fiber was TAT-8, which went into operation in 1988"

Directions and Opportunities

Industry & academic engagement to monitor advances and demands in quantum photonics

→ Consortia

→ Collaborative discussion forums

QUANTUM INDUSTRY CANADA

Q-STAR

QUIC European Quantum Industry Consortium

QED·C

CCPR Discussion Forum on Few-Photon Metrology (CCPR-WG-SP-TG7)
→ NMI, industry and academic members

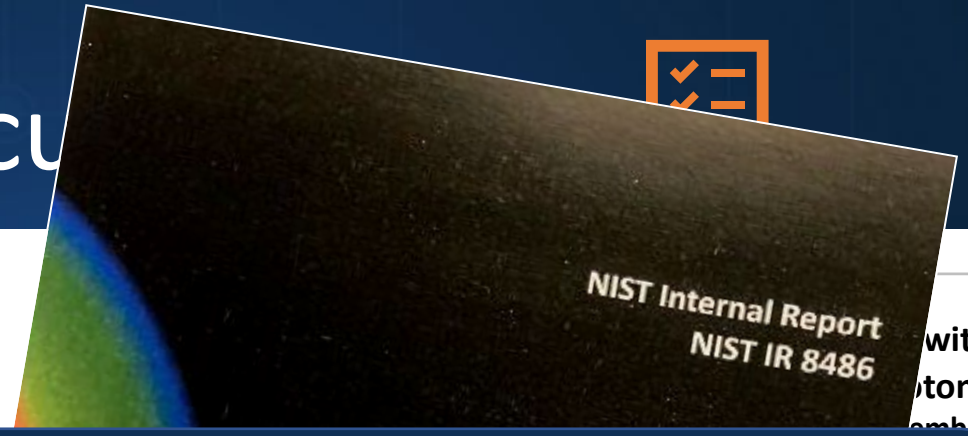
Terminology Docu

Inconsistencies in terminology:

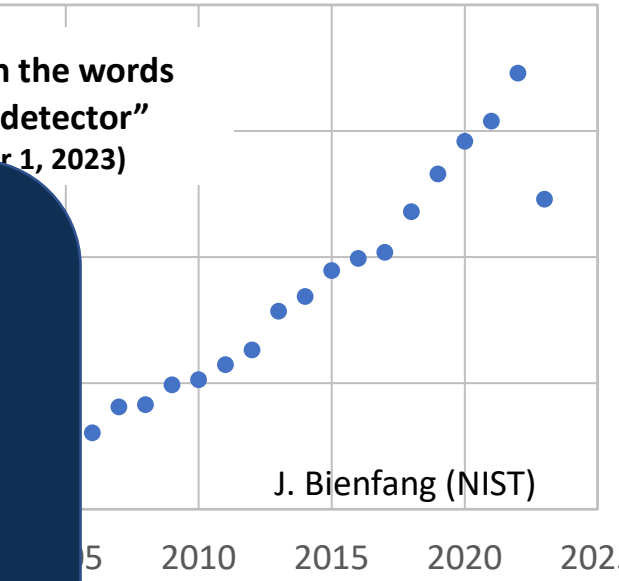
Usage: no well-defined

Context: different mean

Clarity: Incomplete, cor



Resources required!



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https://nvlpubs.nist.gov/
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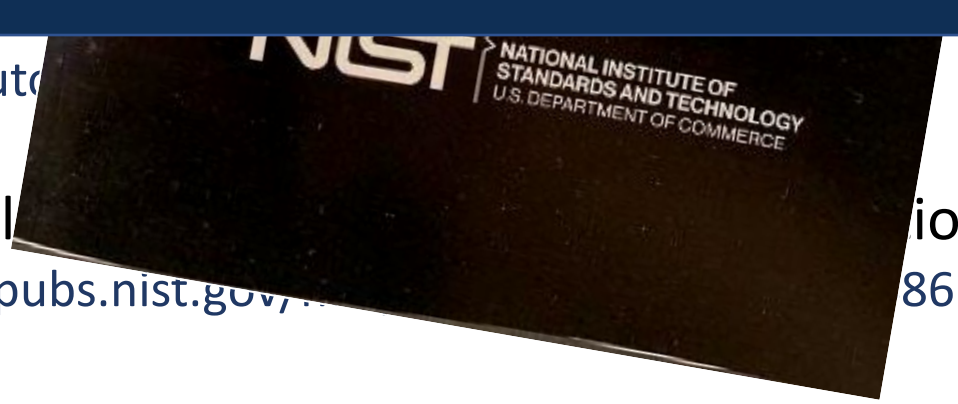


Direction: Documentary standards

< NIST | NRC >

NMIs have contributed to:

- Revision of ISO/IEC 18031 – Random Bit Generators [approved]
- ISO/IEC 23837:2023 Security requirements, test and evaluation methods for QKD
- ETSI GS QKD 016:2023-04 Common Criteria Protection Profile – Pair of Prepare and Measure QKD Modules
- ETSI GR QKD 007 V1.1.1 (2018-12) QKD: Vocabulary
- ETSI GR QKD 003 V2.1.1 (2018-03) QKD: Components and Interfaces
- ETSI GS QKD 011 V1.1.1 (2016-05) QKD: Component characterization: characterizing optical components for QKD systems

Direction: Documentary standards

< NIST | NRC >

Recent standards development activities:

June 2020

ISO/IEC JTC 1/WG 14
Quantum Information Technology: standardization program on Quantum Computing

March 2023

CEN/CLC/JTC 22 (4 WGs)
Quantum Technologies

→ **Standardization Roadmap on Quantum Technologies**

Support deployment of quantum technologies in European industry

February 2024

IEC/ISO JTC 3 Quantum technologies

Quantum information, metrology, sources, detectors, communications and fundamental technologies

Information exchange: Discussion Forum on Few-Photon Metrology

CCPR

Direction: NMI Cooperation

Outcome of CCPR-WG-SP-TG7 Discussion Forum on Few-Photon Metrology

→ Single-Photon Radiometry TG (CCPR-WG-SP-TG11) CCPR

→ Pilot study on detection efficiency of single-photon detectors (11 participants)

What next?

Documentation

- ❑ Recommended measurement practices
- ❑ Pitfalls to avoid

Technology

- ❑ Required uncertainties (per application)
- ❑ Develop shorter SI-traceability path

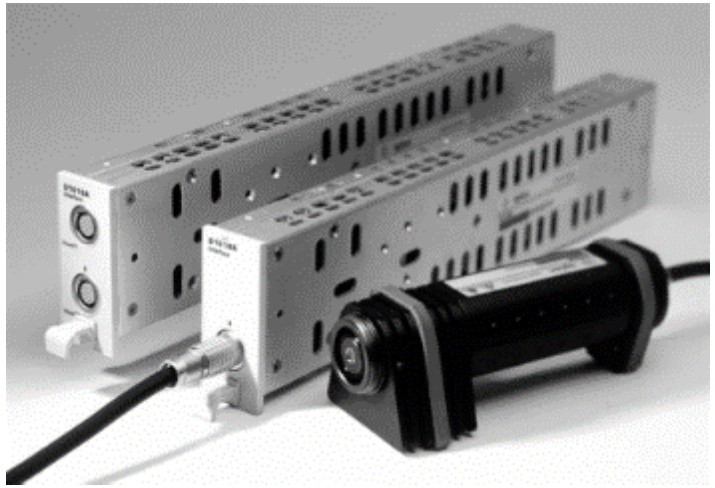
SI-Traceability: Quantum Photonics

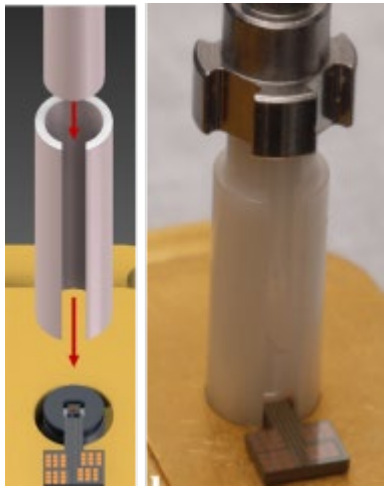
Underpinned by radiometry: optical power (cryogenic radiometer)

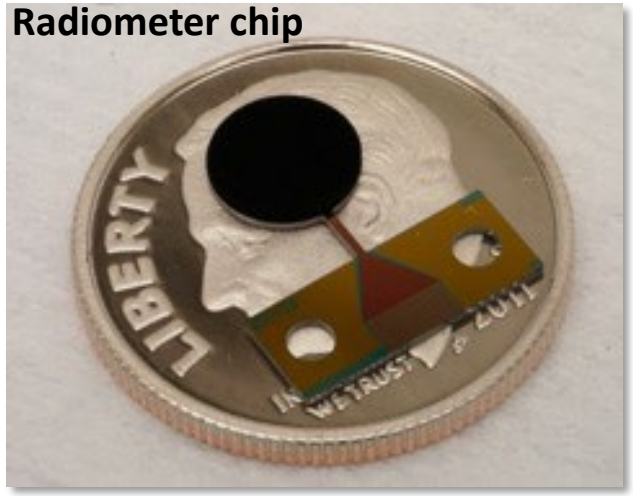
Example: Technology ⟳ Metrology

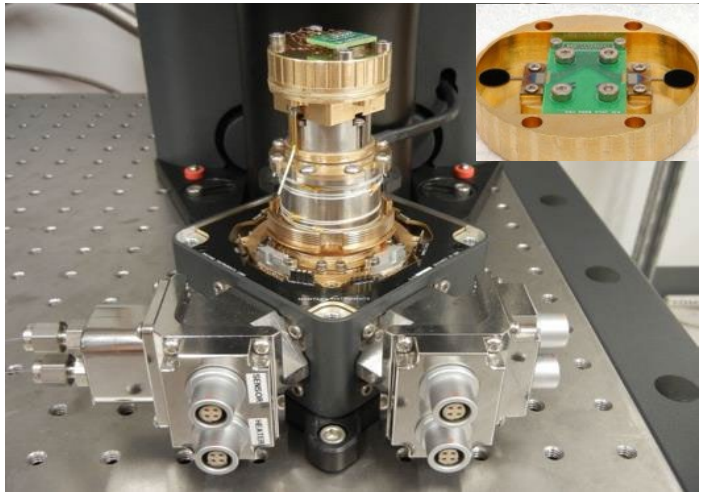
→ Shorter traceability chain for fibre-coupled photodetectors

Impact: telecommunications and information technology sectors









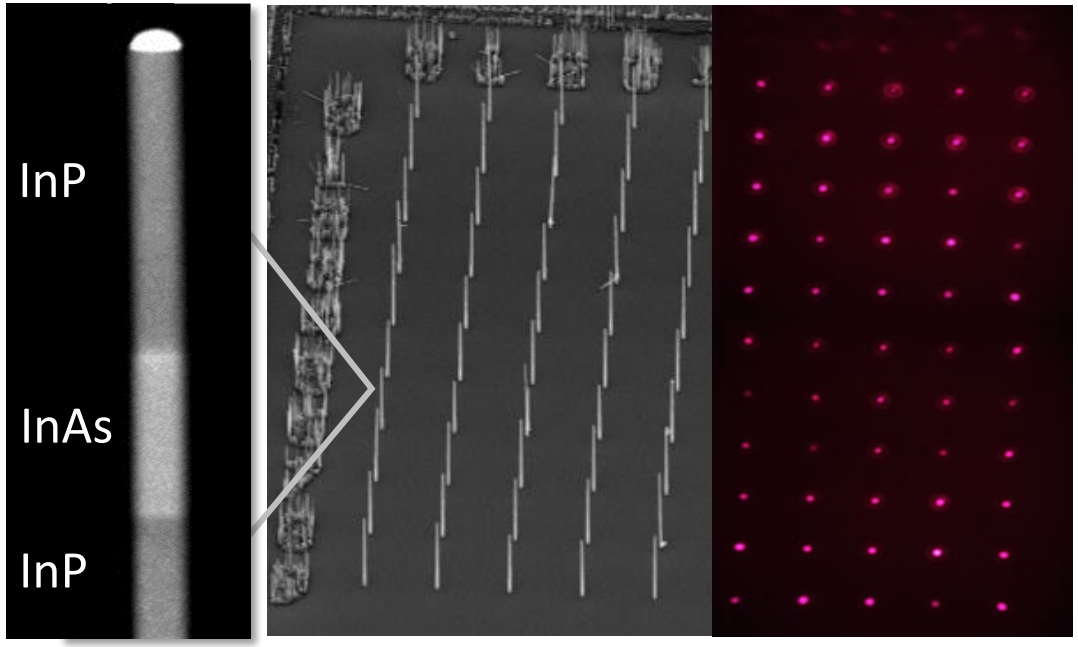
NIST CENAM CENTRO NACIONAL DE METROLOGÍA CZECH METROLOGY INSTITUTE

SI-Traceability: Quantum Photonics

What next? Metrology solutions for future quantum photonics infrastructure

Quantum photonics ⟳ **Metrology**

NRC quantum dot emitters



Sci. Rep. 12, 6376 (2022)

NRC·CNRC

NIST faint-light radiometer

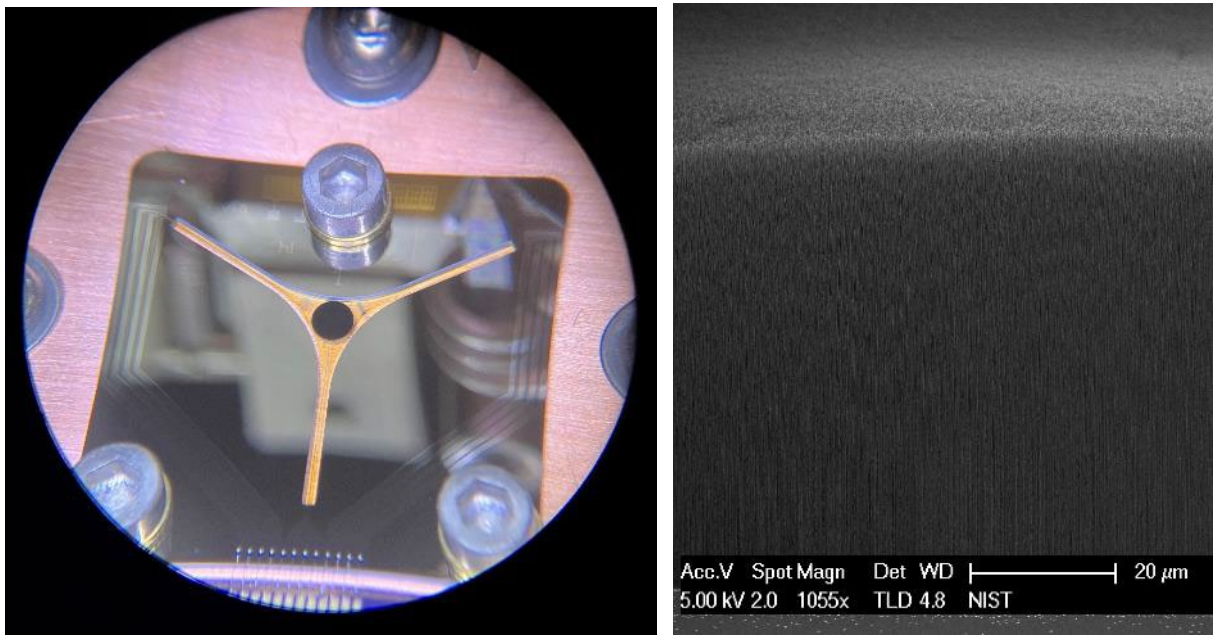
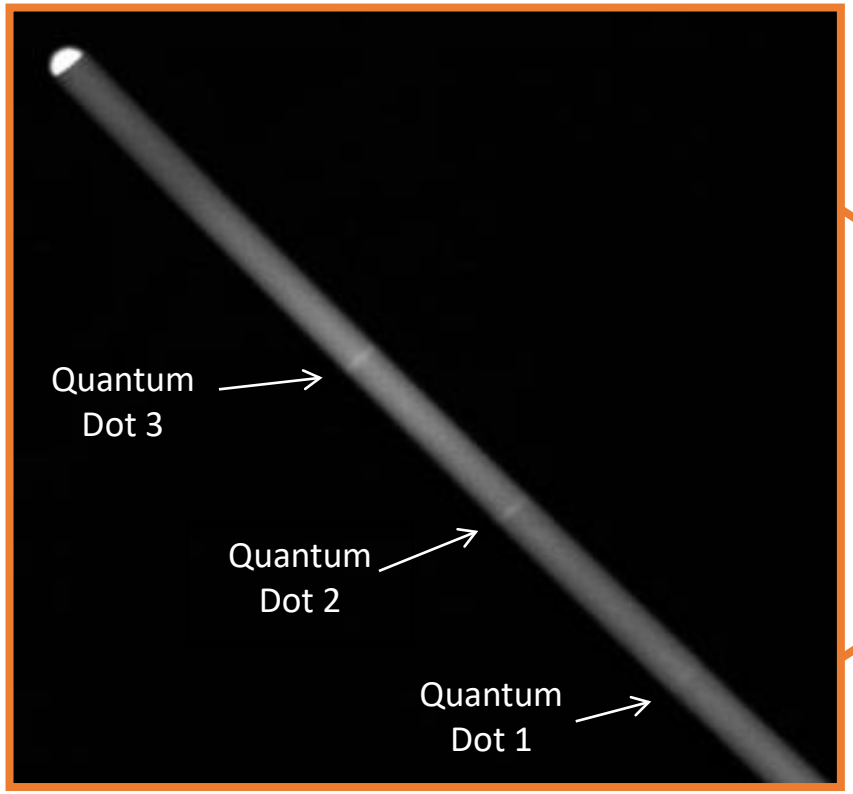


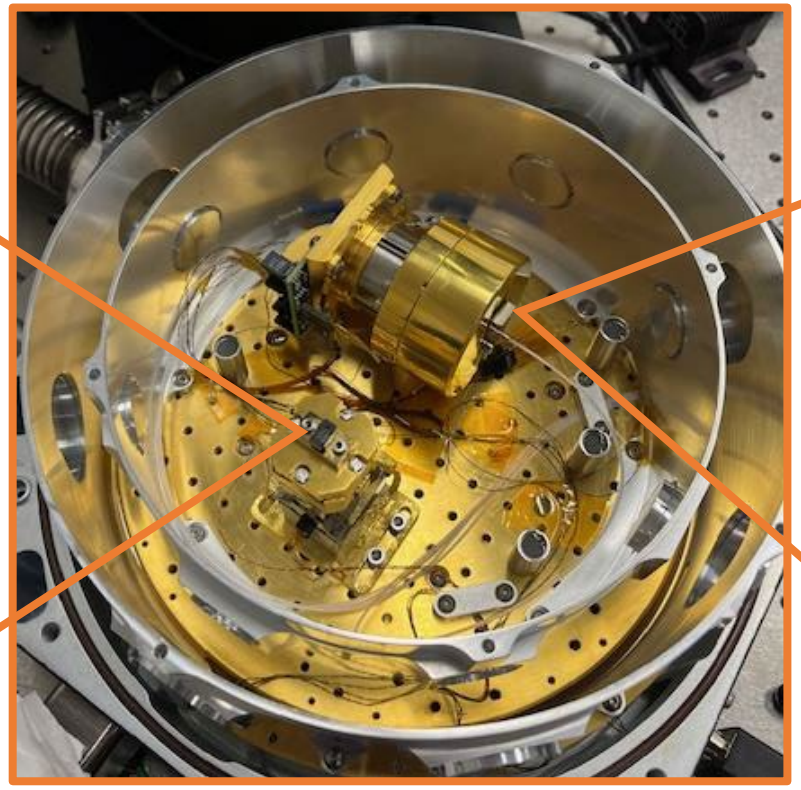
Photo: N. Tomlin

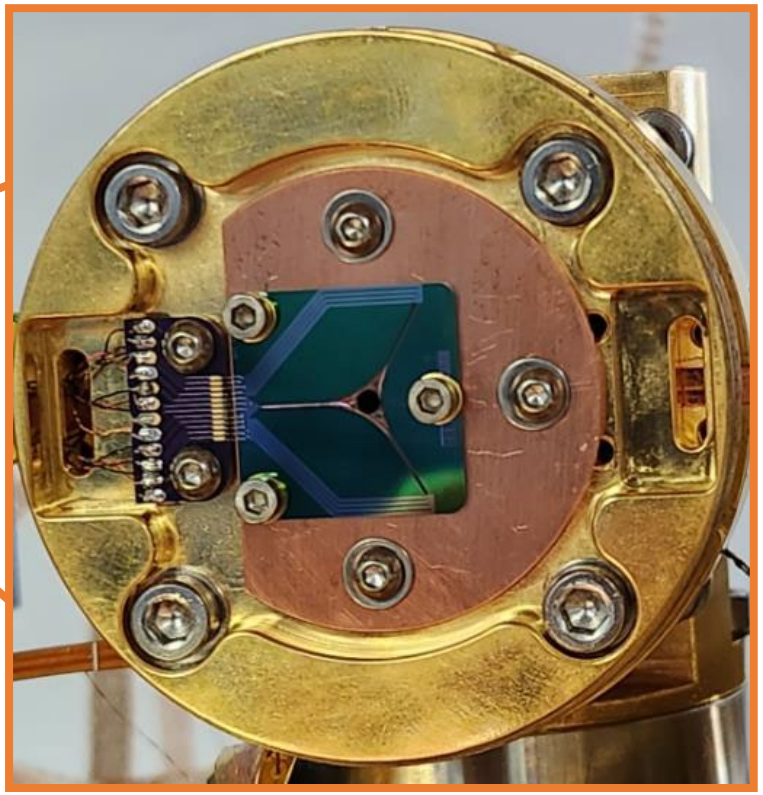
NIST

SI-Traceability: Quantum Photonics

NMI collaboration: Combining technologies





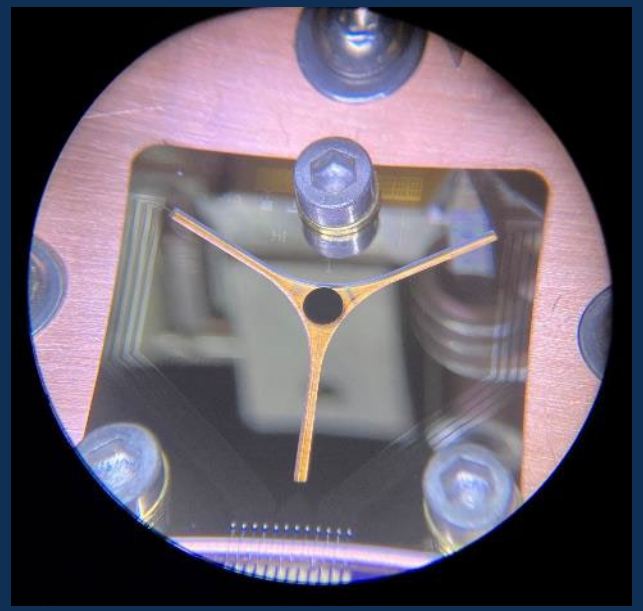


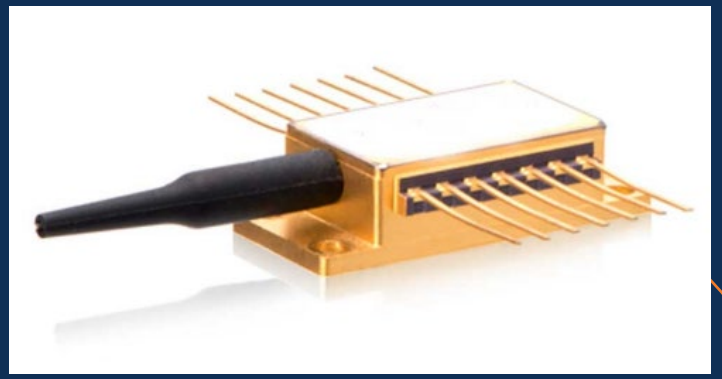
First measurements of NRC quantum dot emitters with a specialized faint-light sensor

SI-Traceability: Quantum Ph[illegible]nics

NMI collab[illegible]

Future SI-traceable QPIC calibrations





[illegible]egrated circuit development

[illegible]itters & NIST single photon detectors

Strength in Collaboration

Short Term Goals:

Common language

- ❑ Terminology – make the single-photon dictionary a standard

Understanding of measurements

- ❑ Publish recommended measurement practice/pitfalls technical notes

Long Term: Support quantum photonics measurements & future infrastructure

- ❑ Identifying comparison activities (detectors, sources, etc.)
- ❑ Practical calibrations and SI-Traceability

Summary

Progress in quantum photonics standards activities

- ✓ **Communication**
- ✓ **Collaboration**
  - → **Discussion Forums & Networks**
  - → **Motivation**
  - → **Terminology documentation**
  - → **Technology Integration**

Outcomes from BIPM Workshop (NMI-Q)

- NMI-QP drafted a white paper of quantum photonics section (J. H. Lehman, NIST)
- Overlap with TG7:
  - Industry engagement:
    - How to get input from industry on measurement needs for single photon sources, detectors, etc?
      - Clients, Conferences/workshops, Consortia (QED-C), etc. https://quantumconsortium.org/single-photon-report/
  - Monitor few-photon-related standards development activities (ISO/IEC, etc.)
    1. https://www.iso.org/standard/80432.html
    2. https://jtc1info.org/sd-2-history/jtc1-working-groups/wg-14/
    3. https://www.cencenelec.eu/media/CEN-CENELEC/AreasOfWork/CEN-CENELEC_Topics/Quantum%20technologies/Documentation%20and%20Materials/fgqt_q04_standardizationroadmapquantumtechnologies_release1.pdf

Outlook for TG7:

Monitor few-photon-related standards development activities

Plan: Survey TG members and consolidate list of past on ongoing industry engagement activities (TG7 Chair)

https://www.spw2024.org/

<u>Meetings:</u>

- Last virtual meeting February 2024
- Planning for quarterly virtual meetings
- Last in-person meeting SPW2022 Seoul November 2022
- Next in-person meeting SPW2024 Edinburgh November 2024