

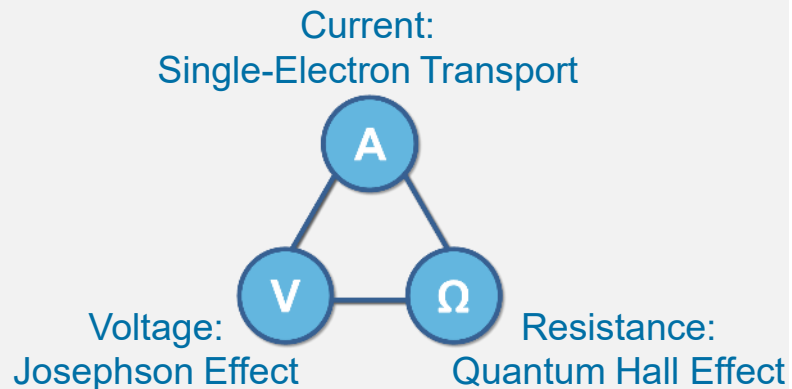
Hansjörg Scherer (PTB)



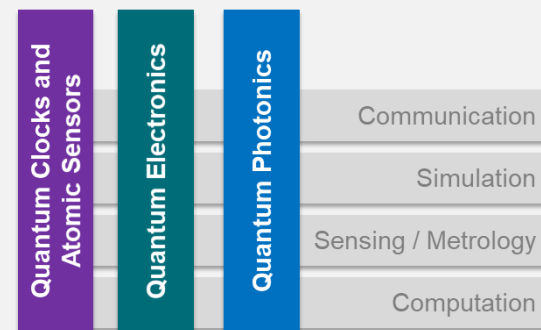
My personal functions



At PTB:
Head of Department
“Electrical Quantum Metrology”



In EMN-Q:
Vice Chair,
Section Coordinator “Quantum Electronics”
together with two Vice Coordinators:
Félicien Schopfer (LNE)
Antti Manninen (VTT-MIKES)

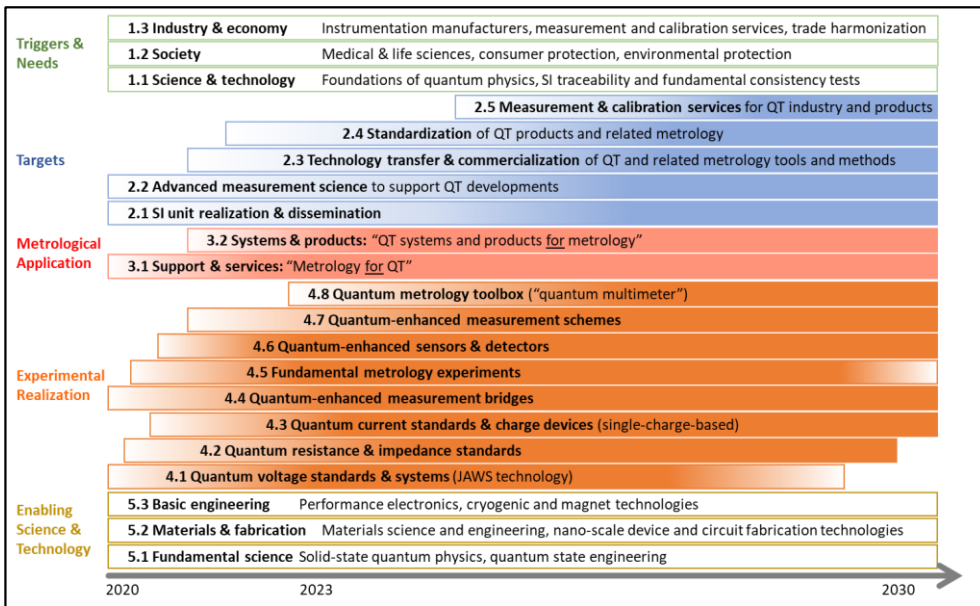


“Quantum Electronics” in EMN-Q

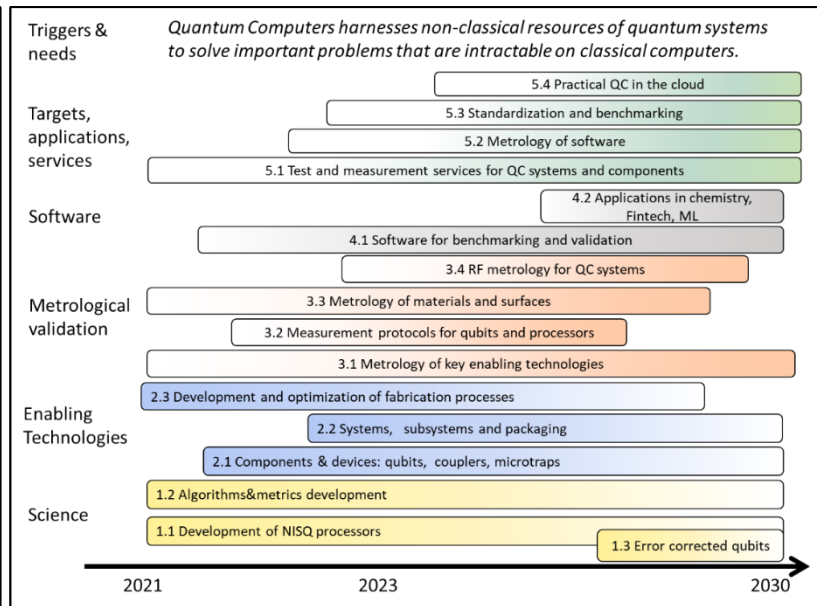
Two sub-fields

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

Quantum Metrology & Sensing



Quantum Computing



Quantum Metrology & Sensing:

- **Quantum voltage standards / systems**
based on the Josephson effect
- **Quantum resistance and impedance standards / systems**
based on the quantum Hall effect(s)
- **Quantum current standards and single-charge devices**
based on single-charge transport

→ **Integrated quantum metrology systems**

e.g., quantum “multimeters” integrating different standards
(in cryogen-free setups)

“Quantum classical”
methodologies, based
on “1st generation QT”,
established in NMIs.

• **Quantum-enhanced measurement systems, sensors and detectors**

e.g., Josephson and digital impedance bridges, cryogenic current comparators,
magnetometry with nitrogen-vacancy centres in diamond crystals, single-electron detectors ...

“Quantum Electronics” in EMN-Q

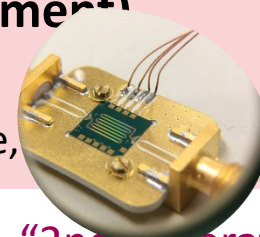
Quantum Computing:

- Qubits and qubit couplers (superconducting)
- Quantum-enhanced methods for qubit readout (measurement) and qubit control (manipulation)

e.g., superconducting amplifiers with quantum-limited noise performance, rf/microwave measurement methods and systems ...

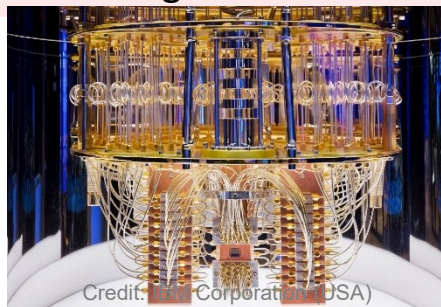
- Standardised protocols, methods and software

e.g., for benchmarking and validation of qubits, processors, data analysis



“2nd generation QT”:

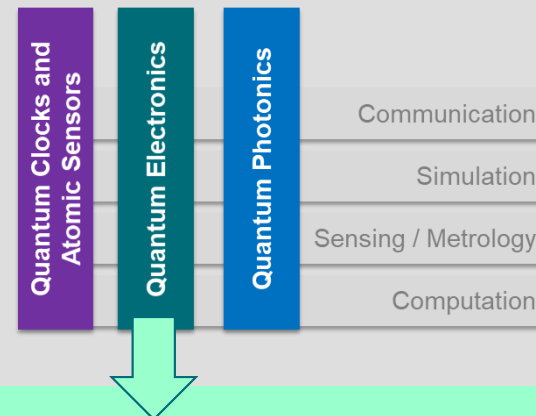
Entangled quantum states,
quantum-limited /
quantum non-demolition
techniques.



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 bodies)



From these: **70** stakeholders in “Quantum Electronics”

From these: **30** stakeholders are industrial companies

20 of these industrial stakeholders have contacts to PTB ...








Industry Stakeholders in EMN-Q “Qu-Electronics”

with contacts to PTB



QUANTUM
TECHNOLOGIES

Measurement systems & instrumentation, high-performance electronics (enabling technologies):

- **Magnicon**  DE
- **Sympuls**  DE
- **Signal Conversion**  UK
- **Applicos**  NL
- **Guildline Instruments**  CA
- **Zurich Instruments**  CH
- **Grimm Aerosol Technik**  DE

Cryogenic systems (enabling technologies):

- **Entropy**  DE
- **Oxford Instruments**  UK
- **Bluefors**  FI



Quantum standards, systems & detectors (applications):

- **Supracon AG**  DE
- **Measurement International**  CA
- **Graphensic**  SE
- **Graphene Waves**  US
- **Qzabre**  CH
- **Qnami**  CH

Industrial calibration labs (applications):

- **esz calibration & metrology**  DE
- **1A Cal**  DE

Quantum computing (applications):

- **IBM Research Quantum Europe**  CH
- **IQM**  FI/DE

Industry Stakeholder Products: Examples

Josephson Voltage Standards

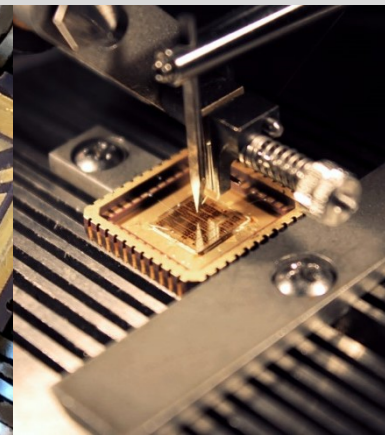
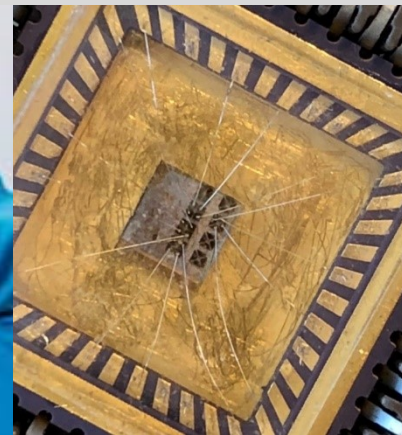
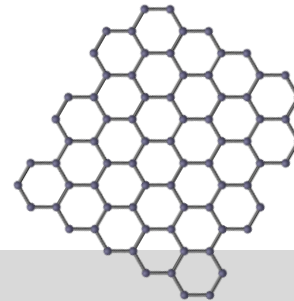
DC and AC 'quantum voltmeters' (up to 10 V, few kHz), commercially available, suppliers in DE, US.



Industry Stakeholder Products: Examples

Quantum Hall Resistance Standards

Graphene devices commercially available, suppliers in SE, US.



Industry Stakeholder Products: Examples

Cryogenic Current Comparators



QUANTUM
TECHNOLOGIES

... for high-end resistance bridges
used in quantum Hall resistance metrology.
Commercially available, suppliers in DE, UK.

SQUID
electronics

Digital double current source
incl. nanovoltmeter

CCC with SQUID null detector
(in Nb screen)



Industry Stakeholder Products: Examples

SQUID Sensors & Systems

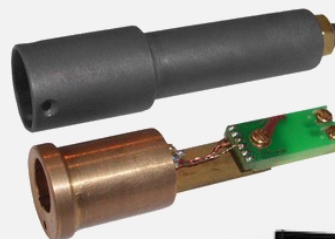
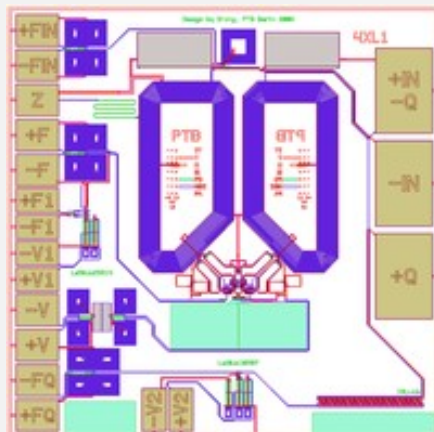


QUANTUM
TECHNOLOGIES



... for various applications.

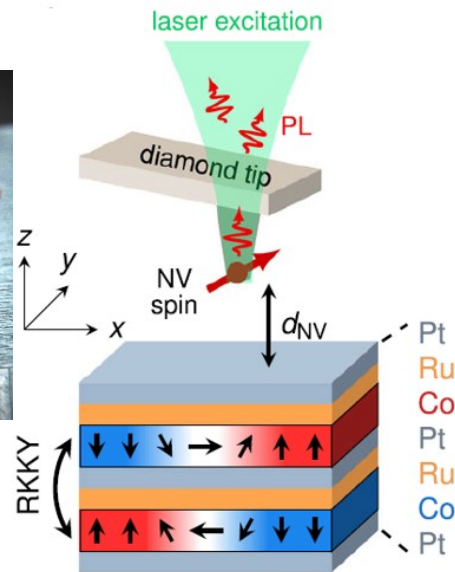
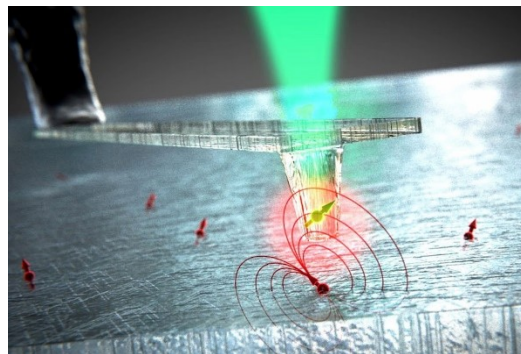
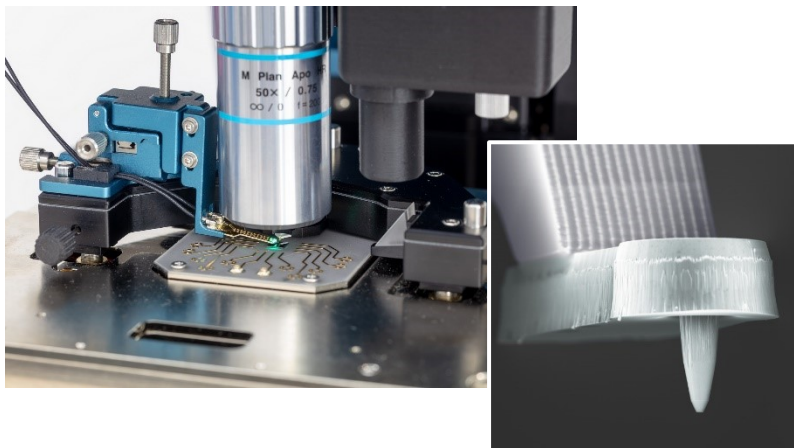
Commercially available, many suppliers world-wide.



Industry Stakeholder Products: Examples

Scanning Magnetic Microscopy Sensors & Systems

... using nitrogen-vacancy centres.
Commercially available, e.g., suppliers in CH.



Finco et al., *Nat Commun* 12, 767 (2021).
<https://doi.org/10.1038/s41467-021-20995-x>

Project cooperation with NMIs



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.

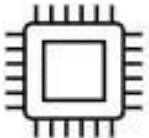



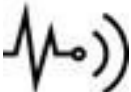

EMN-Q members:





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

“Qu-Electronics” in red

<p>Testbed 1</p> 	<p>Quantum Computing</p> 	<p>Cryogenic quantum devices, cryogenic qubits (superconducting and semiconducting, photonic) and ion traps.</p>
<p>Testbed 2</p> 	<p>Quantum Communication</p> 	<p>Devices for Quantum Key Distribution (QKD) and Quantum Random Number Generation (QRNG).</p>
<p>Testbed 3</p> 	<p>Quantum Sensing</p> 	<p>Sensing and metrology instruments provided by industry, and quantum sensors (e.g., clocks, gravimeters, magnetometers).</p>

EMN-Q Infrastructure in FPA ‘Qu-Test’



EMN-Q facilities *“Qu-Electronics” in red*

Piemonte Quantum Enabling Technology (nanofabrication facility)	INRIM
Cryomagnetic characterisation environments for quantum devices	
QR Labs (micro/nanofabrication facilities)	
Clean Room Centre	PTB
“Ion Traps” in the Quantum Competence Centre	
“Metrology of Ultra-Low Magnetic Fields”	
“Optical QT” in the Quantum Competence Centre	
“Single Photons” in the Quantum Competence Centre	
“Electrical Quantum Metrology” in the Quantum Competence Centre	LNE
Fundamental (primary standard) metrology laboratories	
Quantum electrical metrology laboratories	
Nanotech Institute / Innovation Centre “NanoMeasureFrance”	
Quantum Metrology Platform	

Infrastructure: QT Centres @ NMIs

Example: PTB's Quantum Technology Competence Centre (QTZ)

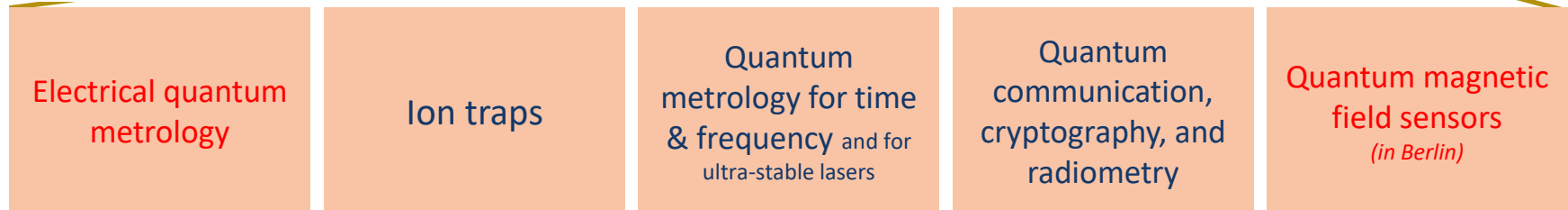
Since 2019.

Mission: To support development of quantum technology and industry in metrology (focus on technology transfer to start-ups and SMEs).

Activity pillars:



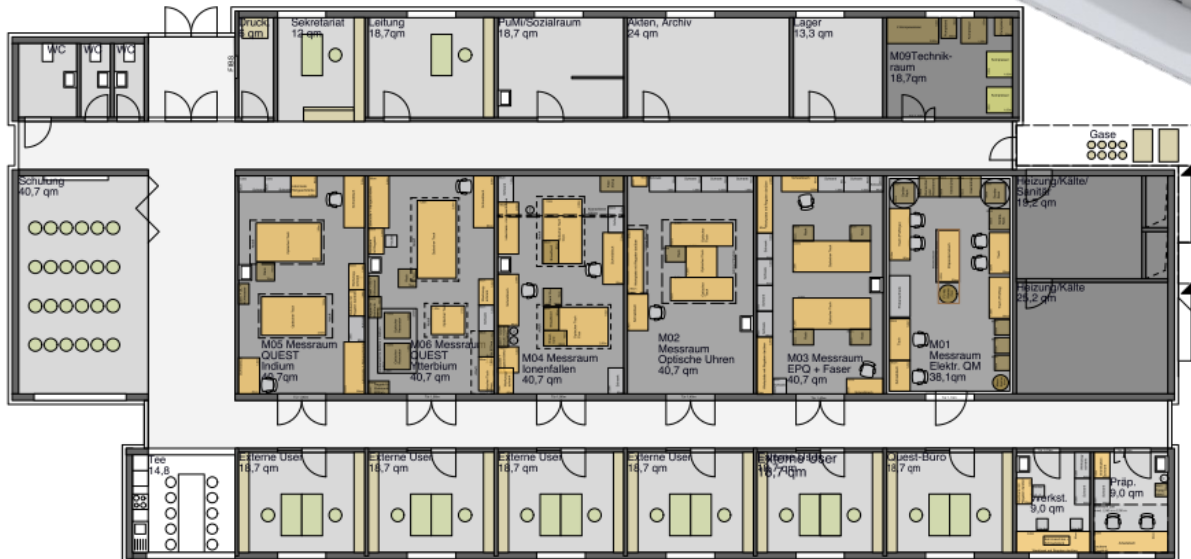
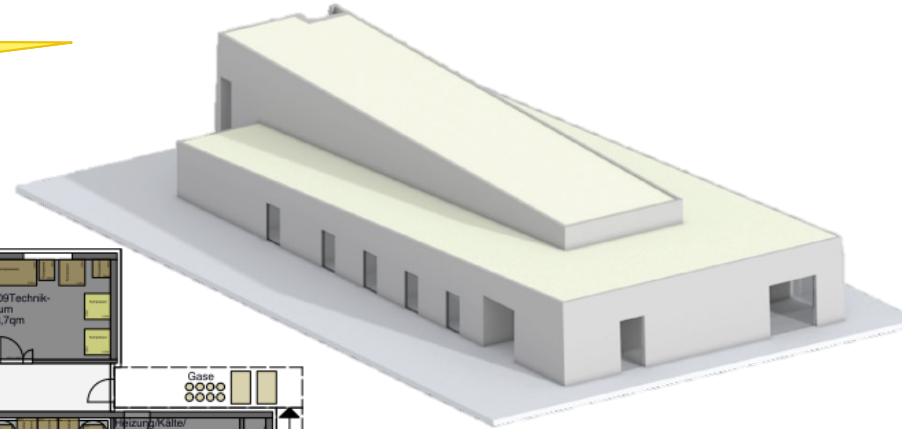
User platforms: *“Qu-Electronics” in red*



Infrastructure: QT Centres @ NMIs

Example: PTB's Quantum Technology Competence Centre (QTZ)

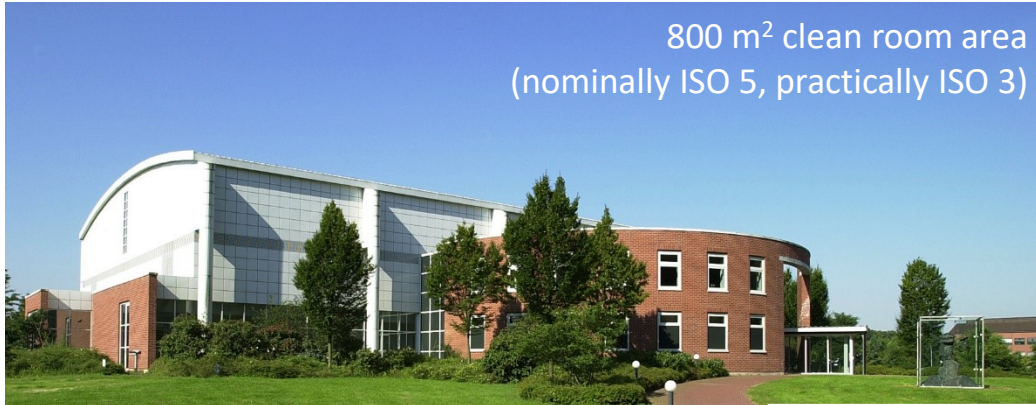
New building @ PTB Braunschweig



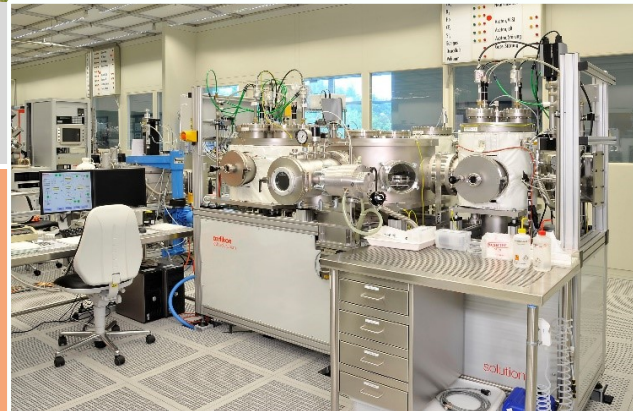
Infrastructure: QT Centres @ NMIs

Example: PTB's Clean Room Centre

800 m² clean room area
(nominally ISO 5, practically ISO 3)




- Electron beam lithography (100 kV)
- Molecular beam epitaxy
- Thin-film technology process/fabrication lines
- **Electrical quantum standards:**
 - QHR: GaAs and Graphene
 - JVS: Niobium
 - SET: GaAs
- **Sensors:** (nano) SQUIDs



EMN-Q in Standardisation



 Focus Group on Quantum Technologies	Issue Date: 2022-10-04	CEN-CLC/FGQT	N270
	Deadline: 2022-11-03	Supersedes: N238	
	Status: FOR APPROVAL		
TITLE	FGQT Standardization Roadmap – Version L		
PROJECT	QT Standardization Roadmap		

150 pages

“Qu-Electronics” topics:

Enabling Technologies

- Colour centres in (nano)diamonds and other crystals
- Superconducting quantum circuits
- Traveling wave parametric amplifier
- Semiconductor quantum dots for quantum electronics

QT Components and Subsystems

- Single-photon detectors
- Single-electron sources
- ...

Quantum Computing and Quantum Simulation Systems

- Cryogenic solid-state based quantum computing architectures
- Room-temperature solid-state based quantum computing architectures

Quantum Metrology, Quantum Sensing, and Quantum Imaging

- Quantum magnetometers
- ...



Quantum Electronics in EMN-Q



“Quantum Metrology: the present and the future”

21 November 2022



Physikalisch-Technische Bundesanstalt Braunschweig and Berlin

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