Report from the BIPM electricity laboratories 2021-2023

CCEM meeting

8-9 March 2023

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Poids et
Mesures

BIPM ongoing comparisons

On-site comparisons of quantum standards, using transportable BIPM quantum standards

BIPM.EM-K10.a/b	JVS on-site comparison: 1.018 V / 1V and 10 V
BIPM.EM-K12	QHR on-site comparison: $R_H(2)$/100 Ω, 100 Ω/1 Ω, 10 kΩ/100 Ω

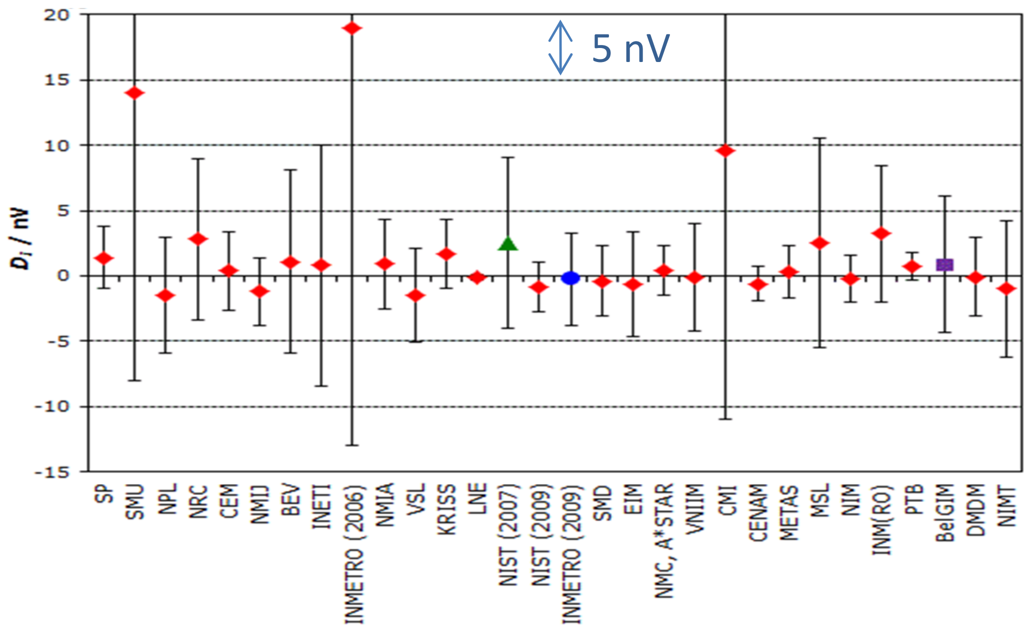
Bilateral comparisons using conventional BIPM transfer standards

BIPM.EM-K11.a/b	voltage: 1.018 V and 10 V
BIPM.EM-K13.a/b	resistance: 1 Ω and 10 kΩ
BIPM.EM-K14.a/b	capacitance: 10 pF and 100 pF at 1592 Hz and/or 1000 Hz

BIPM.EM-K10: on-site comparison of Josephson voltage standards (1.018 V and 10 V)

- Direct comparison of the NMI's and the BIPM's JVS in the laboratory of the NMI (BIPM staff on-site)
- Typical duration about 1 week

10 V Josephson voltage, degrees of equivalence in nV



- On average 2 comparisons / year
- Typical comparison uncertainty at 10 V: 5 x 10^{-10} (5 nV)
- Collaborative work leads to improvements of the participant's JVS in most of the comparisons

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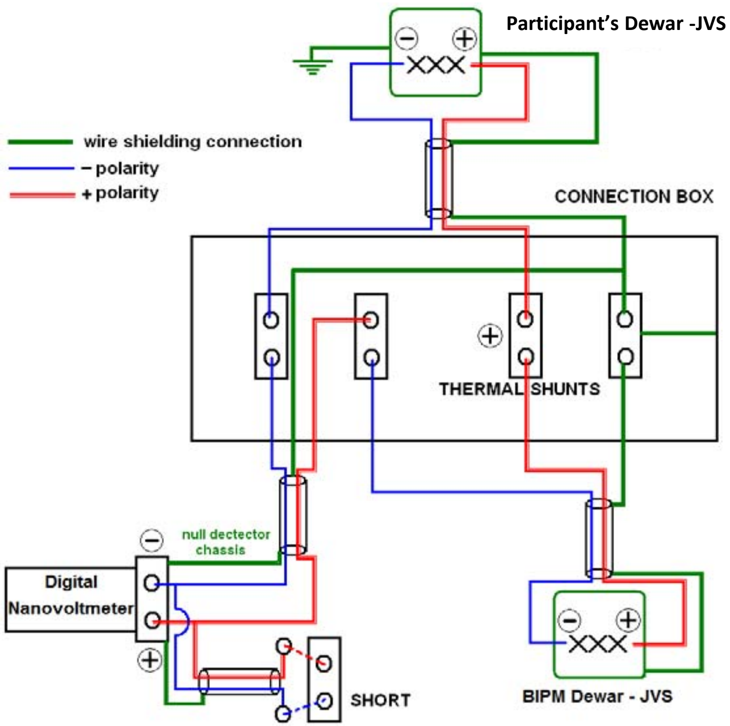

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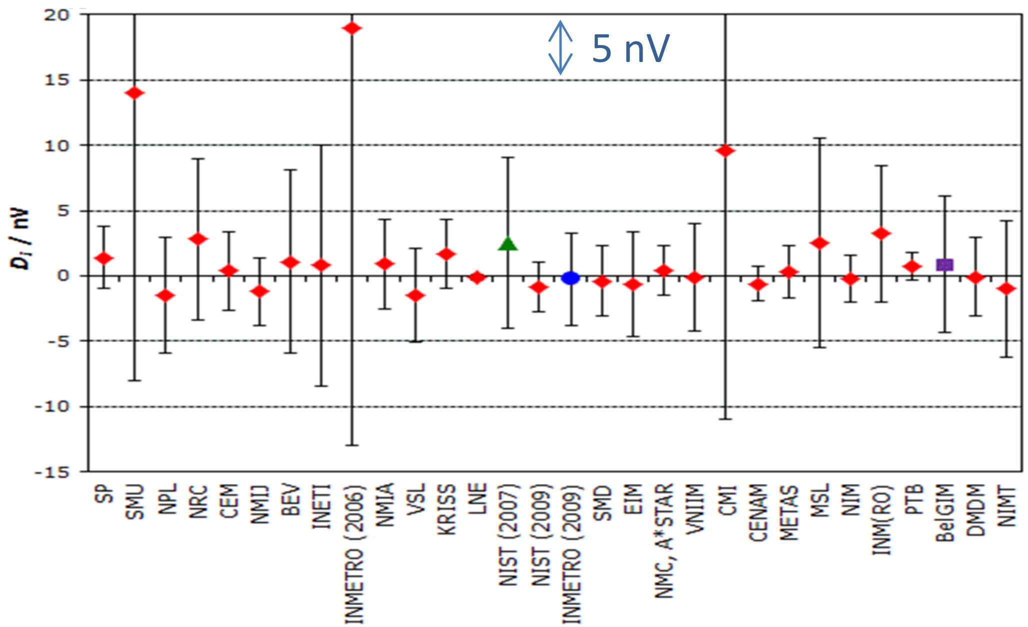

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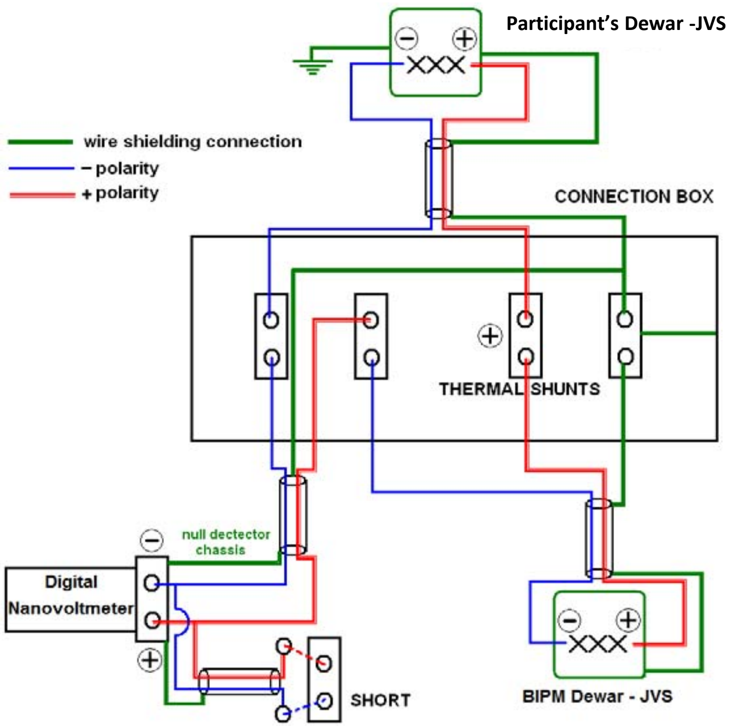

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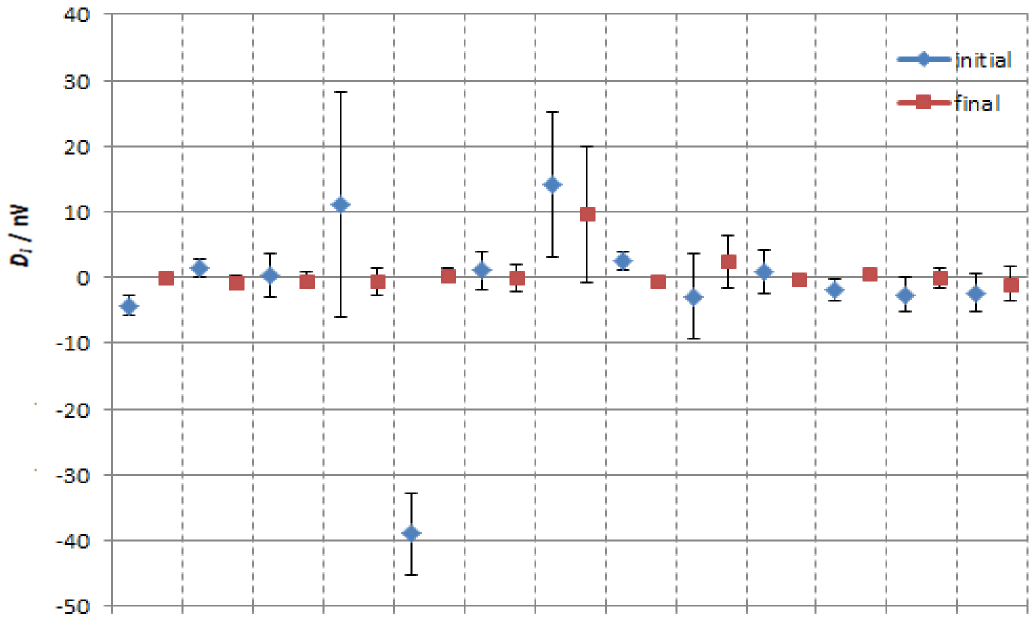

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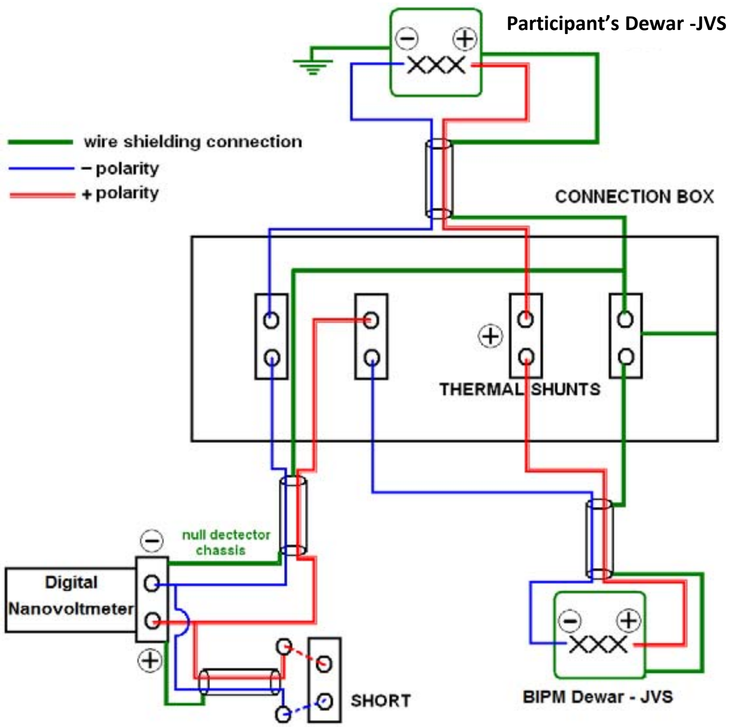

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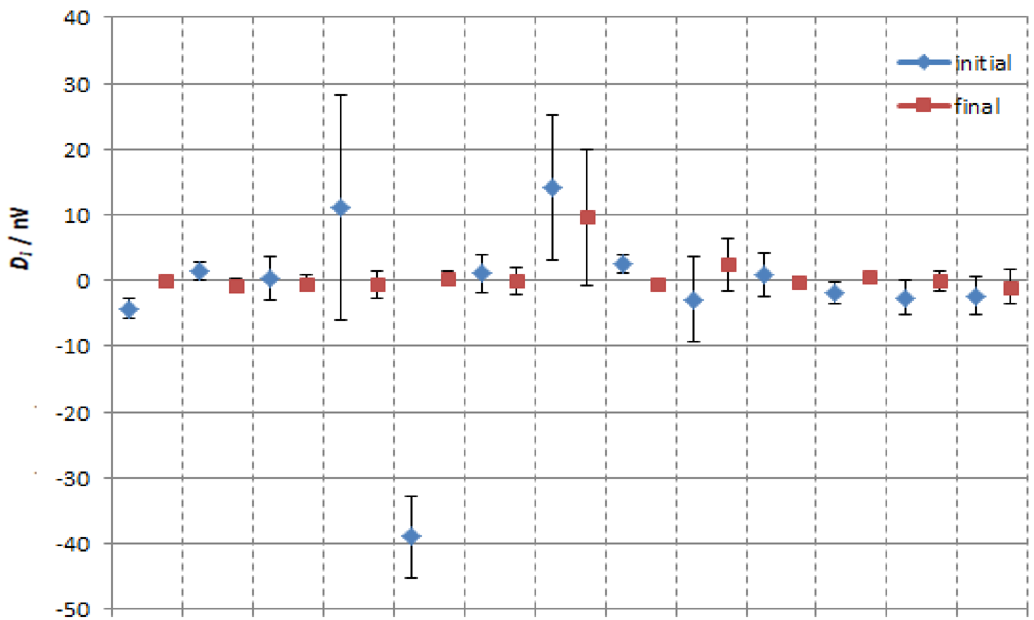
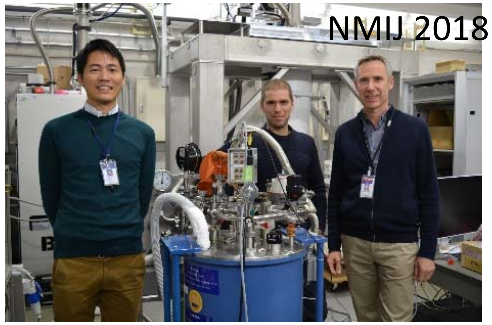


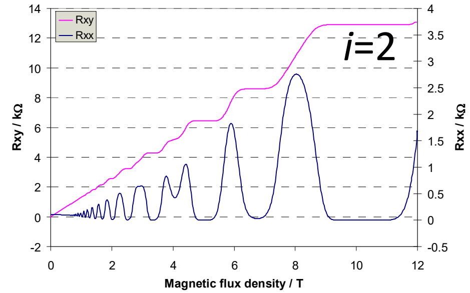
No on-site comparisons 2020, 2021, 2022

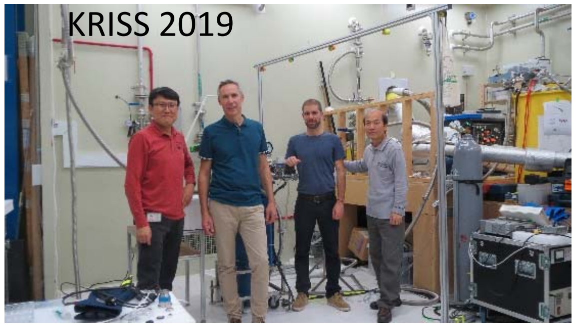
Planned for 2023: DEFNAT or BIM

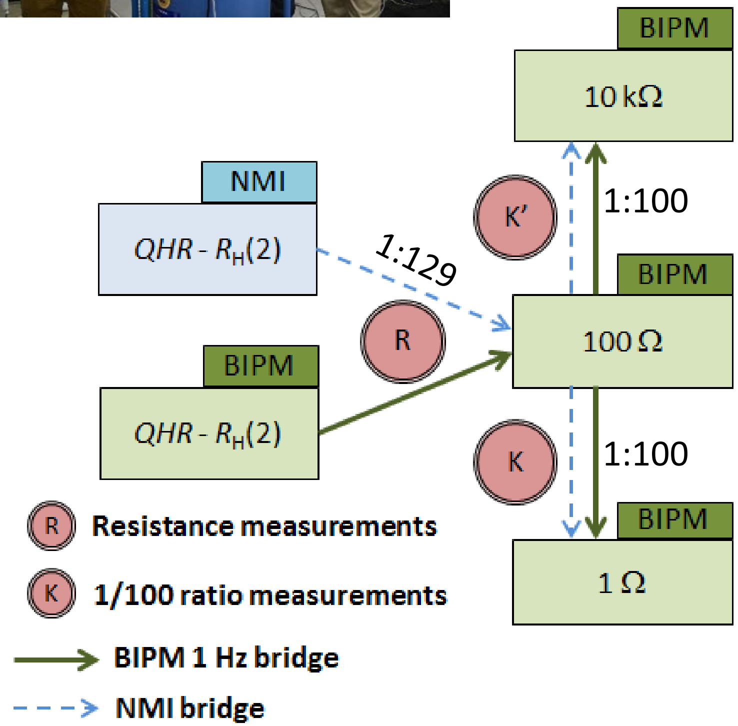
BIPM.EM-K12: On-site quantum Hall resistance key comparison

- To verify coherence of primary resistance standards by comparing quantum Hall effect based standards of the NMIs with that of the BIPM
- Typically 2 comparisons per year









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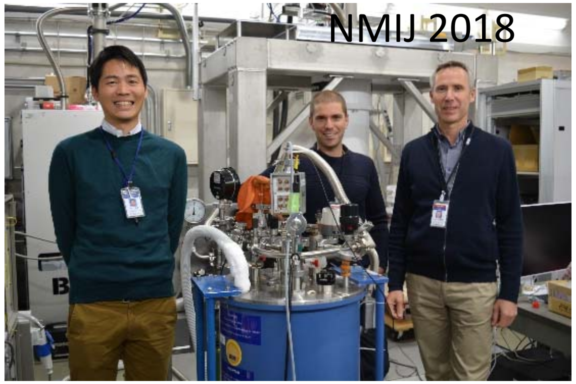
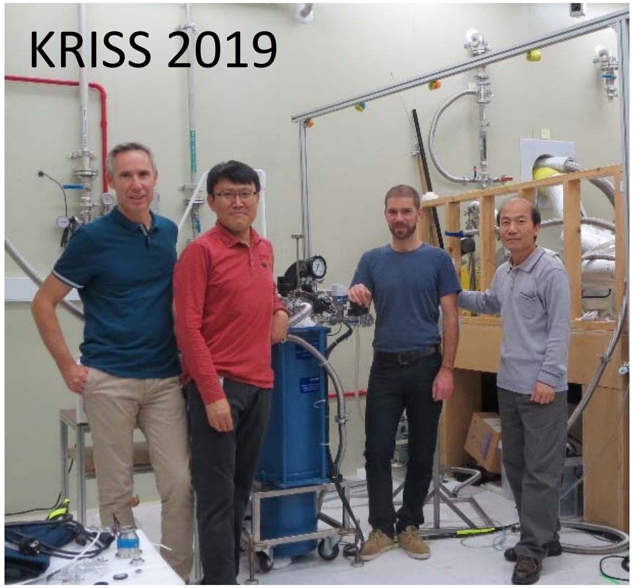
On-site quantum Hall resistance key comparisons (BIPM.EM-K12)



2013:	PTB
2015:	VSL
2017:	CMI, METAS
2018:	NRC, NMIJ
2019:	A*STAR, NIM, KRISS



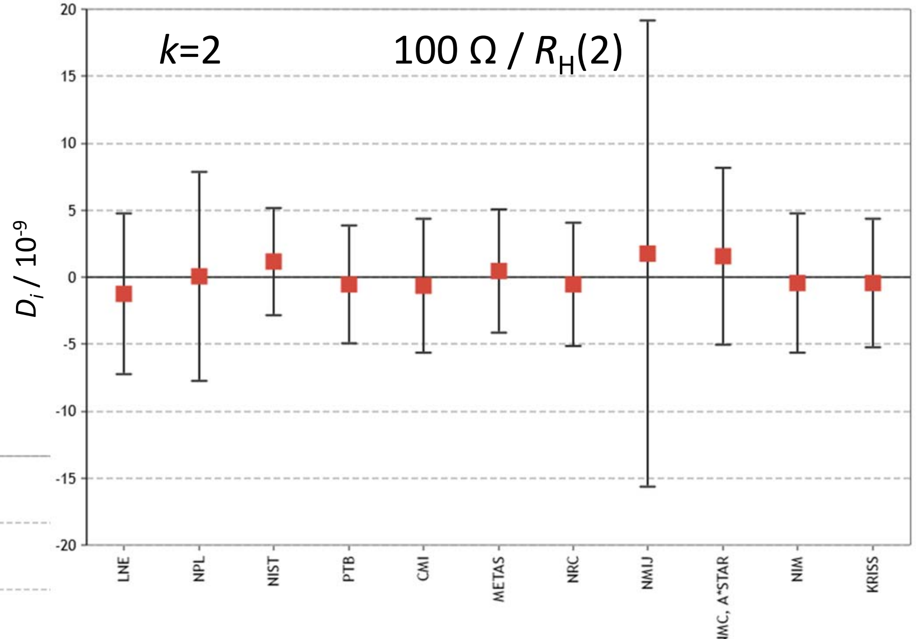
No comparisons 2020-2021

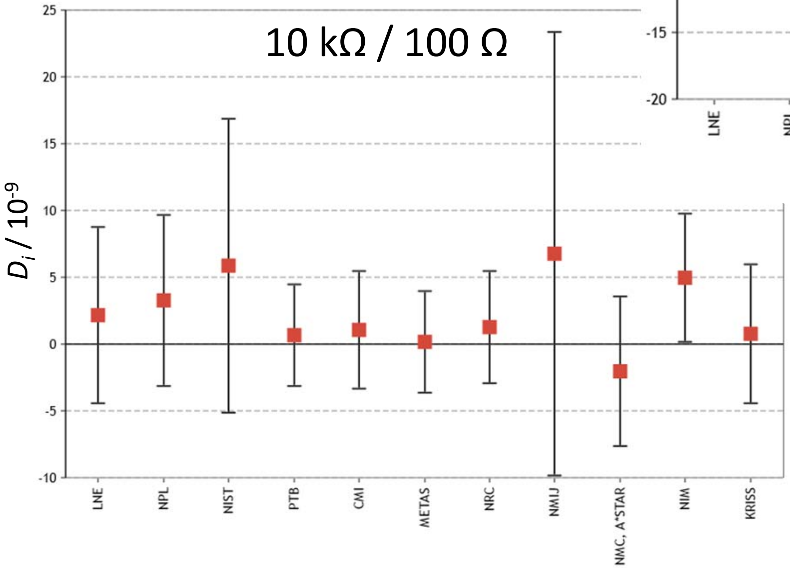
Planned for 2022: LNE, INMETRO
Both postponed, requested by participants

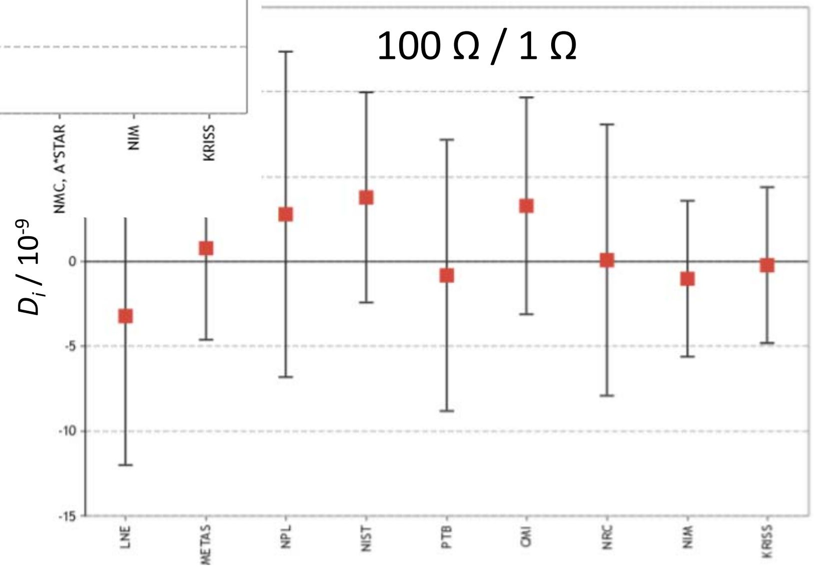
Planned for 2023: LNE, INRIM, to be confirmed

Questionnaire on interest in on-site comparisons (dc/ac JVS, QHR) will be sent soon

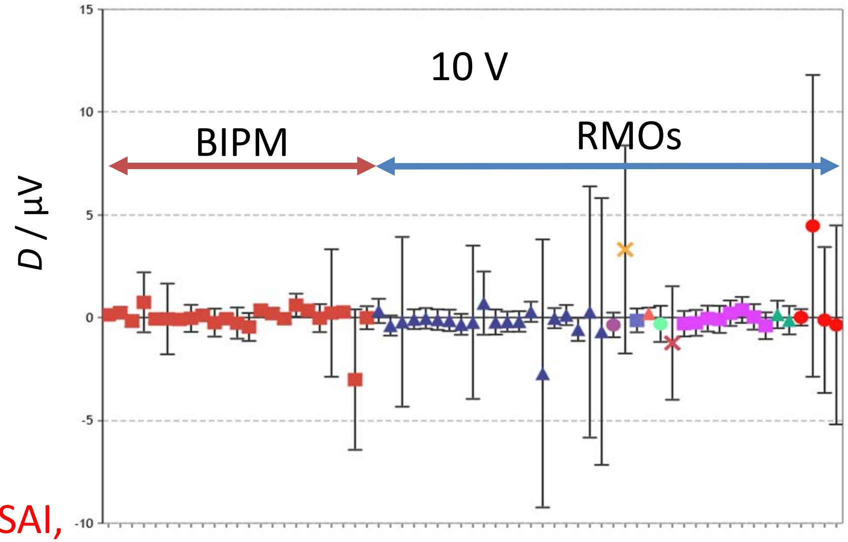
On-site quantum Hall resistance key comparisons (BIPM.EM-K12)





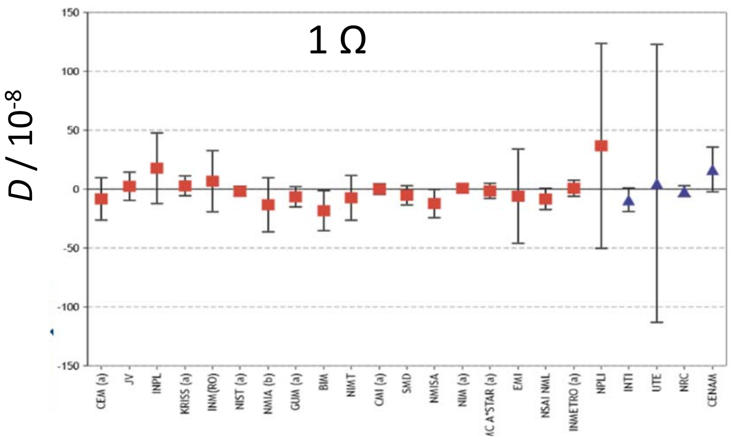


Bilateral comparisons using transfer standards

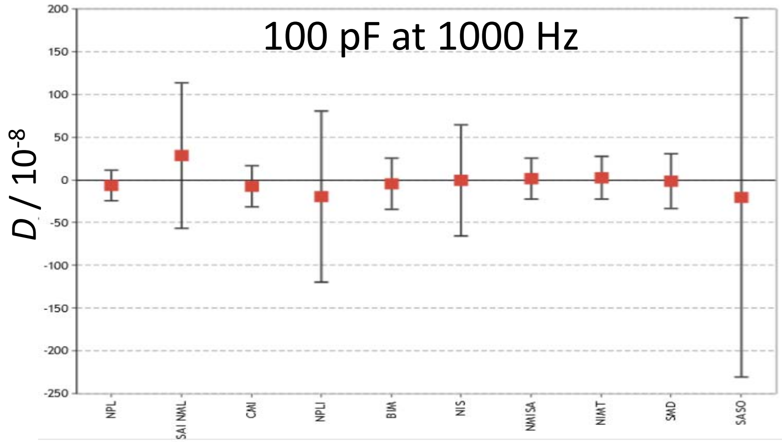


BIPM.EM-K11
Voltage 1.018 V, 10V
2021/22: SMD, NPLI, DEFNAT
planned 2023: NSAI, SASO, A*STAR

BIPM.EM-K13
Resistance 1 Ω, 10 kΩ
2021/22: NPLI, NSAI, INRIM, CEM, INMETRO
planned 2023: KazInMetr, NSAI, CENAM, INPL

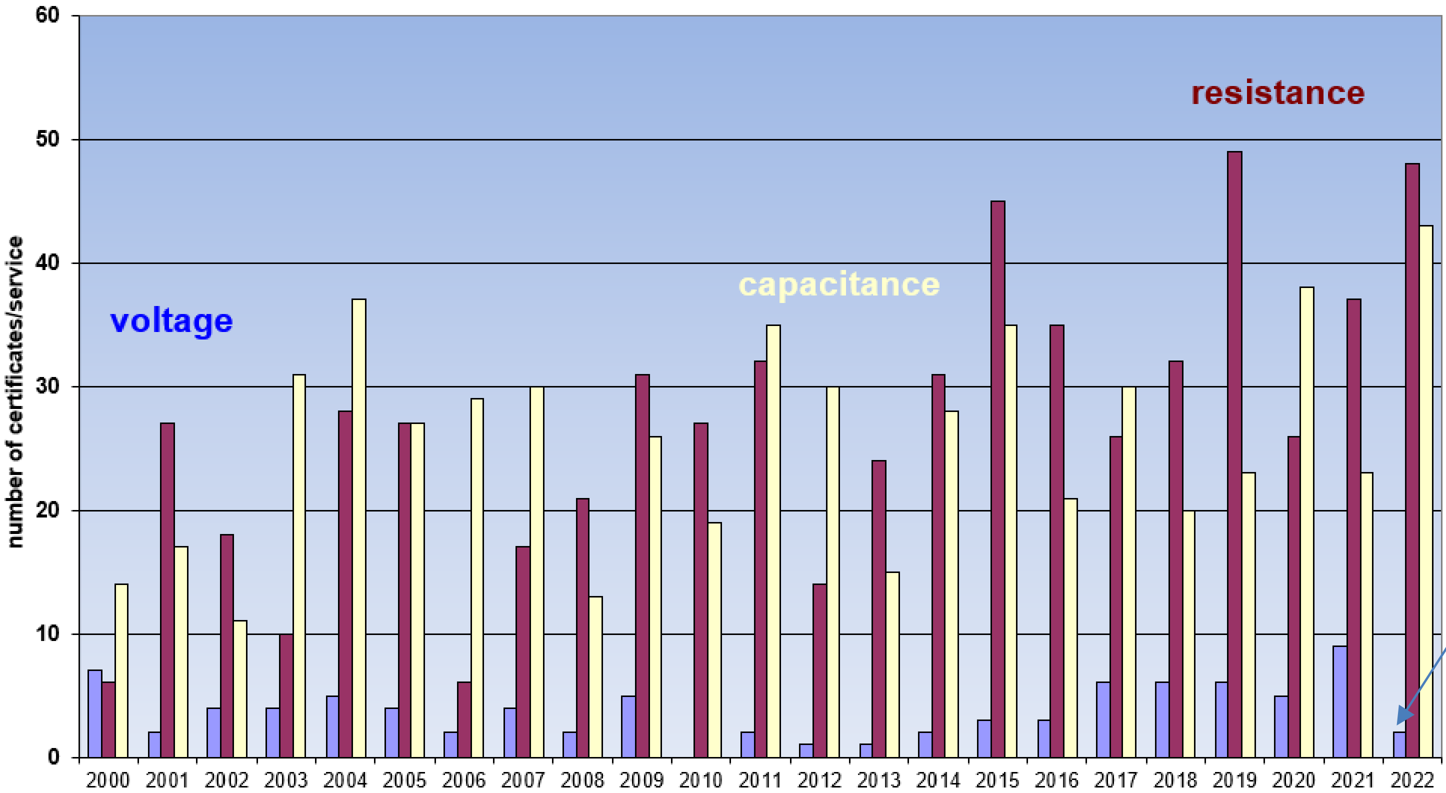


BIPM.EM-K14
Capacitance 10 pF, 100 pF
2021/22: SIRIM
planned 2023:LNE



Calibrations

voltage:	**1.018 V, 10 V**	**on average**	**5 per year**
resistance:	**1 Ω, 100 Ω, 10 kΩ**		**38 per year**
capacitance:	**1 pF, 10 pF, 100 pF**		**30 per year**



Several requests postponed to 2023 due to air conditioning failure during several months

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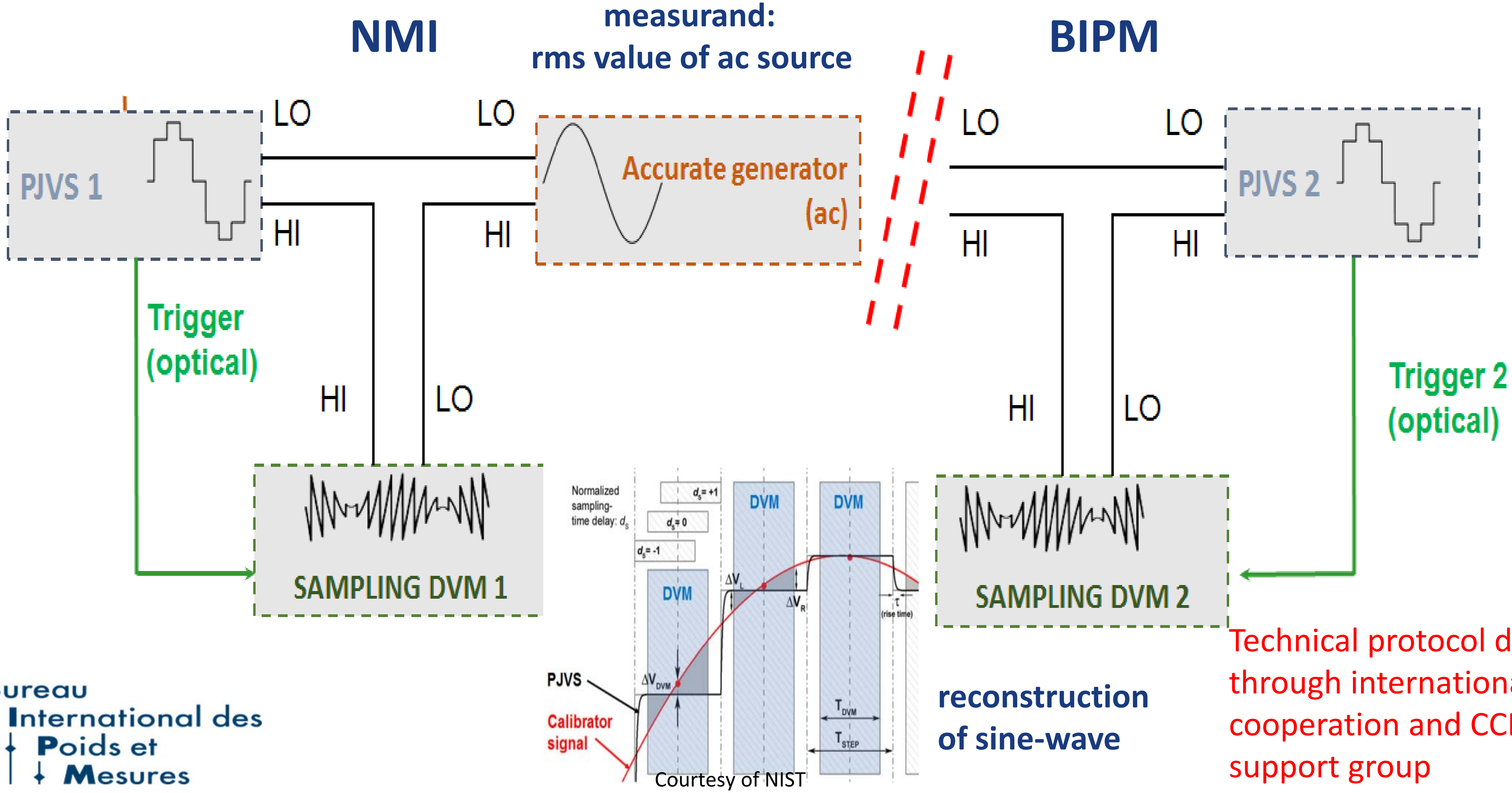
Future on-site comparison using PJVSs at ac – Possible measurement scheme using differential sampling



Technical protocol developed through international cooperation and CCEM support group

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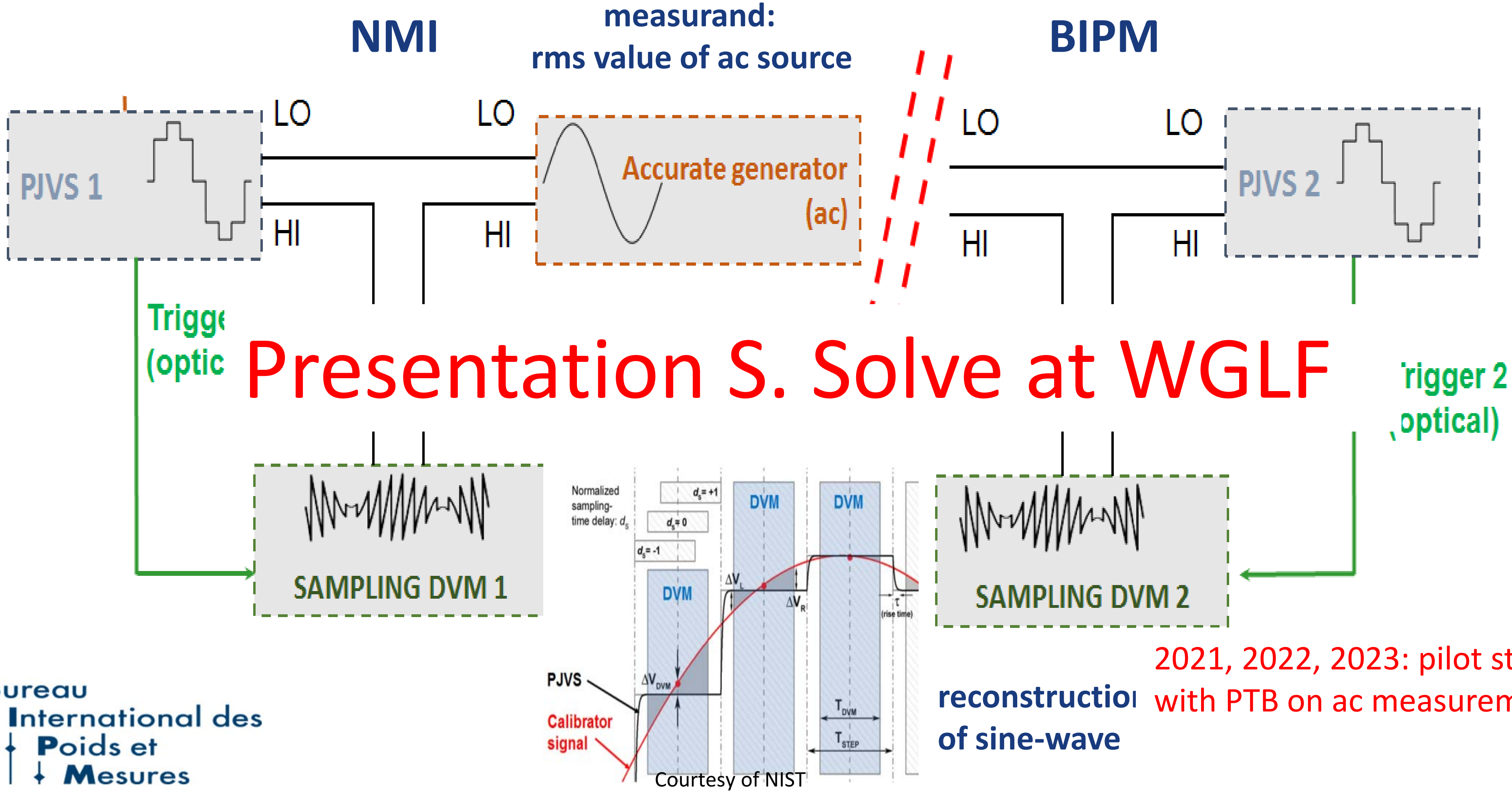

2021, 2022, 2023: pilot studies with PTB on ac measurements

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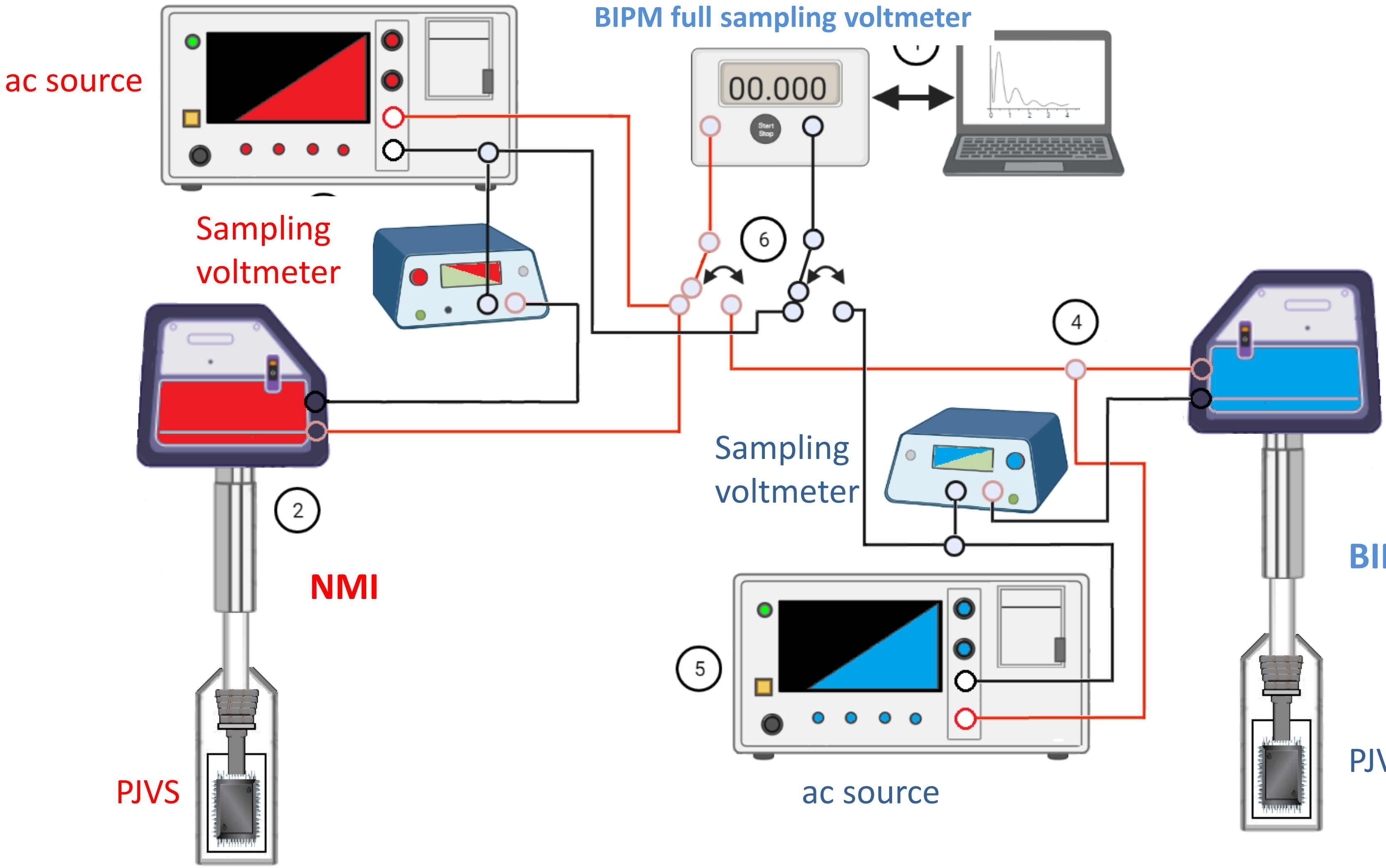
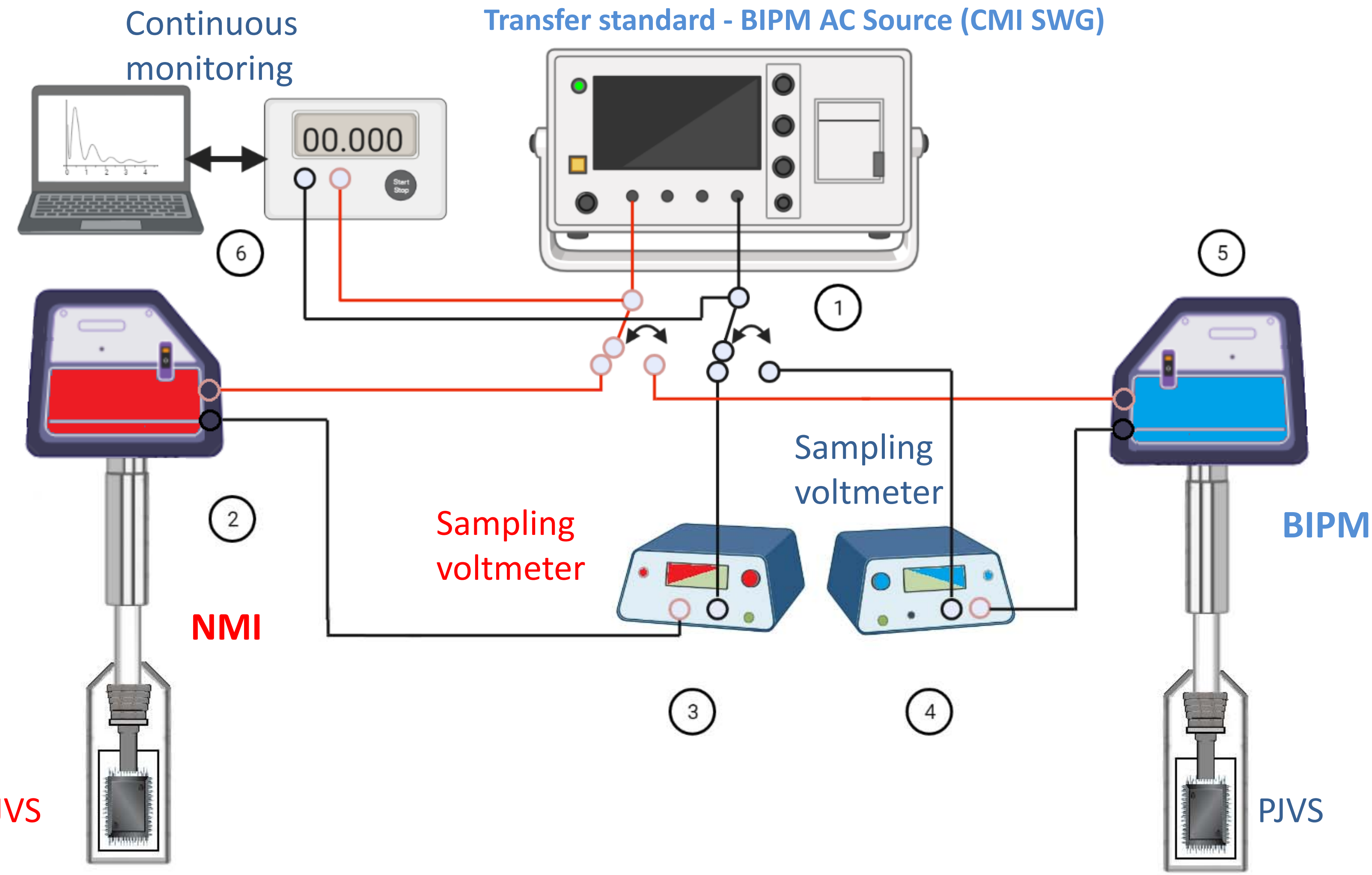
The new comparison protocol: Option III



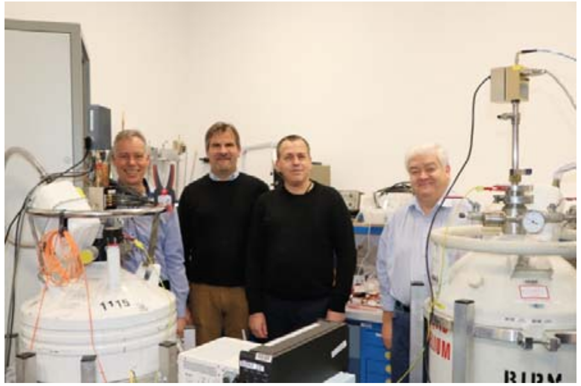
Possible frequencies: 10 Hz, 50 Hz, 60 Hz, 62.5 Hz, 100 Hz, 312.5 Hz, 625 Hz, 976 Hz, 1 kHz

Voltage (rms value): 0.85 V and/or 7 V

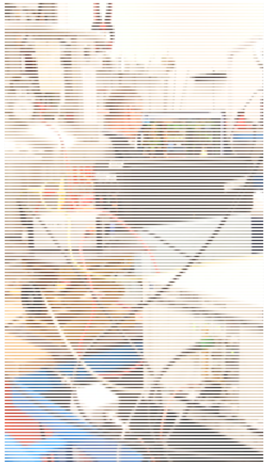
The new comparison protocol: Option IV



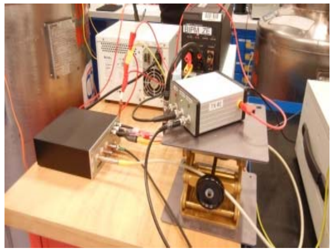
PTB-BIPM Pilot Studies December 2021 and August 2022

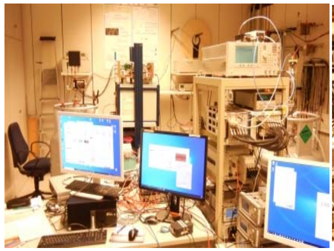


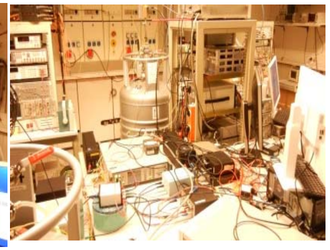
BIPM laboratory Dec. 2021

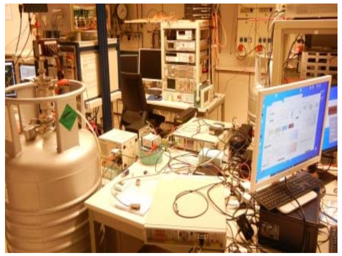


PTB laboratory Aug. 2022









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PTB
Physikalisch-Technische Bundesanstalt
Nationales Metrologieinstitut

KRISS
Korea Research Institute of Standards and Science

2023 program

Pilot studies extended into 2023 (PTB and KRISS)

Optimized sampling parameters for option III

Ongoing investigations on the influence of the full sampling voltmeter at the level of parts in 10^7 and lower

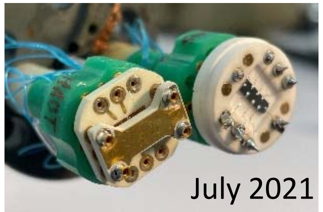
Influence of different samplers and software for option IV

New QHR based on graphene

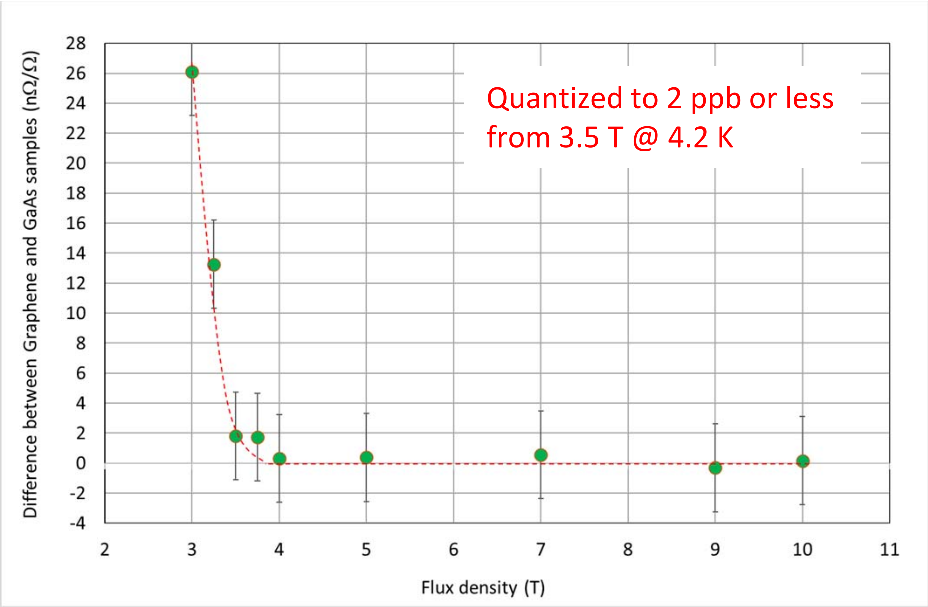
Replacing the GaAs QHR standard to simplify QHR implementation during onsite comparison and reduce their cost

- test of graphene QHR devices from different sources
  - → 2020: test of commercial devices from Graphene Waves (NIST technology)
  - → 2021: test of PTB device designed within the framework of the GIQS EURAMET project
  - → No test in 2022 due to LHe shortage but test of devices from other sources still considered

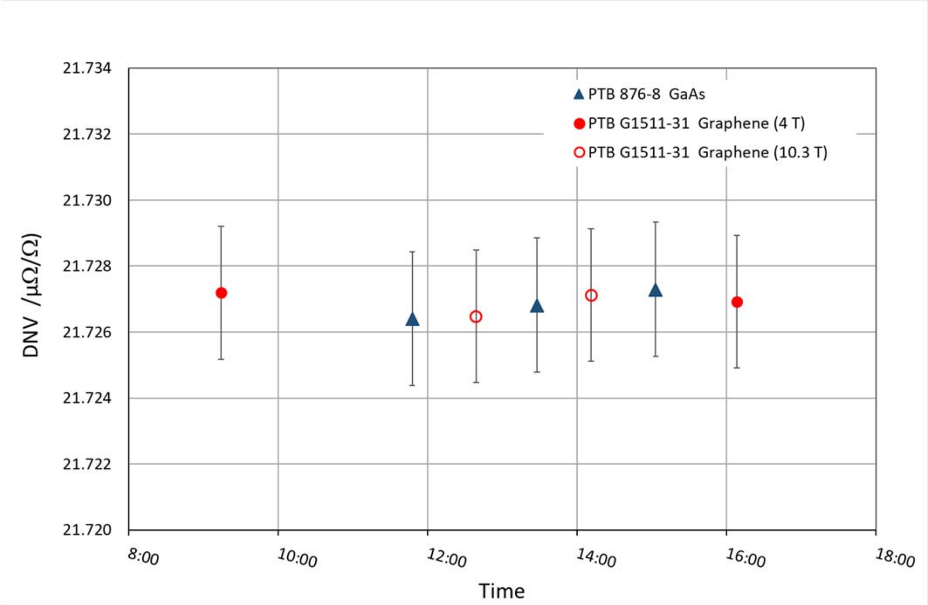
PTB devices
Graphene (left), GaAs (right)



Quantization of PTB graphene QHR at 4.2 K



Comparison between graphene and GaAs QHRs from PTB at BIPM

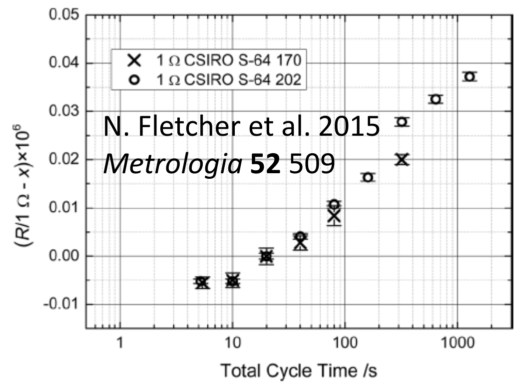


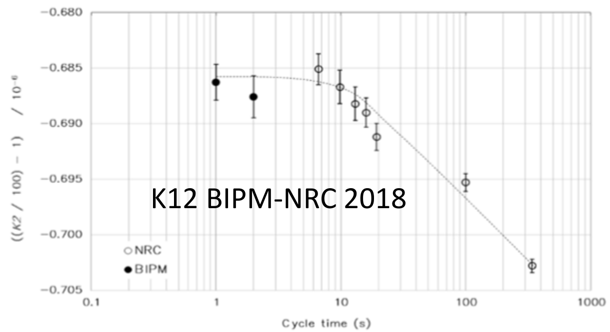
Study of 1 Ω standards for BIPM.EM-K12 comparison

Characterizing 1 Ω standard prototypes to find one with ideally no low frequency dependence

- Analysis of precision measurements of 1 Ω standards during BIPM.EM-K12 comparisons is often an issue due to frequency dependence of these standards
- Characterization of new resistor prototypes developed by the NMIJ and Alpha Electronics (different resistance pattern, internal definition point, corrected resistance value, terminals)
- Study carried out in collaboration NMIJ, PTB, BIPM
- First round of measurements completed early 2022 ⇒ encouraging results but some unexplained discrepancies below 25 mHz for some measurement configurations

⇒ A second measurement round, intended to find an explanation to those discrepant results, started late 2022 and is still in progress





Prototypes of Alpha/NMIJ resistance standards

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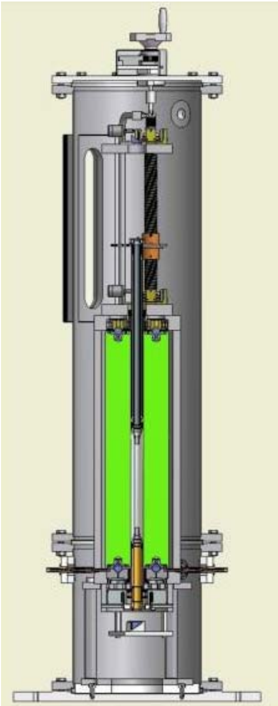
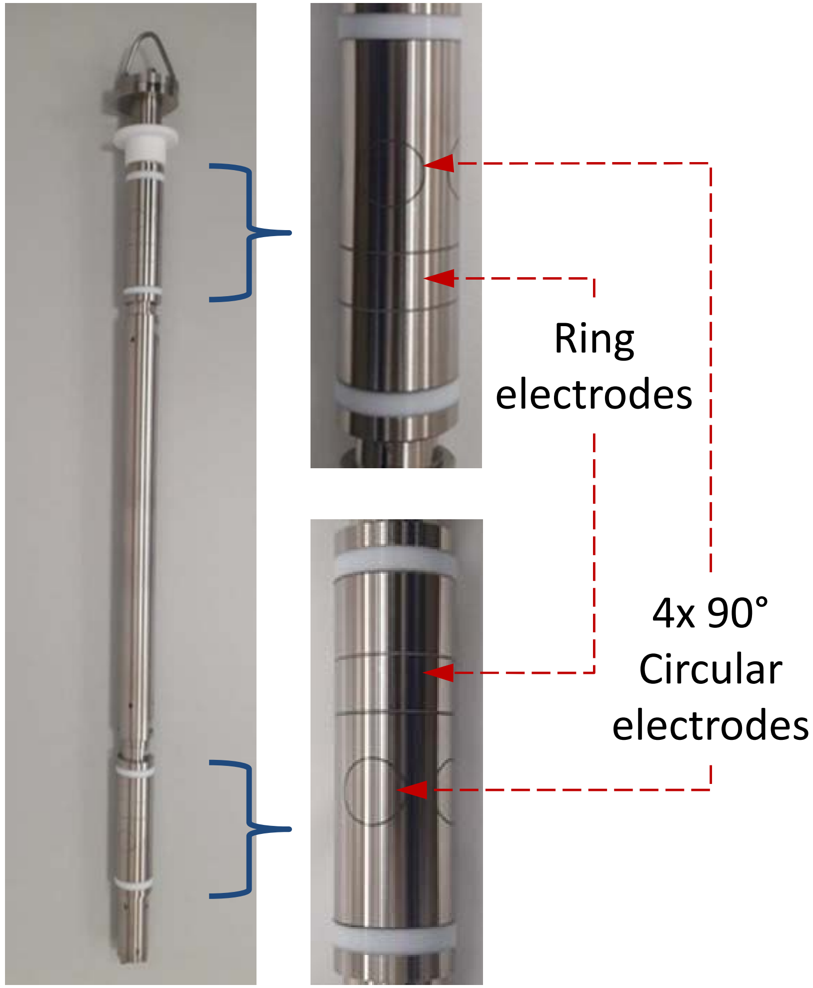
BIPM Calculable Cross-Capacitor

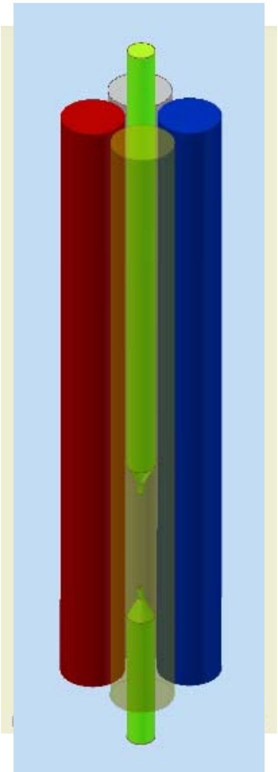


Alignment of the electrode system using capacitive probes

- *Improvement of the characterization of a capacitive probe to measure the angular position of the electrodes.*
- *This allowed the positioning of the electrode's axis on the vertices of a square within ± 0.3 mrad, and reduction of the skew angle to less than 1.4 mrad (1 nF/F skew contribution).*



BIPM Calculable Cross-Capacitor



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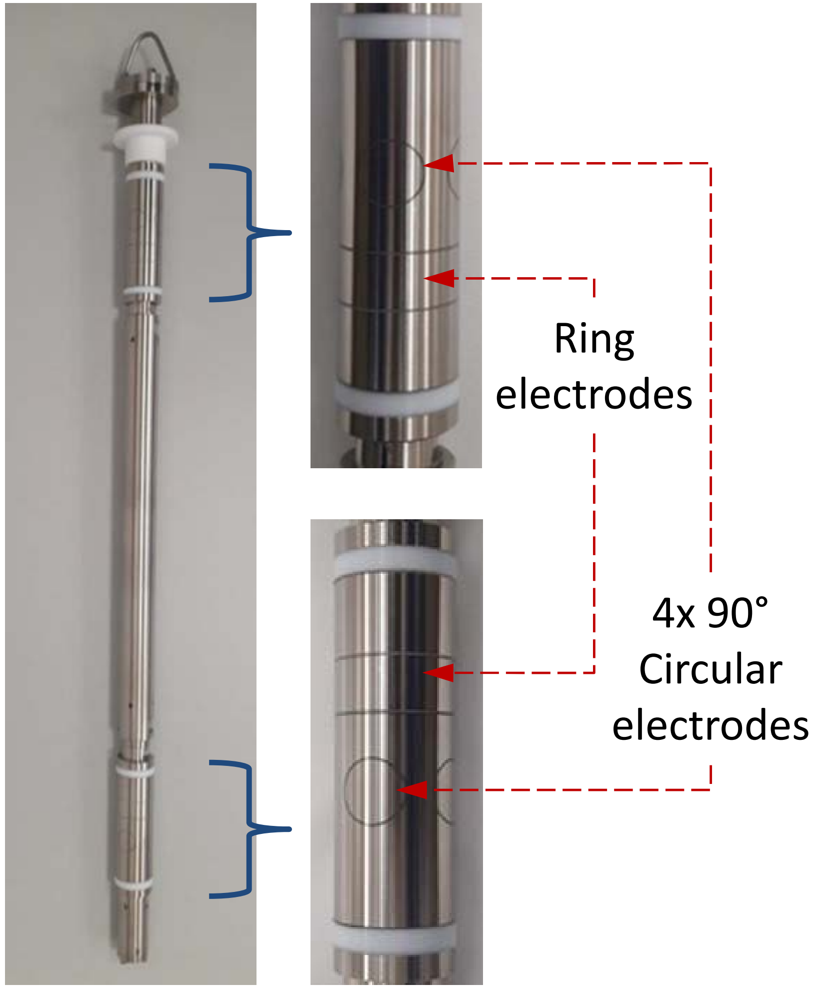


Last measurement:

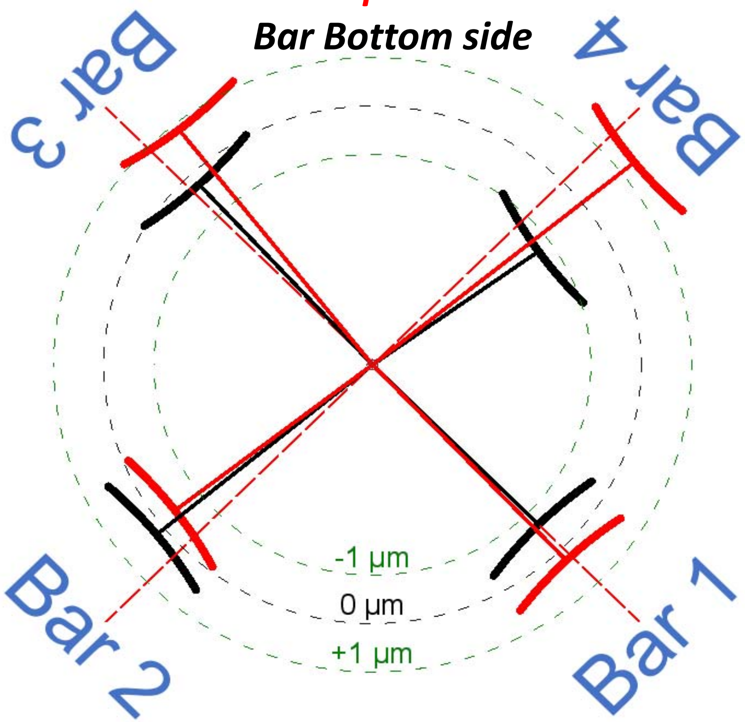


**Diagram not at scale.*

- *Diagonal distances within ± 1 µm in average.*
- *Angles adjusted at 90° within ± 0.3 mrad.*

Still to do for alignment:

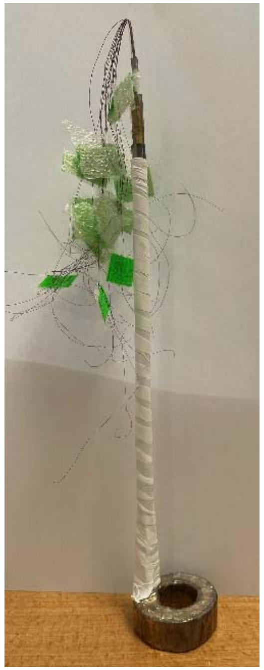
- *Measure lateral gaps (need to be constant along length of the electrodes)*
- *Very fine adjustment to equalize diagonal distances within ± 200 nm.*
- *Check Skew.*

Fabrication of a new Cryogenic Current Comparator

A new multi-ratio superconducting CCC and its associated cryo-probe have been designed and fabricated. Assembling is currently in progress.

This new CCC is intended to replace one of the two cryogenic current comparators of the BIPM which has recently been found defective.

The design of a new digital double current source intended to be used with this new CCC is also in progress.



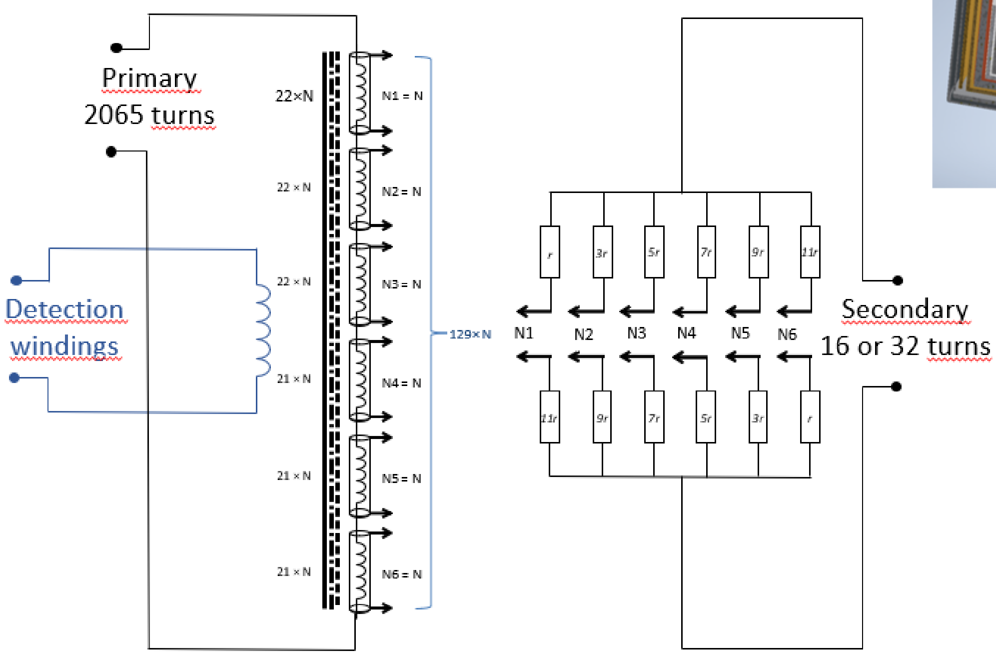
Shieldings are not represented

New Low Frequency Current Comparator of ratio 129:1

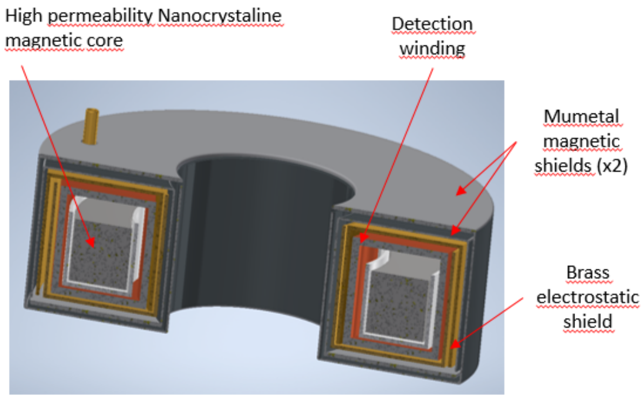
To equip a new 1 Hz resistance bridge for comparison and calibration services

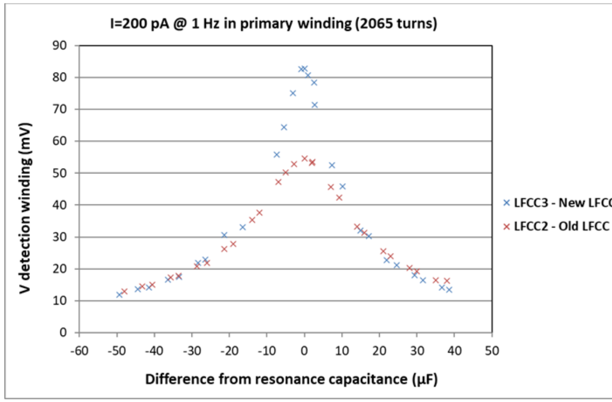
LFCC ratio 129:1

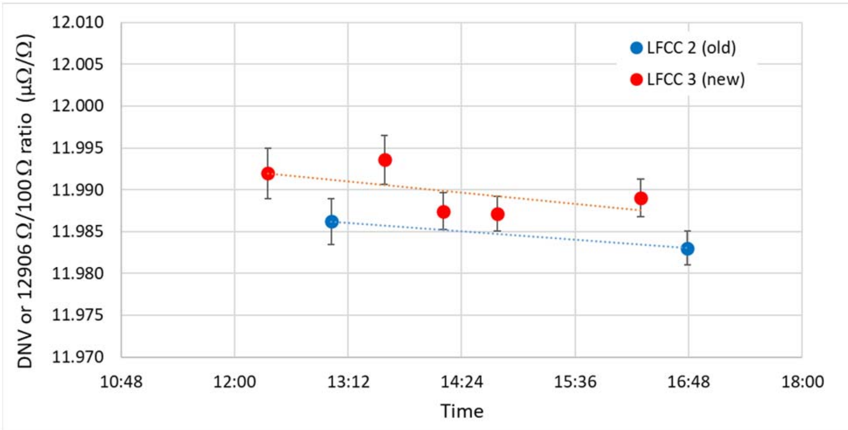
(2065 turns / 16 or 32 turns)



Detection coil







Agreement of few nΩ/Ω before optimization of guarding scheme

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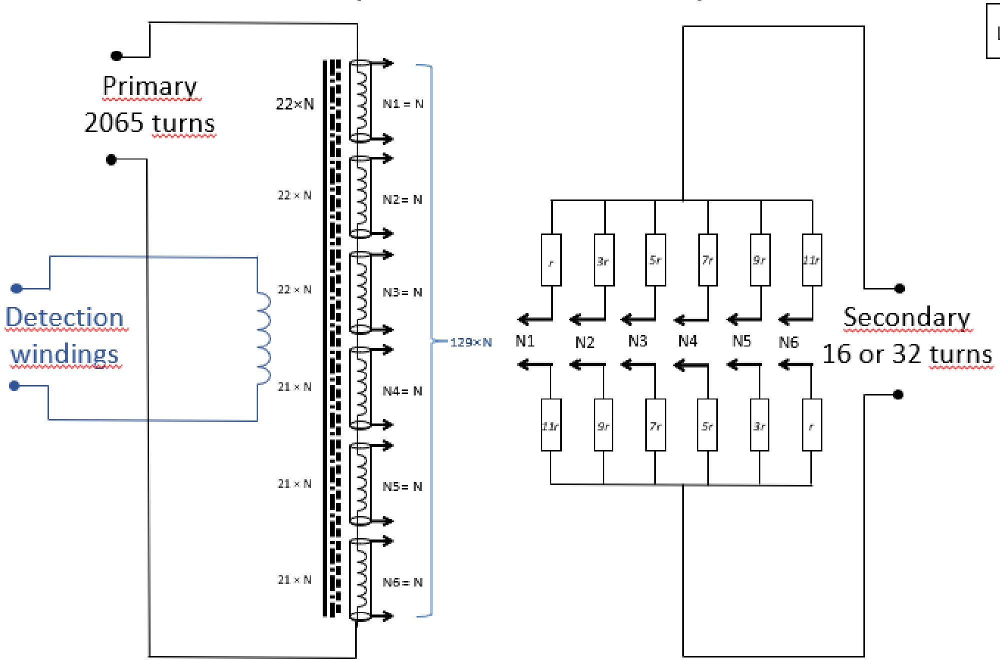

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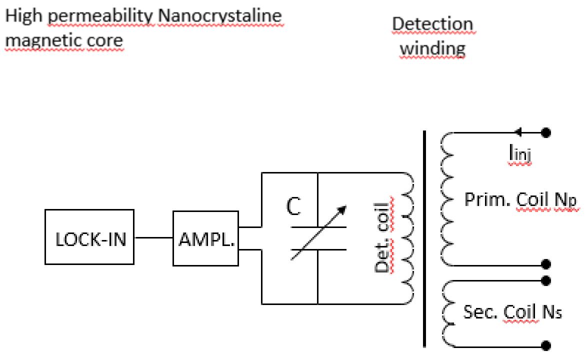
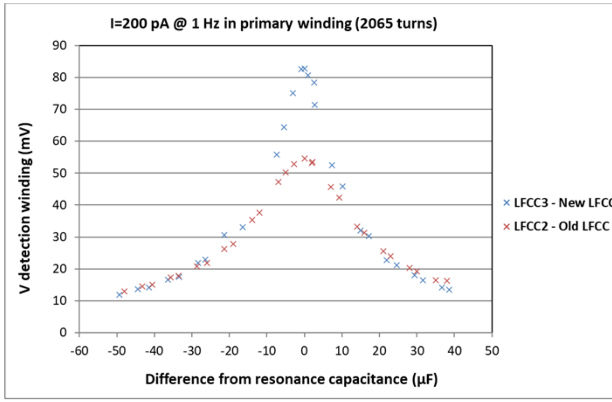
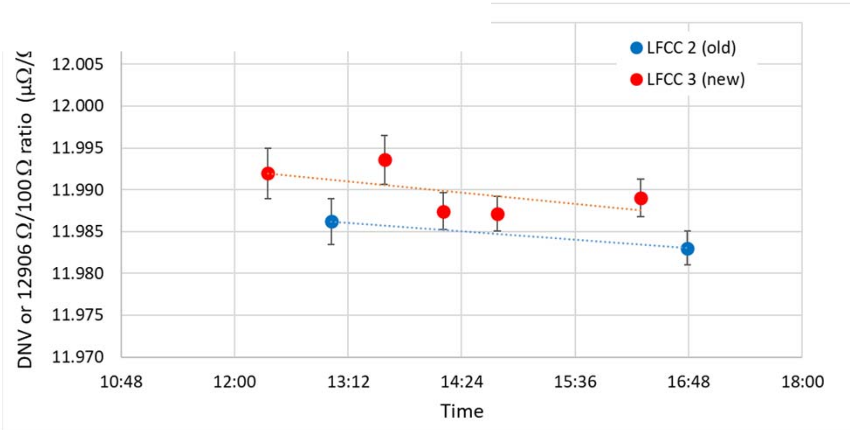
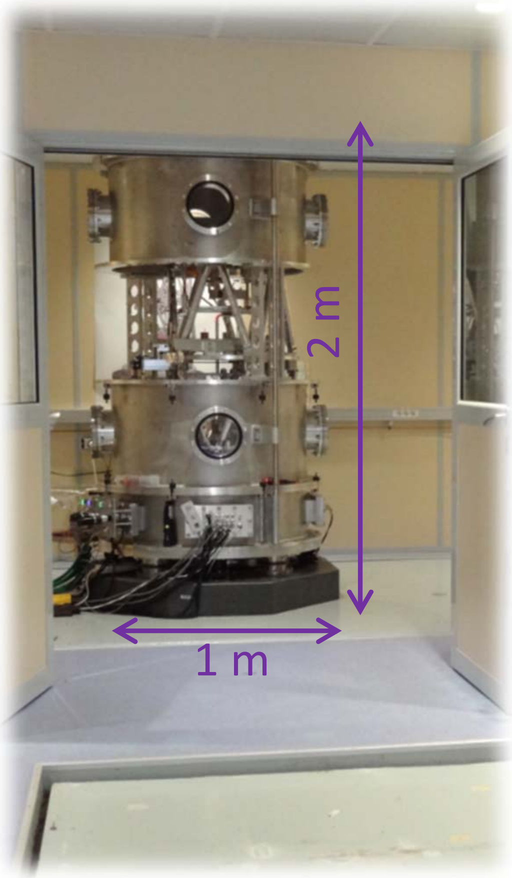


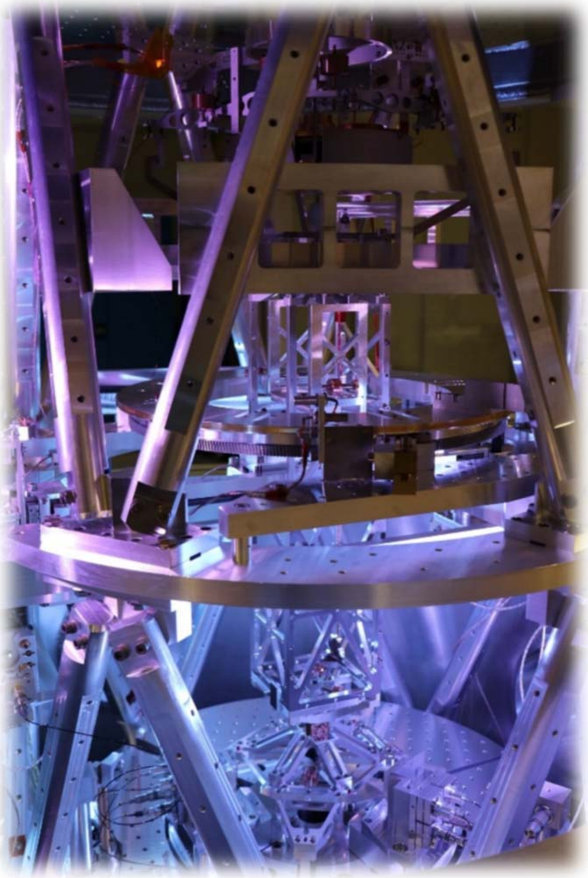




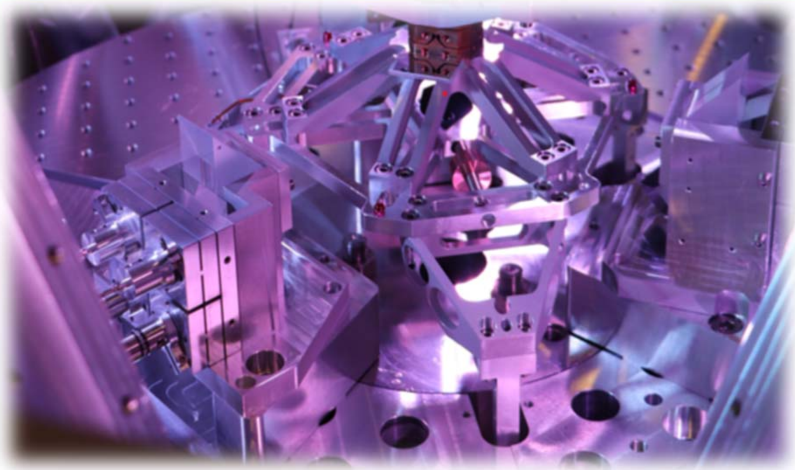
Agreement of few nΩ/Ω before optimization of guarding scheme

The BIPM Kibble balance





- magnetic flux density 0.47 T
- bifilar coil (each 26 layers & 1100 turns)
- current 10 mA for a 1 kg mass
- standard resistor 100 Ω
- voltage drop 1 V
- velocity 1 mm/s
- induced voltage 0.5 V

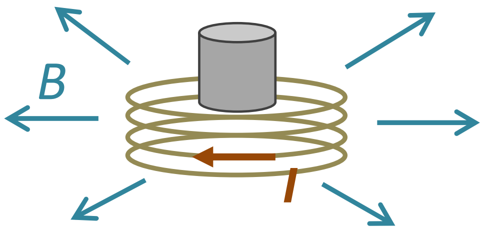


Measurement scheme

One-mode two-phase scheme

weighing phase

$mg = BLI$

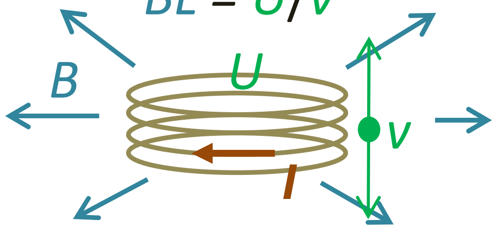


$$\frac{m}{h} = \frac{n_1 n_2}{4r}\frac{f_1 f_2}{g v}$$

n: integer number
f: frequency
r: calibration factor

moving phase

$BL = U/v$



- Constant Joule heating of the coil (60 mW) -> better temperature stability
- Optimization of the measurement scheme

Investigation & improvement of electrical circuit

- all devices separated in three groups and electrically grounded in a star scheme to avoid ground loops

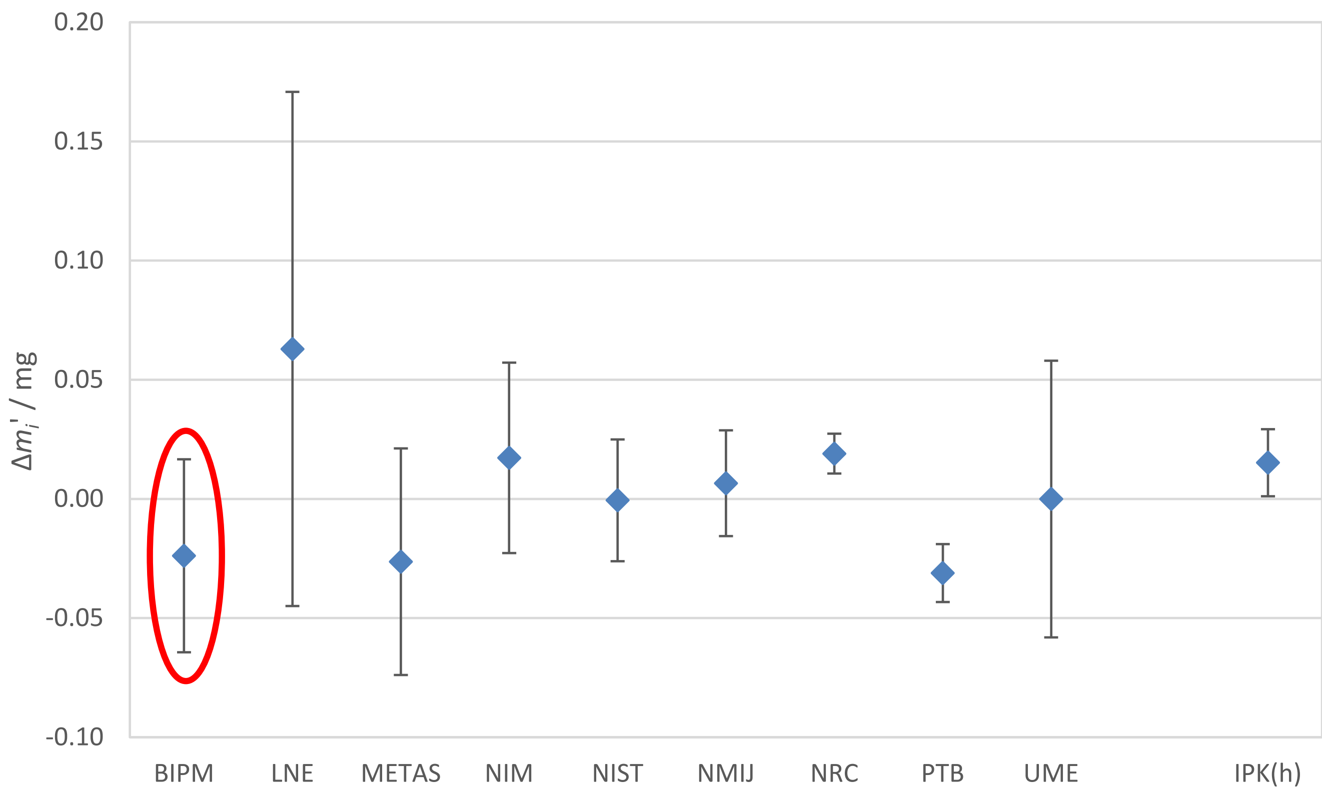
- use of 2 PJVSs (1 V & 2 V) and 2 bias sources, different grounding configurations
- three main issues identified and resolved:
  - gold-plated forks manually connected to the PJVS system (replaced with plug-in connector)
  - nanovoltmeter inside PJVS system introduced bias (now disconnected)
  - switchbox introduced bias (replaced with new one)
- measurement uncertainty reduction (30 ppb → 14 ppb)

Use of a cryo-cooler with pulse-tube refrigerator for PJVS

- use of cold water of the air conditioning of the building for cooling down the compressor
- new PJVS array
  - 1 V NIST array out of service (old generation)
  - use of a new 2 V PJVS array, kindly supplied by the NIST
  - fabrication of a shortened holder (impossible to accommodate present one due to low ceiling in KB room)

CCM.M-K8.2021: second key comparison of kilogram realizations

Differences between mass values attributed to a 1 kg weight



- Pilot: BIPM
- 9 participants: 6 Kibble balances, 1 joule balance, 2 XRCD
- Mass of travelling standards of each participant: measured in vacuum
- Comparison at BIPM during Feb./ Mar. 2022
- Final Report published in Jan. 2023
- KCRV calculated as the weighted mean of the participants' results with $u_R(x_R)$ = 7.4 µg

Publications

F. Bielsa, H. Fang, A. Kiss, M. Stock, **A new Interferometric System for the BIPM Kibble Balance**, *IEEE Trans. Instrum. Meas.*, 2021, 70, 7002706

F. Bielsa, H. Fang, A. Kiss, M. Stock, **Report on the BIPM Kibble balance**, CPEM 2022 Final Digest, December 2022

F. Bielsa, H. Fang, A. Kiss, M. Stock, **A new beam mechanism for the BIPM Kibble balance**, CPEM 2022 Final Digest, December 2022

P. Gournay, J.A. Moreno, **Status of the BIPM Calculable Capacitor Project**, CPEM 2022 Final Digest, December 2022

S. Solve, **BIPM on-site Josephson comparison programme: from DC to AC voltages**, CPEM 2022 Final Digest, December 2022

M.-S. Kim, H. Cho, S. Solve, **Differential sampling of AC waveforms based on a programmable Josephson voltage standard using a high-precision sampler**, 2022 *Metrologia* **59** 01500

B. Rolland, P. Gournay, **Fabrication and characterization of a guarded-type low frequency current comparator for resistance ratio measurements**, CIM 2023

A. Moreno, P. Gournay, **Progress in the alignment of the main electrode bars of the BIPM calculable cross-capacitor**, CIM 2023

Thank you for your attention !