


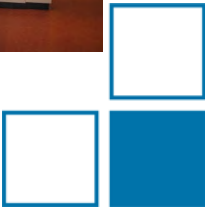
 **Physikalisch-Technische Bundesanstalt**
Braunschweig and Berlin
National Metrology Institute

Metrology for Innovation: Industry, Society and Science



A PTB perspective

Prof. Dr. Joachim Ullrich
President of PTB





Metrology Symposium 2018 at CENAM


What is Metrology?

Metrology: International

- the science and application of precise measurements
- establishing traceability to measurement units: **the SI**

Le Système international d'unités
The International System of Units



all these measurements have to be correct and globally accepted!

quantum standards length force

&
States

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What is Metrology?



Metrology: International

- the science and application of precise measurements
- establishing traceability to measurement units: **the SI**



- 97.6 % of the world economic power
- global measurement infrastructure
- cornerstone of quality infrastructure

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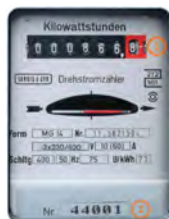
National Metrology Institute

What is Metrology needed for?

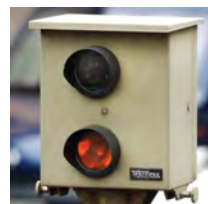


Ensuring the correctness of measurements in official, commercial and scientific use

Wherever society relies on measurement instruments:



electricity meter, gas meter, water meters, fuel oil, dosimetry, tire pressure, radar, sound, pollutants, lighting, MRT safety, cytometry (e.g. blood count) ...



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What is Metrology needed for?



...in global market ...in a competitive market:

Does the nut from Argentina fit the bolt from Germany?

Does a computer from China work with the German 230 V



- Reduce technical barriers to trade
- Better be better: lowest uncertainties, highest quality

...in a diverse market:

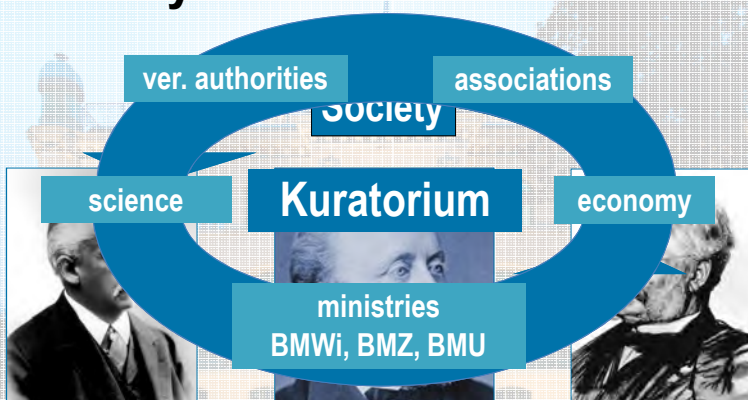
- Empower specific economies and industry

□ Essential for (Germany's) global economy and welfare

Metrology in Germany: then and now




since 130 years

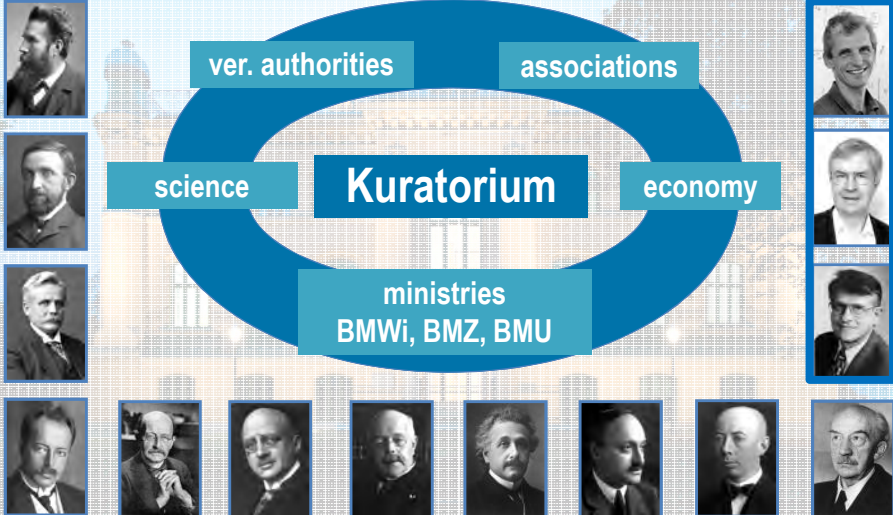


28 high-rank representatives of PTB stakeholders
 Providing the national
 Decisive for our impact in industry, society & politics

Metrology in Germany: then and now



since 130 years




ver. authorities associations

science **Kuratorium** economy

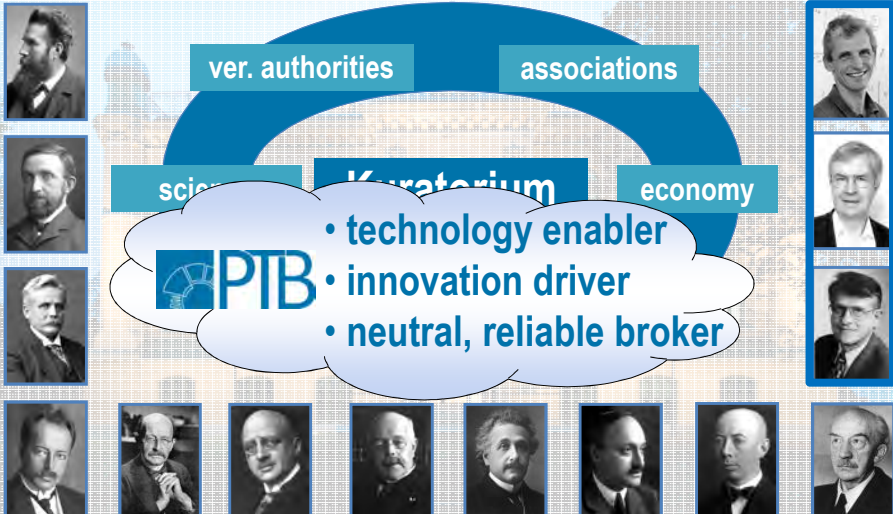
ministries
BMW, BMZ, BMU

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Metrology in Germany: then and now



since 130 years



ver. authorities associations

science **Kuratorium** economy

PTB

- technology enabler
- innovation driver
- neutral, reliable broker

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Physikalisch-Technische Bundesanstalt 

Our business areas



Fundamental Metrology	Metrology for Society
International Harmonization	Metrology for Industry








Selected examples: metrology underpinning innovation

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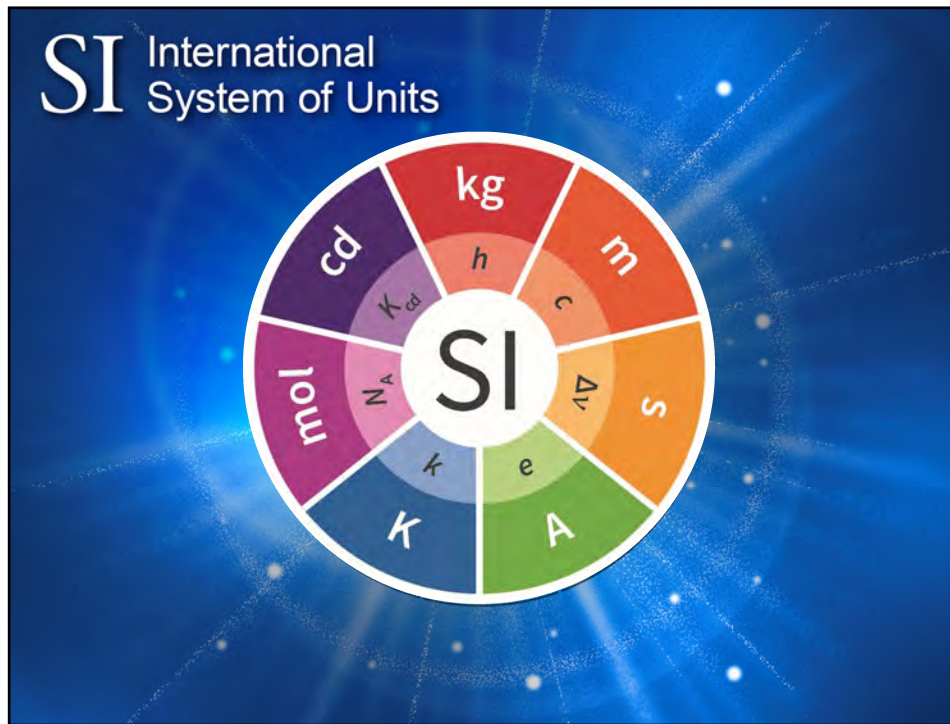
SI International System of Units




The diagram shows a circular arrangement of SI units. The outer ring contains the units: kg, m, s, A, K, mol, and cd. The inner ring contains the symbols: h, c, Δν, e, k, N_A, and K_{cd}. The center contains the letters 'SI'.

Guaranteeing:

- long-time stability
- realization everywhere
- with ever-increasing accuracy as technologies improve
- triggering **innovation** in science, industry and technology



Revised International System of Units 

units
defining constants

time

A circular diagram showing the seven base units and their defining constants for the revised SI system. The units are: s (second), m (meter), kg (kilogram), A (ampere), K (kelvin), mol (mole), and pc (pico). The defining constants are: $\Delta\nu$, c , h , e , k , N_A , and K_{pc} .

$$1 \text{ s} = \frac{9\,192\,631\,770}{\Delta\nu(^{133}\text{Cs})_{\text{hfs}}}$$

Physikalisch-Technische Bundesanstalt ■ Braunschweig and Berlin, National Metrology Institute

Fundamental Metrology: Time/Frequency



PTB's Cesium Fountain Clock

Realization of SI second

- highest reliability
- small uncertainty: 2.0×10^{-16}

One of the most accurate realizations worldwide!

Impact: coordinated time for GALILEO, ACES

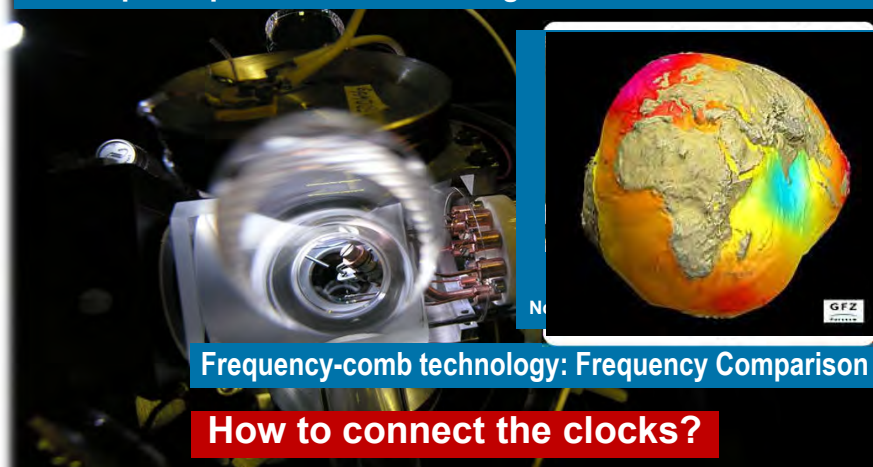
$$1 \text{ s} = \frac{9\,192\,631\,770}{\Delta\nu(^{133}\text{Cs})_{\text{hfs}}}$$

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Fundamental Metrology: Time/Frequency

The “optical pendulum” for next-generation atomic clocks



Frequency-comb technology: Frequency Comparison

How to connect the clocks?

Systematic uncertainty (single-ion clock-frequency): 1×10^{-18}

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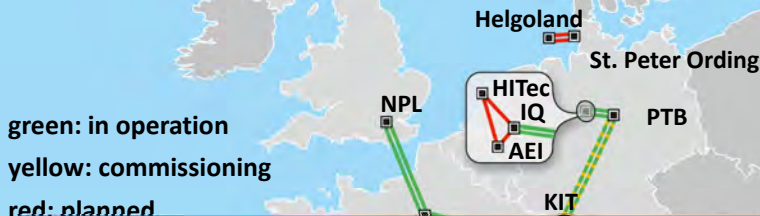
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Fundamental Metrology: Innovation



Brillouin amplification supports 1×10^{-20} accuracy in optical frequency transfer over 1400 km of underground fibre

Sebastian M. F. Raupach,^{1,*} Andreas Koczwar,¹ and Gesine Grosche¹
¹Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, D-38116 Braunschweig, Germany
 (Dated: March 20, 2015)



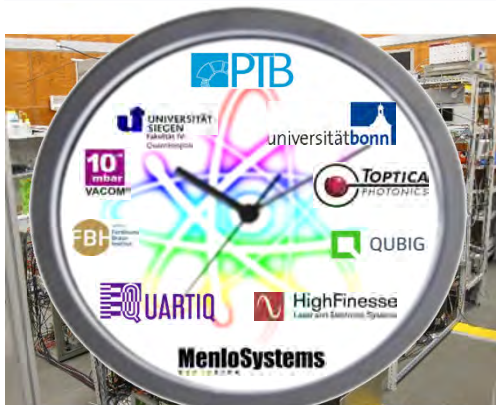
A European fiber network for

- high-precision frequency / time transmission,
- quantum cryptography,
- ultra-broadband information transmission

Fundamental Metrology: Innovation



Next-generation portable clocks: replace H-Maser



$<10^{-16}$ Uncertainty

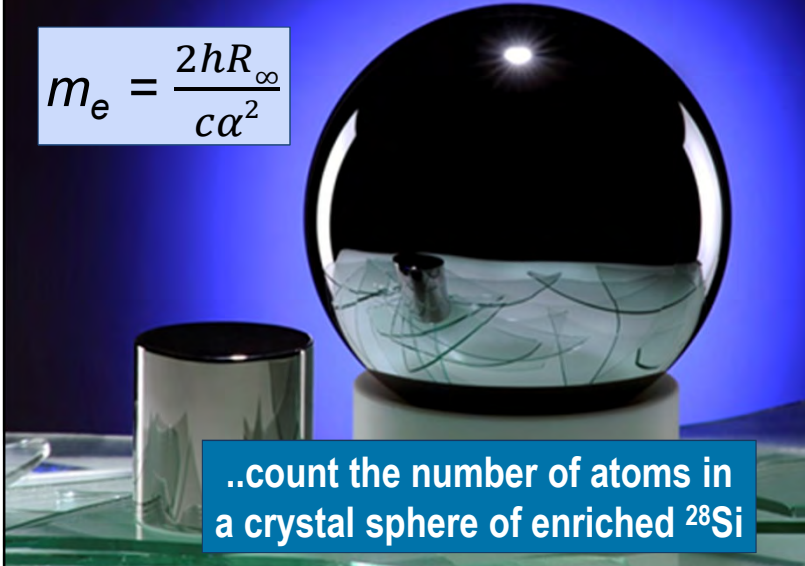
$<10^{-1}$ OptiClock Consortium Clock
 Optical Single Ion Clock

- Data network synchronization,
- Geoid surveying

The Quantum Mechanics provides the mass scale via fundamental constants

$$m_e = \frac{2hR_\infty}{c\alpha^2}$$

..count the number of atoms in a crystal sphere of enriched ^{28}Si

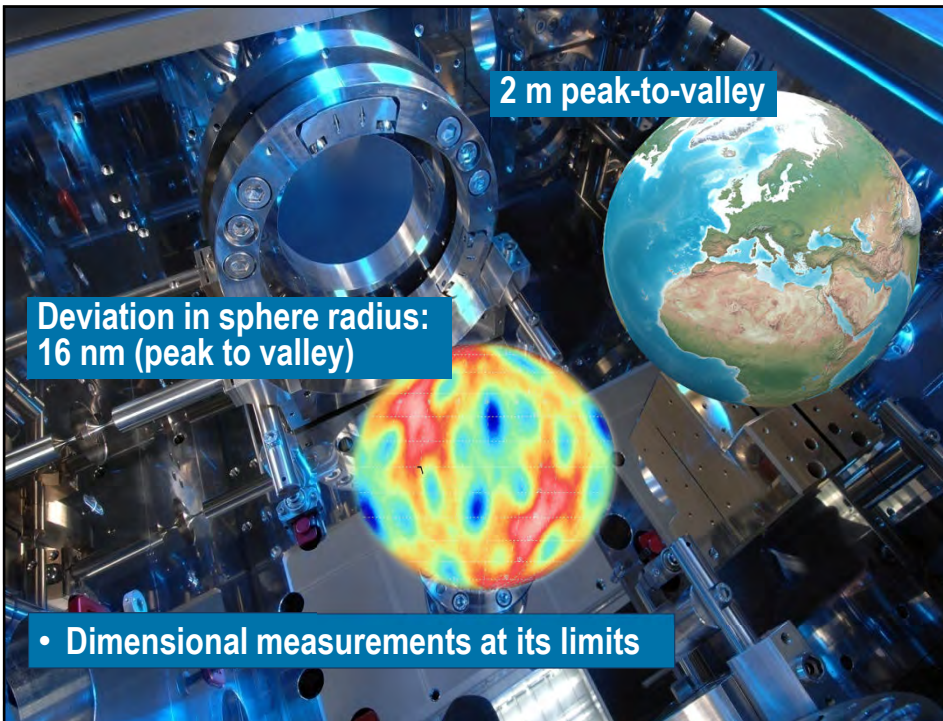


Logos on the right side of the slide include: Bureau International des Poids et Mesures (BIPM), INRIM, ITRM, NIST, Australian Government National Measurement Institute, NMIJ, NPL (National Physical Laboratory), and PIB.

2 m peak-to-valley

Deviation in sphere radius: 16 nm (peak to valley)

- Dimensional measurements at its limits



Fundamental Metrology: Innovation



Commercial Kibble Balances

- “self-calibrating”
- high precision
- industrial application: E1, E2
- “off-the-shelf” components
- connected to the IoT

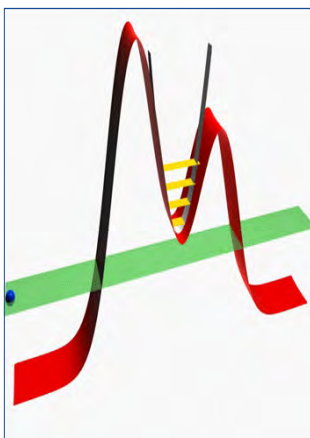


Version	Mass range	MPE OIML R111-1	$U_r \leq 1/3 \cdot MPE$ $k=2$	Environment
PB 2 (E2)	1 mg...100 g	$16 \cdot 10^{-7}$	$5.3 \cdot 10^{-7}$	Air
PB 1 (E1)	1 mg...1 kg	$5 \cdot 10^{-7}$	$1.7 \cdot 10^{-7}$	High Vacuum

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Fundamental Metrology: Electrical Units



$$I = \langle n \rangle e f$$

current

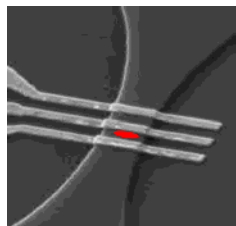
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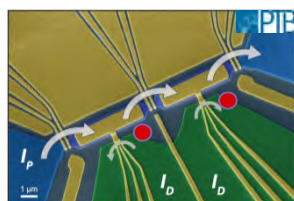
Fundamental Metrology: Innovation



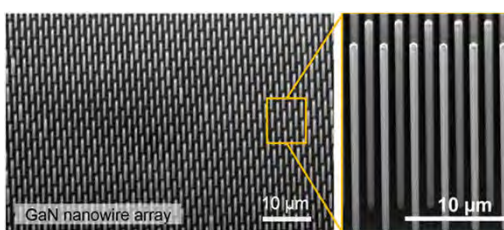
Self-referenced noise-free electrical current



- Future applications**
- Quantum electronic (e.g. spintronics)
 - Shot-noise-free electronics
 - Photonic technologies
 - Quantum information processing



- Series of pumps for improved uncertainty

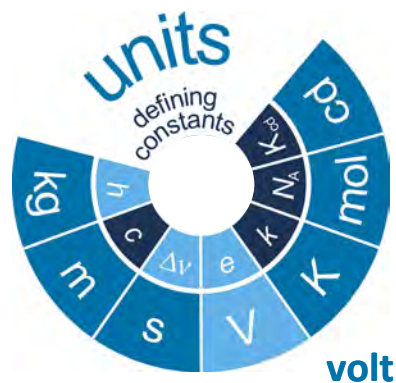


A. Waag, TU Braunschweig

Fundamental Metrology: Electrical Units



$$R_K = h / e^2$$



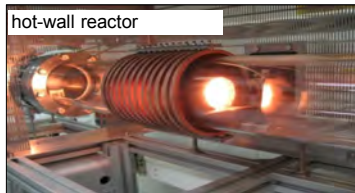
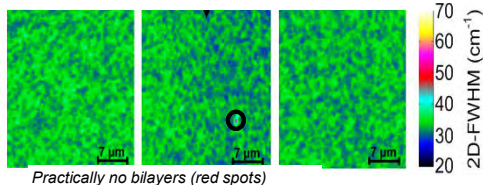
$$K_J = 2e / h$$

Fundamental Metrology: Innovation

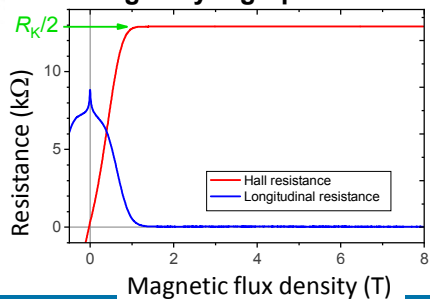


Goal: Operation at small B-field

- Production of epitaxial graphene on SiC established at PTB



- Patented growth method for single-layer graphene

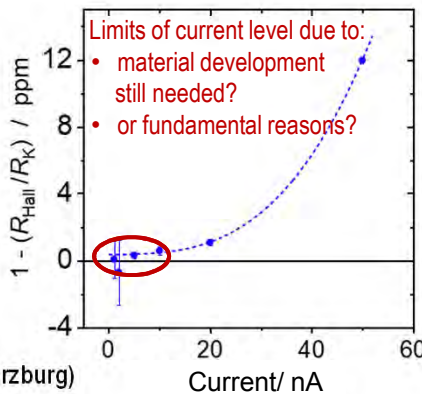
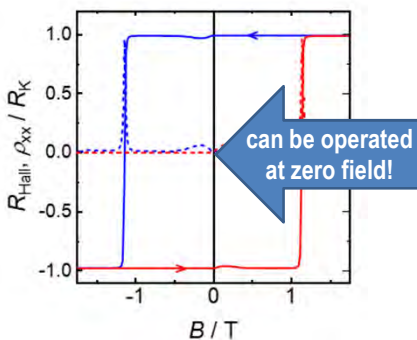


- Excellent dc- and ac-QHE demonstrated
- Yet to be optimized: achieving stable and robust carrier concentration

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Fundamental Metrology: Innovation



Topological Insulators: W. Molenkamp (U. Würzburg)

Proof of universality with 0.25 ppm measurement uncertainty at a few nA

Goal: increase operating currents and S/N by factor 1000

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Fundamental Metrology: Innovation



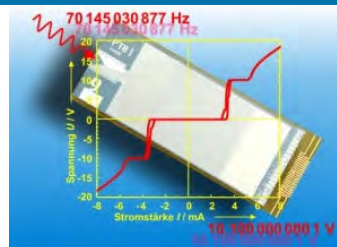
Combined Electrical Standard Device

Quantum Hall Resistor



Best operation:
1.5 K, 10 T

Josephson Voltage Standard



Best operation:
4 K, 0 T

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SI International System of Units



The Quantum SI

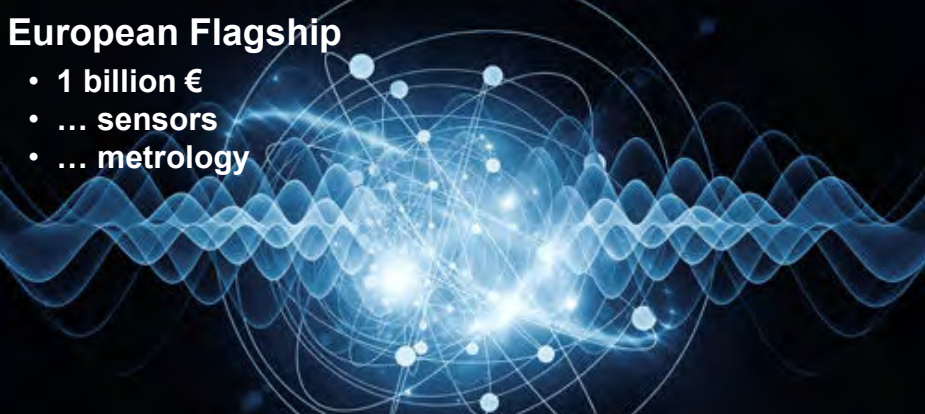
2nd Generation Quantum Technologies

European Flagship

- 1 billion €
- ... sensors
- ... metrology

2nd generation quantum technology:

- Engineering single quanta and quantum systems
- Quantum electronics, ~ sensors, ~computers
quantum cryptography, quantum metrology



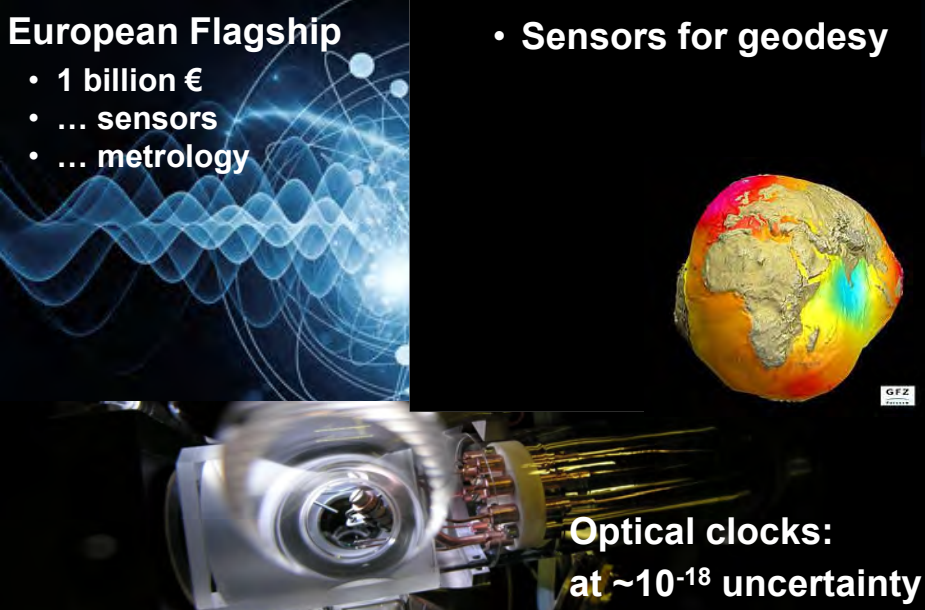
2nd Generation Quantum Technologies

European Flagship

- 1 billion €
- ... sensors
- ... metrology

- Sensors for geodesy

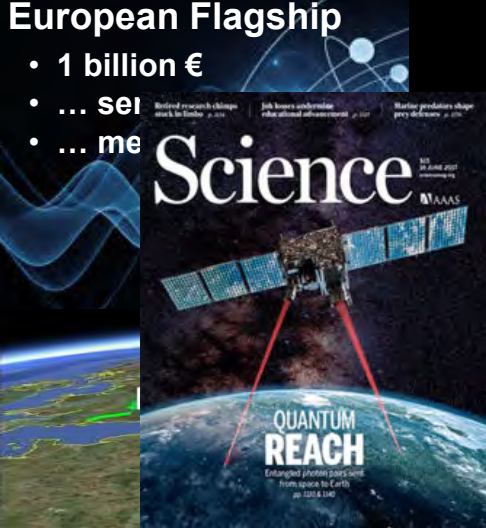
**Optical clocks:
at $\sim 10^{-18}$ uncertainty**



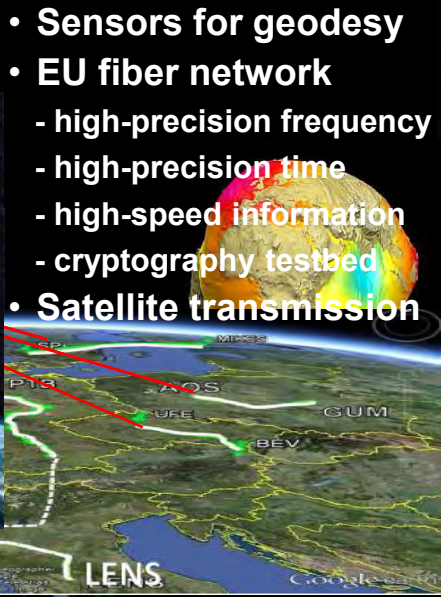
2nd Generation Quantum Technologies

European Flagship

- 1 billion €
- ... sei
- ... me




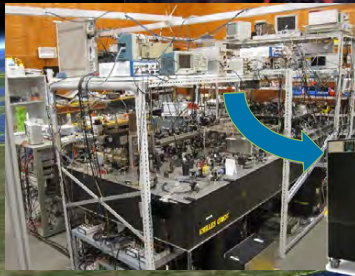
- Sensors for geodesy
- EU fiber network
 - high-precision frequency
 - high-precision time
 - high-speed information
 - cryptography testbed
- Satellite transmission



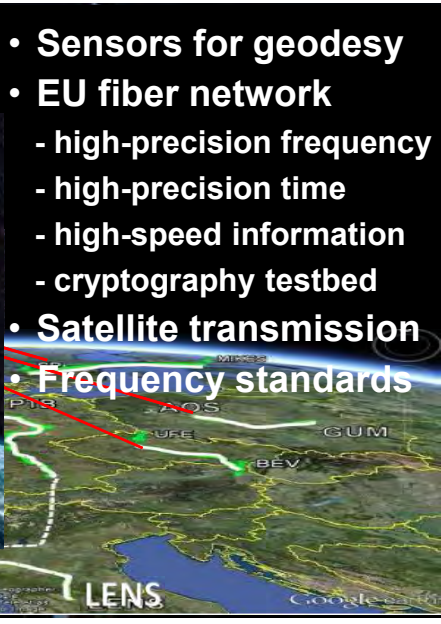
2nd Generation Quantum Technologies

European Flagship

- 1 billion €
- ... sei
- ... me

- Sensors for geodesy
- EU fiber network
 - high-precision frequency
 - high-precision time
 - high-speed information
 - cryptography testbed
- Satellite transmission
- Frequency standards




2nd Generation Quantum Technologies

European Flagship

- 1 billion €
- ... sensors
- ... metrology

- **Sensors for geodesy**
- **EU fiber network**
 - high-precision frequency
 - high-precision time
- high-speed information cryptography testbed
- **Satellite transmission**
- Frequency standards
- Low-noise electronics
- Nano-SQUIDs



Innovation

Empowered by the Quantum SI

❑ **QT centre of competence at PTB**

Physikalisch-Technische Bundesanstalt


Our business areas


Fundamental Metrology

Metrology for Society

International Harmonisation


Metrology for Industry






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Metrology for Society: Health 

Reference Laboratory for Haematology



Innovation!


Measurement cell for micro cytometry: may be used at an accident site

PTB

- is the only reference laboratory for haematology worldwide
- provides reference values for proficiency tests
- provides basis for quality assurance in 3000 clinical labs in Germany: e.g. blood count
- current project: quantify the virus load in a virus infection
- 3D imaging in cytometry

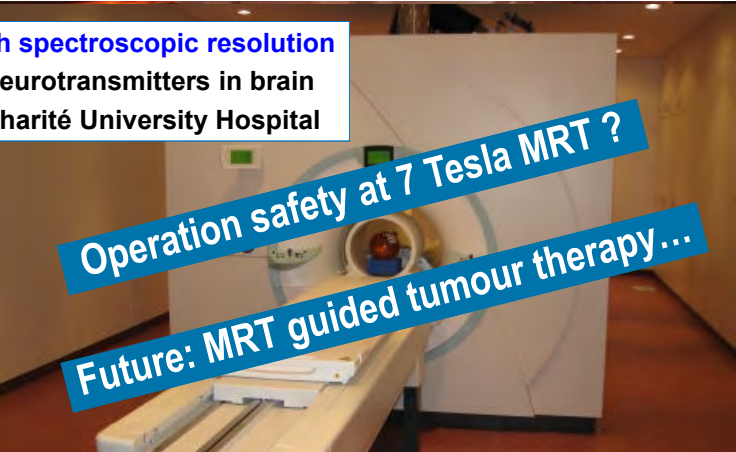
Research!

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Metrology for Society: Health 

High spectroscopic resolution

- Neurotransmitters in brain
- Charité University Hospital



Operation safety at 7 Tesla MRT ?

Future: MRT guided tumour therapy...

...standardization, services, research and innovation go together!

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Our business areas



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Metrology for Industry: Force

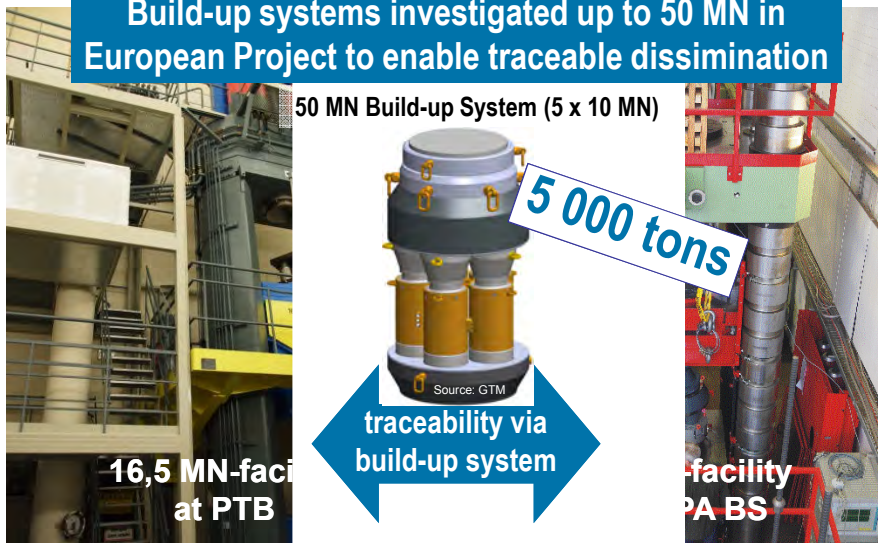


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Metrology for Industry: Force

Build-up systems investigated up to 50 MN in European Project to enable traceable dissemination



16,5 MN-facility at PTB

50 MN Build-up System (5 x 10 MN)

5 000 tons

traceability via build-up system


PA BS

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Society and Industry: Renewables

Wind Energy: New center of competence at PTB

under construction



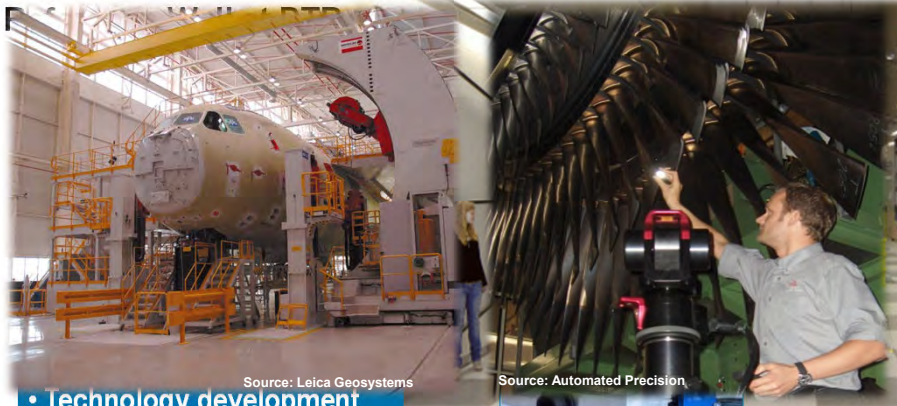
German wind power industry:

- 20 % world market share
- 40 % without China

Measurement Uncertainty = Uncertainty of Return on Investment!

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Metrology for Industry: Length



Source: Leica Geosystems

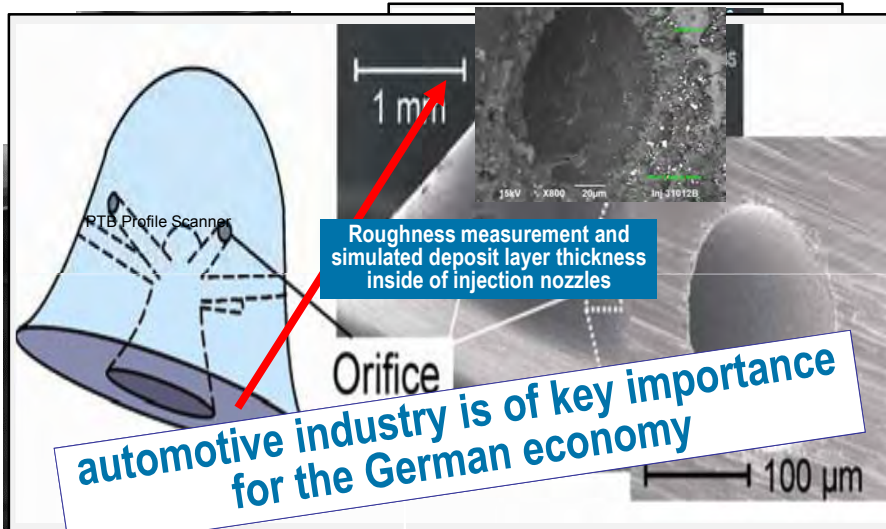
Source: Automated Precision

• Technology development

• Calibration of laser-tracker, radar-scanner

→ For quality assurance in heavy-machine construction

Metrology for Industry: Length



PTB Profile Scanner

Roughness measurement and simulated deposit layer thickness inside of injection nozzles

automotive industry is of key importance for the German economy

Orifice

65x 5kV 15mm

x (µm)

E-Mobility: Li-Ion Batteries







Reference test site for verification of:

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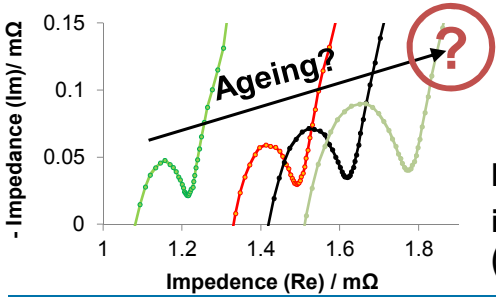
E-Mobility: Li-Ion Batteries





Reference test site for verification of:

- Condition (maximum capacity)
- Charging (actual capacity)





Ageing?

Based on electrochemical impedance spectroscopy (quick measurement procedure)

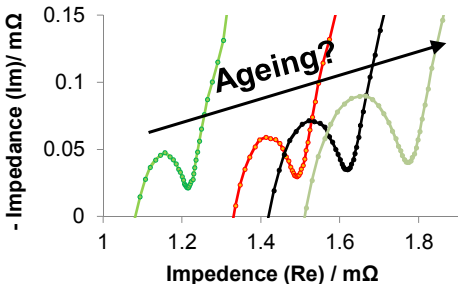
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E-Mobility: Li-Ion Batteries






Second-Use Batteries (EMPIR 2017 LiBForSecUse)



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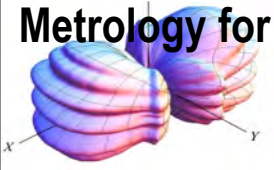



Based on electrochemical impedance spectroscopy (quick measurement procedure)

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Metrology for Industry: Light

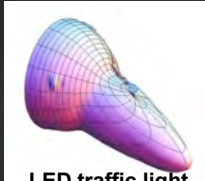
halogen light bulb



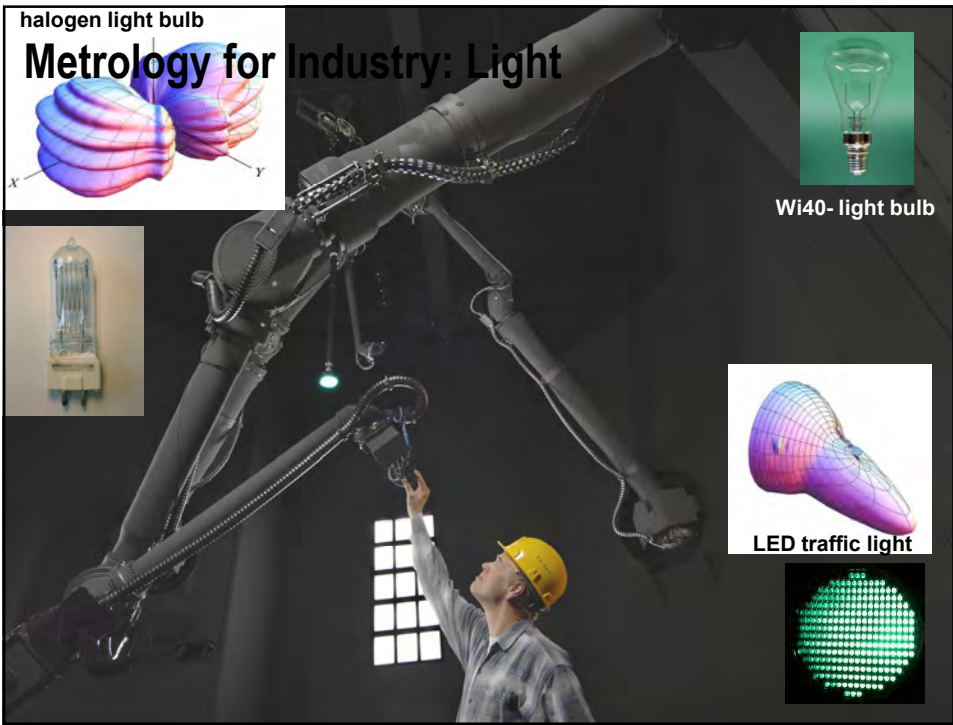


Wi40- light bulb





LED traffic light



Metrology for Industry: Light


Characterization of LEDs and OLEDs



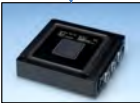
60 in a row!

....a multibillion market of energy efficient lighting!

Metrology for Photovoltaics



PTB's facility for laser-based calibration of reference solar cells



Meas. Uncertainty (k=2)
< 0,4 %

< 1,5 %

Testing traceable to PTB for more than 50 % of solar modules worldwide

Calibration laboratories

Germany: 100 billion Euro investment anticipated until 2035

Measurement Uncertainty = Uncertainty of Return on Investment!

Physikalisch-Technische Bundesanstalt ■ Braunschweig and Berlin, National Metrology Institute

Technology Transfer to SMEs



- Transfer of Metrology Technology
- 15 Projects funded so far
- Applications two times per year
- flexible and fast reaction to the most innovative proposals
- Rating through an internal committee
- Running time 36 months
- Maximum contribution of PTB: 350 000 EUR
10 % by the industrial partner



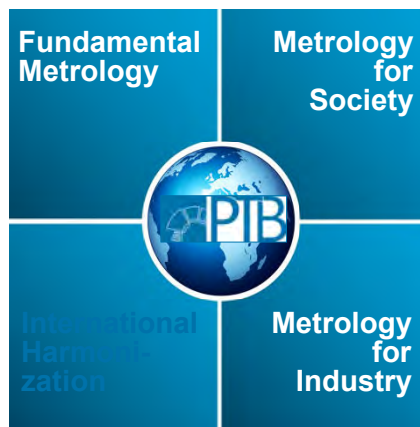
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Our business areas



Metrology for Innovation: Industry, Society and Science

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Our business areas



Fundamental
Metrology

Metrology
for
Society





International
Harmoni-
zation


Metrology
for
Industry


International markets need clear rules for competitive industries!


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Quality Infrastructure in Germany


National Metrology Institute


National Standards Bureau
PTB vice president


accreditation council
National Accreditation Body
~476 accredited labs

5500 calibrations/year
1200 certificates/year

~ 208 national boards
~ 227 internat. boards

Conformity Assessment Bodies

Calibration
Laboratory

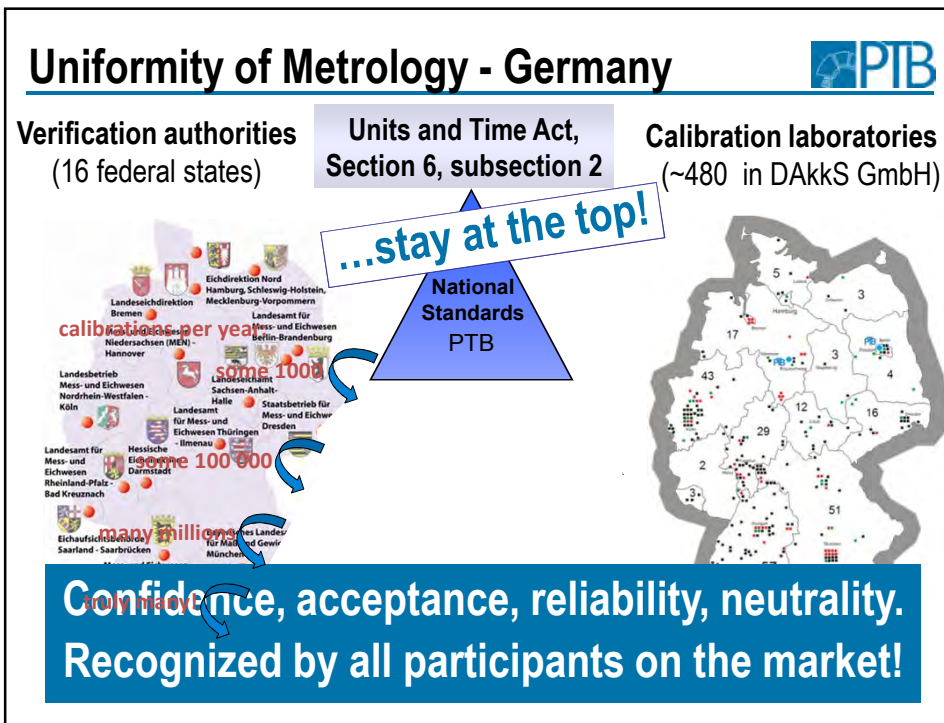
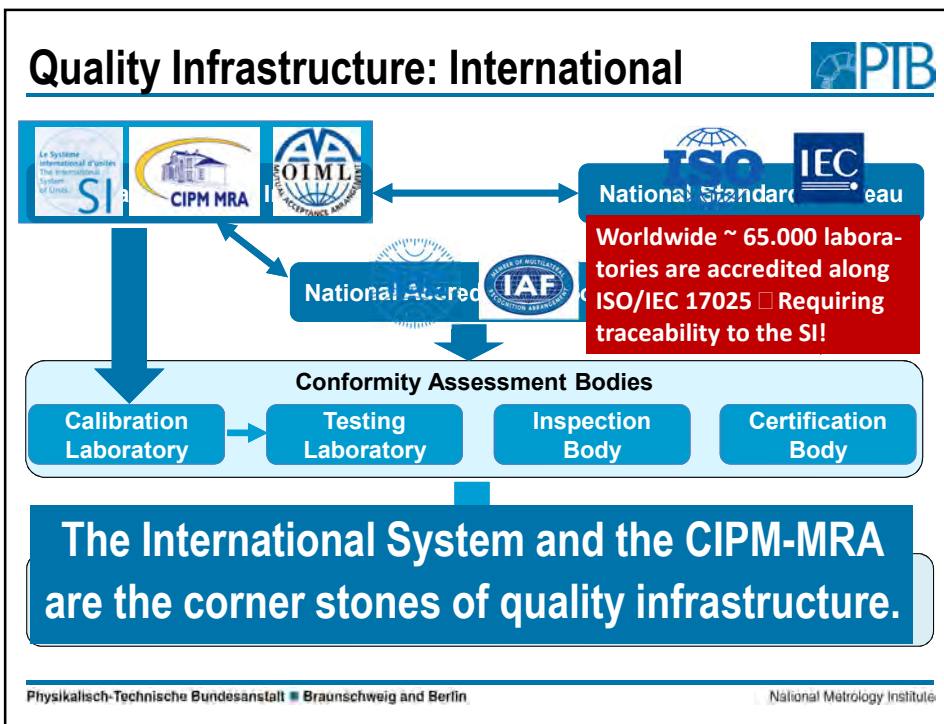
Testing
Laboratory

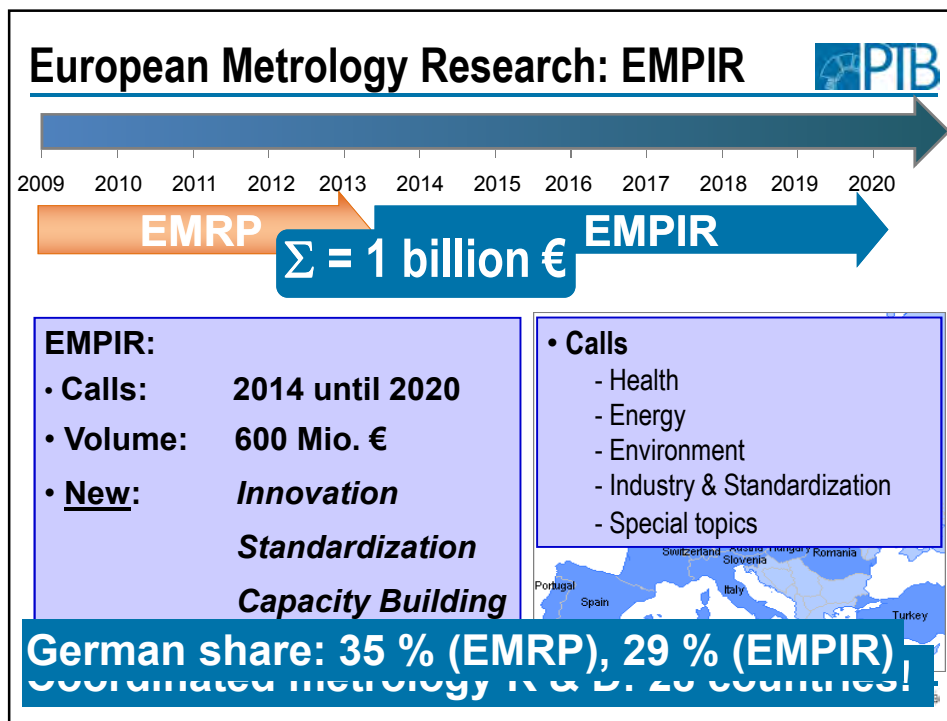
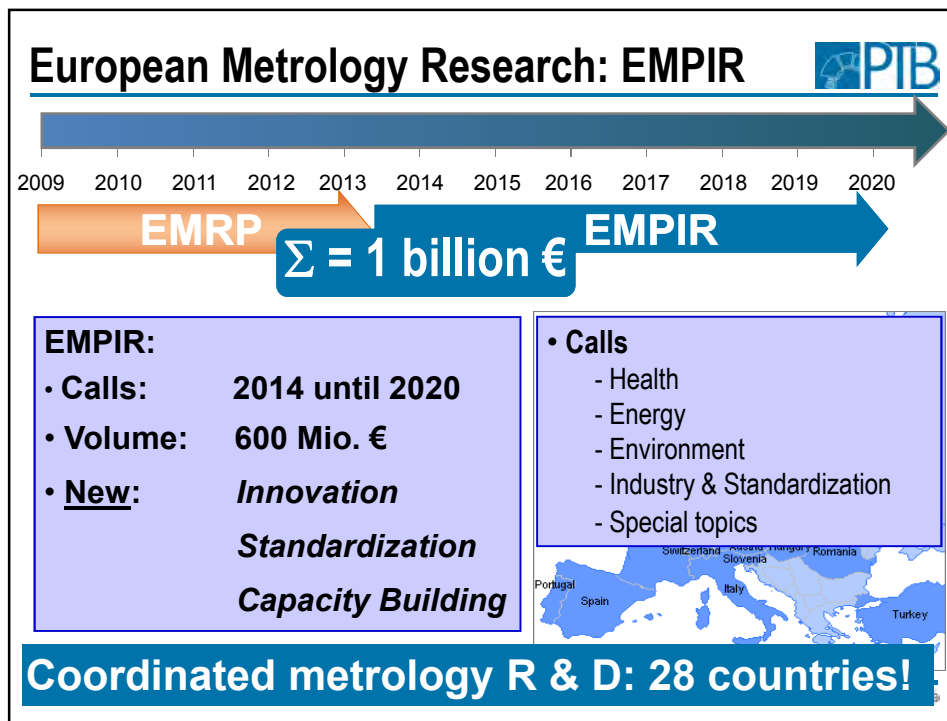
Inspection
Body

Certification
Body

For all enterprises and products: any industry and agriculture
Serving governments, consumers, and the general public

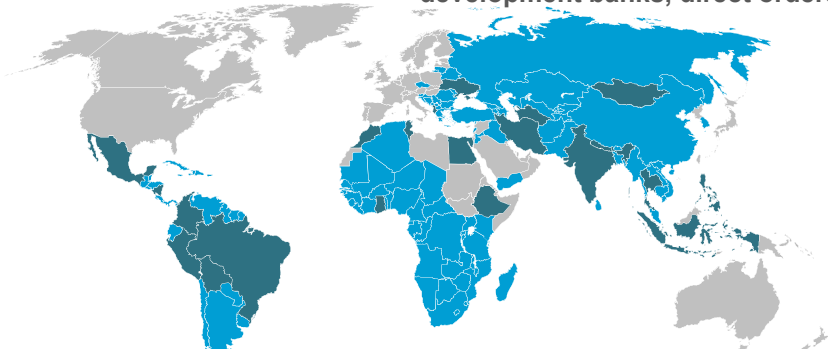
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International Cooperation

- 50 projects in 90 countries
 - 29 bilateral projects
 - 21 are regional projects
- Financial volume ~20 mio. € in 2017
 - >70 employees
 - Clients: BMZ, BMWi, EU, development banks, direct orders



PTB: strongly committed to supporting quality infrastructure projects world-wide

Physikalisch-Technische Bundesanstalt ■ Braunschweig and Berlin
National Metrology Institute


Technical Cooperation



Staff & Experts – our team for Latin America and the Caribbean


Technical Cooperation with CENAM

29 Years Technical Cooperation: PTB-CENAM





25 Jahre Technische Zusammenarbeit
zwischen PTB und CENAM

25 años de Cooperación Técnica
entre el PTB y el CENAM



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**e.g. 2013-2018:
bilateral project on renewable
energies and energy efficiency**

National Metrology Institute

Scientific and Technical Cooperation

Joint Activities:

- Exchange of scientists
- Creation of measurement standards
- Scientific workshops

**Joint Research Project in
European Metrology Research
Programme (EMPR / EMPIR):**

- ENV 52: Traceability for mercury
measurements
- Monitoring and disseminating the
new SI unit kilogram via spheres of
natural silicon

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Thermometry and Optics

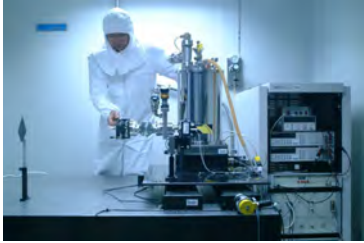
Mechanics and Acoustics

Radiometry

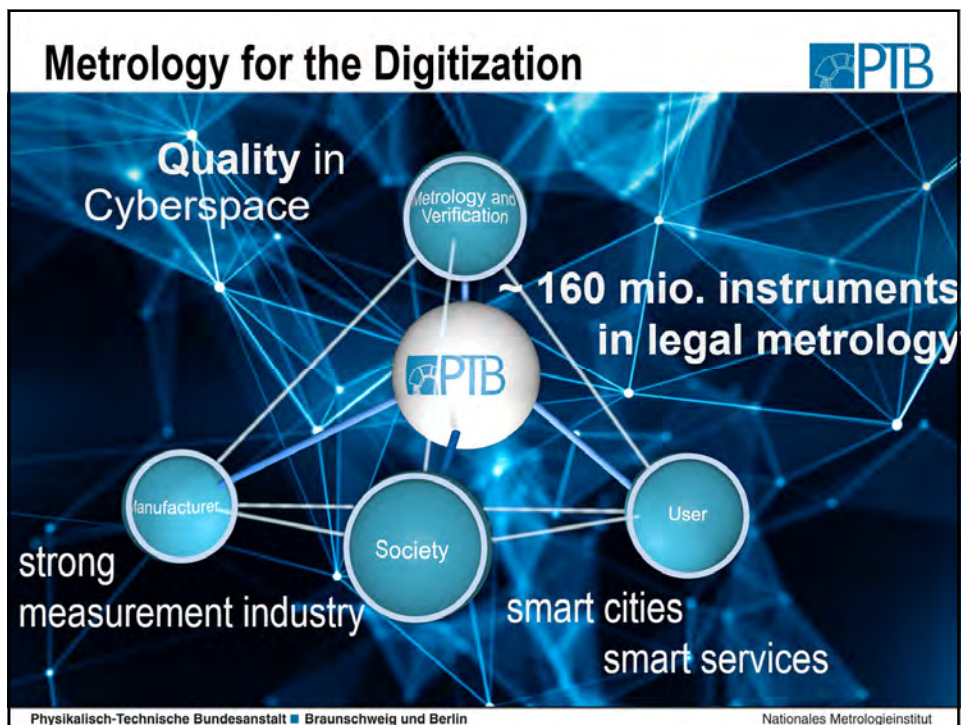
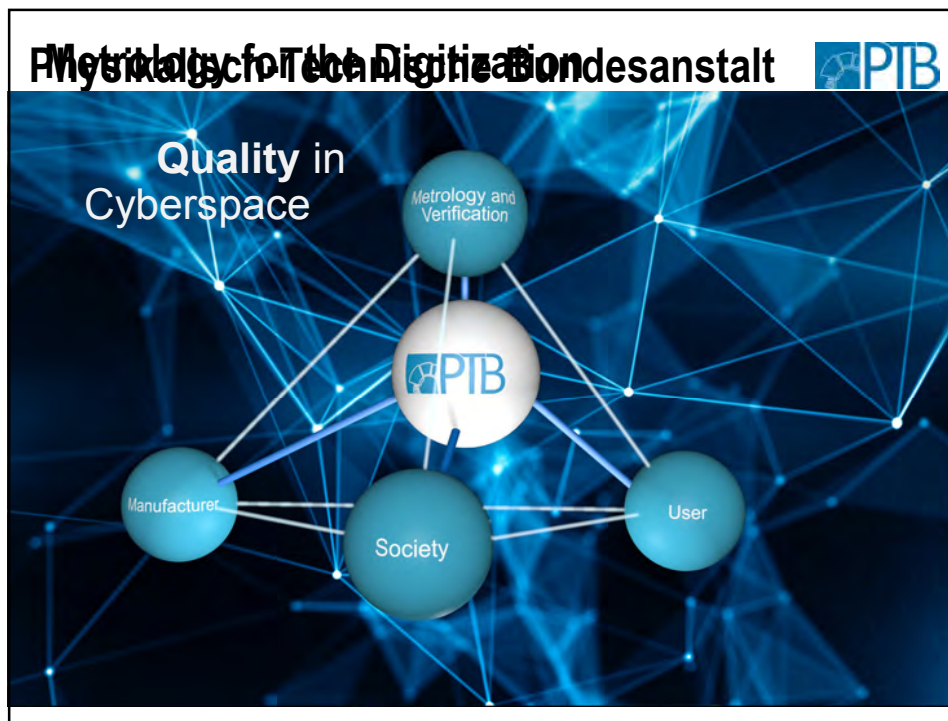
Precision Engineering

Gravimetry

Chemistry



National Metrology Institute



Quality Infrastructure in Cyberspace PTB

Quality in Cyberspace

160 mio. instruments in legal metrology

strong measurement industry

smart cities smart services

Quality Infrastructure in Cyberspace PTB

PTB mitteilungen 4 2018

Metrologie für die Digitalisierung von Wirtschaft und Gesellschaft
Metrology for the Digitalization of the Economy and Society

available online

nw

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- digital twin
- digital calibration
- verify large data sets & machine learning
- communication: 5G

Creating a Metrology Cloud

