Report on the work programme of the BIPM electricity laboratories

CCEM meeting

24 March 2017

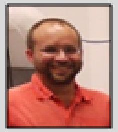
Bureau International des Poids et Mesures

Physical Metrology Department, since October 2015

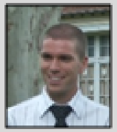
Dr Michael STOCK
Dept. Director
(CCEM)

Impedance

Dr Pierre GOURNAY
Principal Physicist

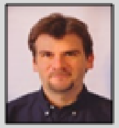


Nick FLETCHER
Physicist

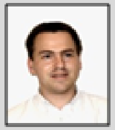


Benjamin ROLLAND
Assistant

Voltage



Dr Stéphane SOLVE
Principal Physicist



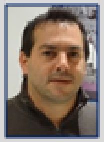
Régis CHAYRAMY
Principal Technician
(also imped.)

Watt balance

Dr Hao FANG
Principal Physicist
(CCM)

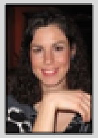
Dr Franck BIELSA
Physicist

Dr Shisong LI
Res. fellow

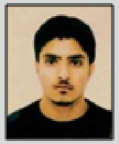


Adrien KISS
Assistant

ERMS



Dr Estefania de MIRANDES
Principal physicist
(CCU, 80 %)



Faraz IDREES
Technician
(also pressure, 50%)

Mass calibr.

Pauline BARAT
Assistant
(also ERMS)

Damien BAUTISTA
Technician
(also QMS)

20

BIPM comparisons

Organized by BIPM

BIPM.EM-K10.a/b	JVS on-site comparison, 1.018 V and 10V
BIPM.EM-K11.a/b	Zener voltage, 1.018 V and 10 V
BIPM.EM-K12	QHR on-site comparison, $R_H(2)$/100 Ω, 100 Ω/1 Ω, 100 Ω/10 kΩ
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
CCEM-K4.2017	capacitance, 10 pF at 1592 Hz (optional 100 pF, 1233 Hz)

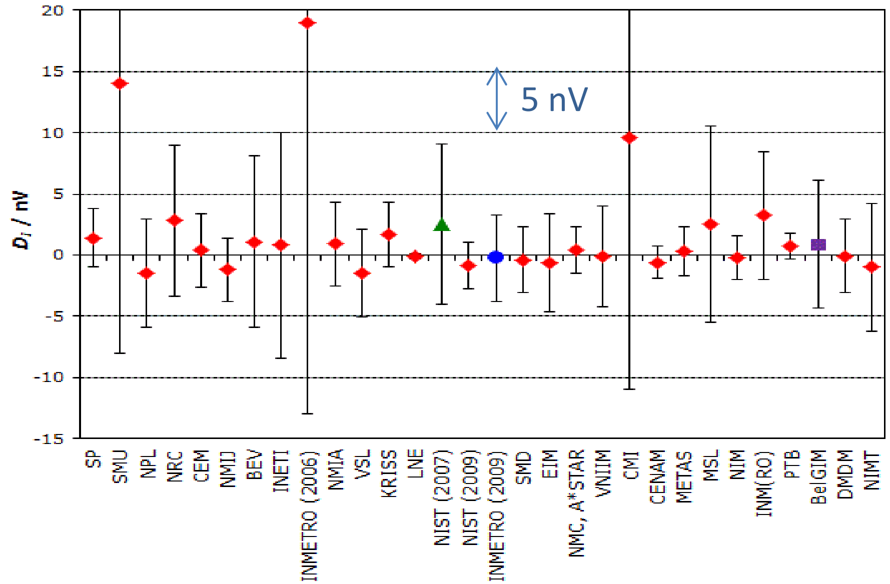
Future acJVS comparison

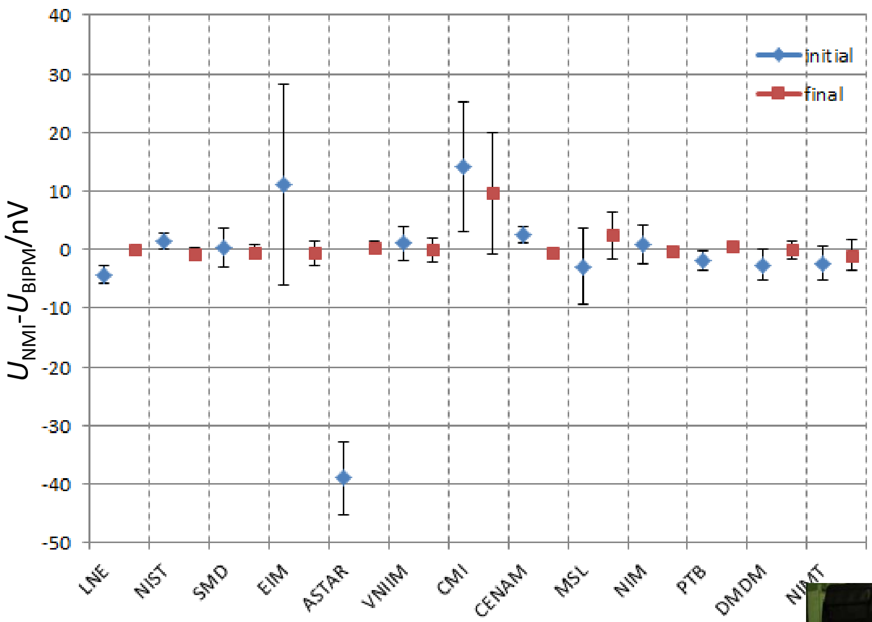
BIPM participation

EURAMET.EM-S31	capacitance and capacitance ratio
GULFMET.EM.BIPM-K11	Zener voltage at 1.018 V and 10 V

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

10 V Josephson voltage, degrees of equivalence in nV





- On average 2 comparisons / year
- Technical expertise and improvements leading to better results for 85% of the comparisons
- Typical uncertainty: a few nV, parts in 10^{10}

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BIPM.EM-K10.b: on-site Josephson comparison (10 V)

► June 2015: **DMDM-Serbia, 10 V:**

$(U_{DMDM}-U_{BIPM})/U_{BIPM} = -0.1 \times 10^{-10}$ $u_r = 1.5 \times 10^{-10}$

► November 2015: **NIMT-Thailand, 10 V:**

$(U_{NIMT}-U_{BIPM})/U_{BIPM} = -1.0 \times 10^{-10}$ $u_r = 2.6 \times 10^{-10}$

► June 2016: **JV-Norway:**

no satisfactory result could be obtained, due to instability of JV standard

No K10-comparisons planned for 2017, to concentrate on ac measurements

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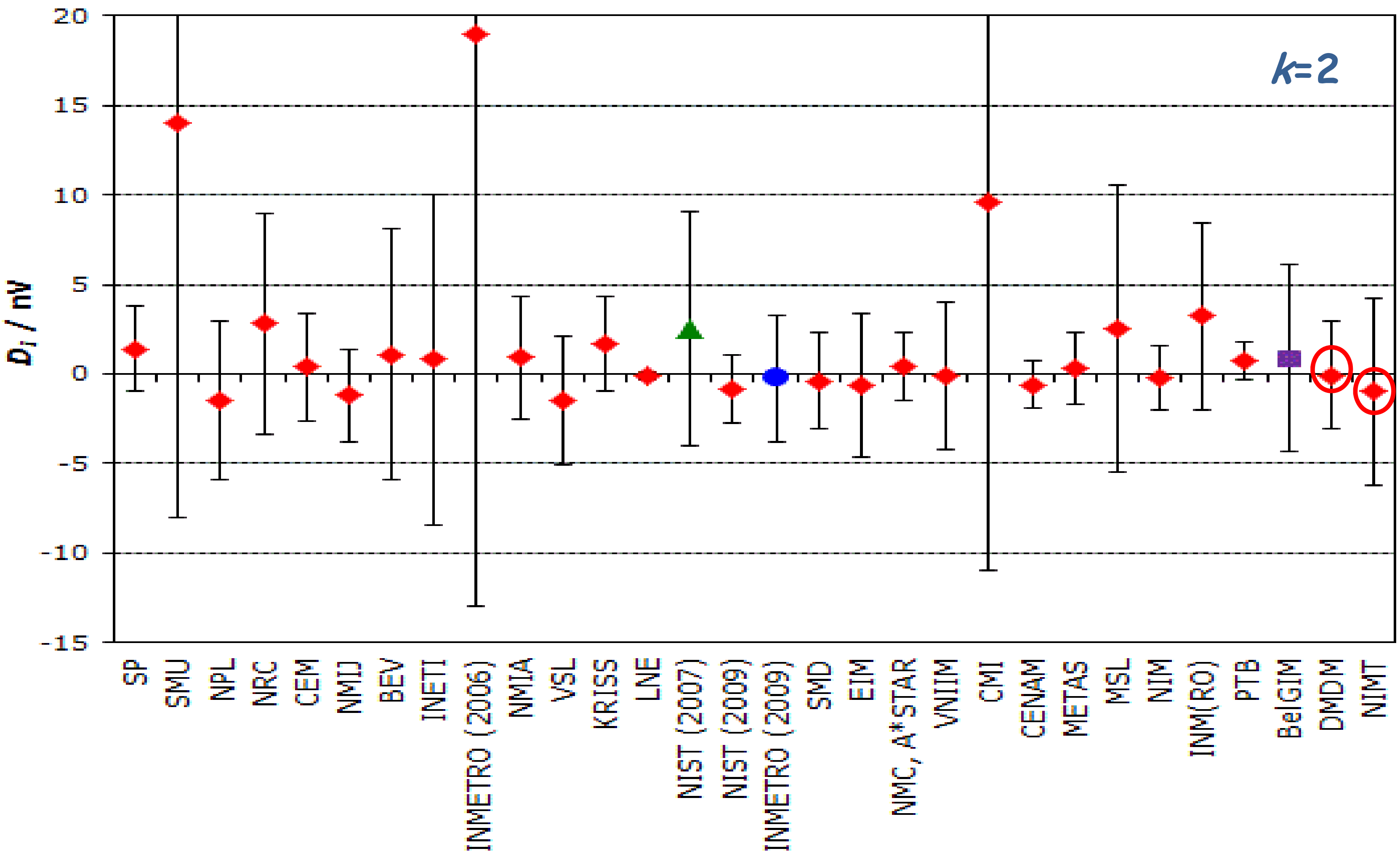
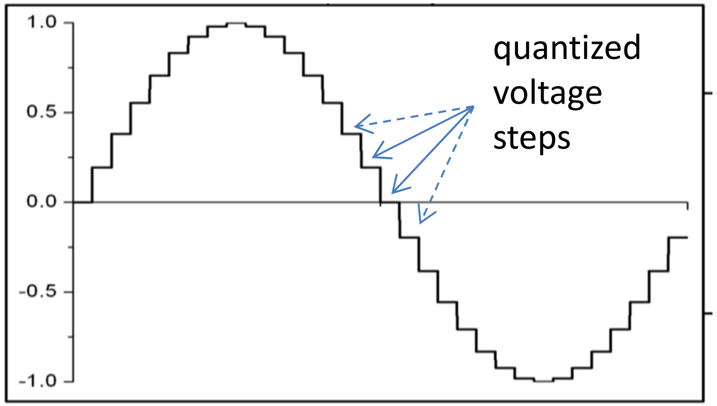
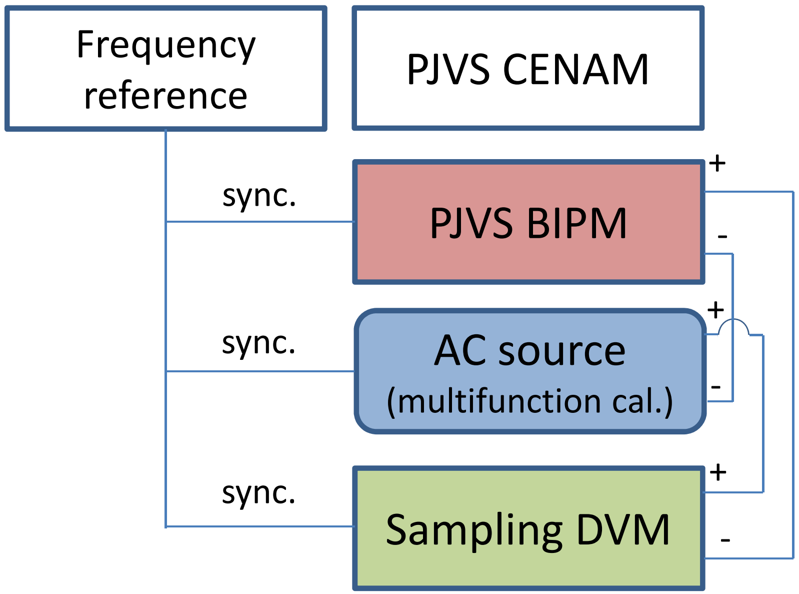
BIPM.EM-K10.b: on-site Josephson comparison (10 V)



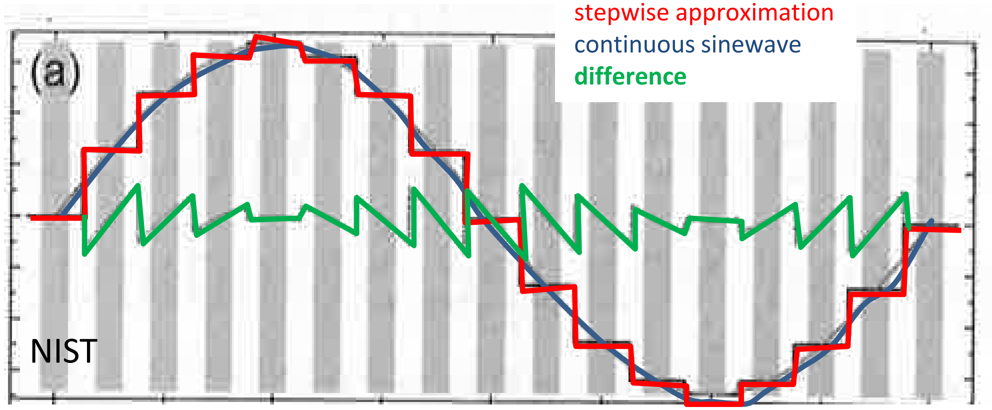
First trial of an ac Josephson voltage comparison, at CENAM

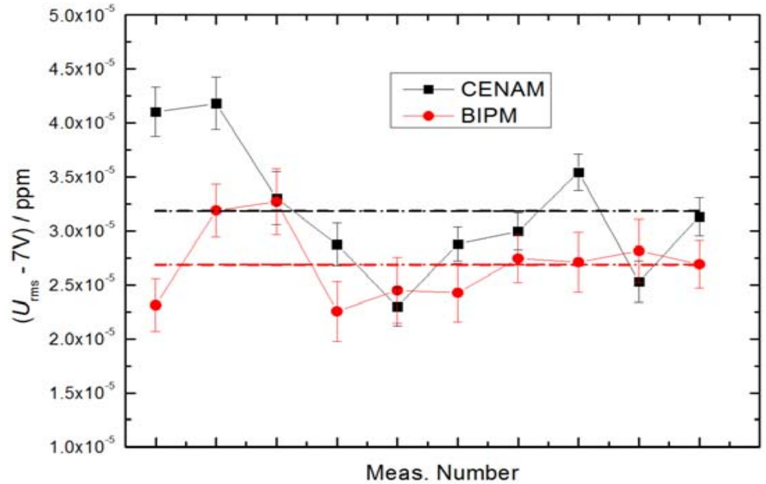
stepwise approx. sinewave at 50 Hz





differential sampling with a continuous sinewave



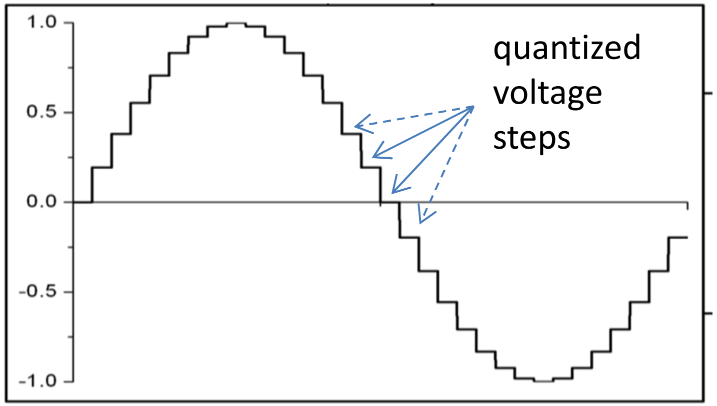


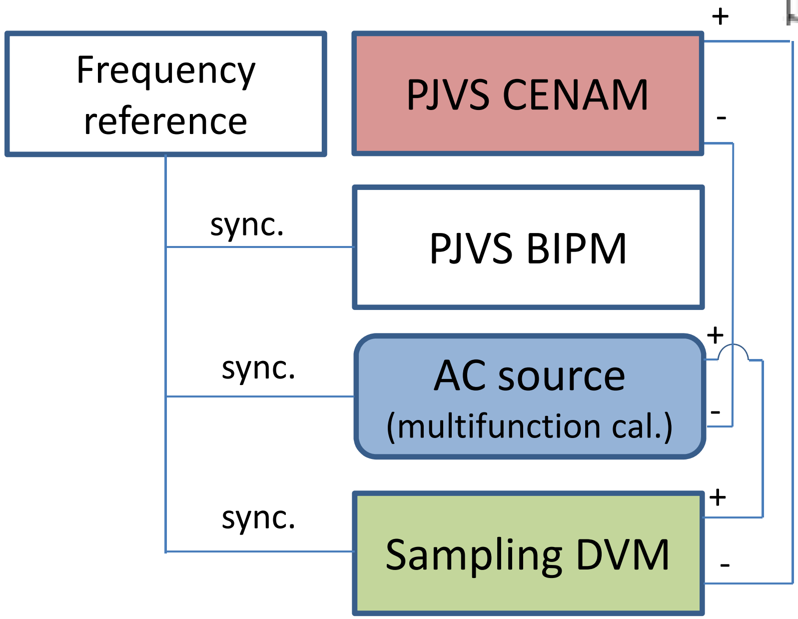
$U_{CENAM} - U_{BIPM}$ = (0.7 ± 0.3) ppm at 7 V rms, 50 Hz

$U_{CENAM} - U_{BIPM}$ = (0.2 ± 0.3) ppm at 0.7 V rms, 50 Hz

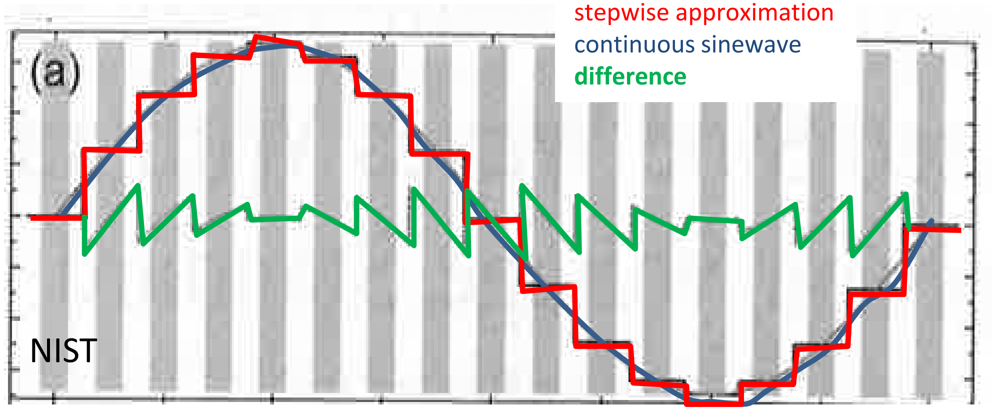
First trial of an ac Josephson voltage comparison, at CENAM

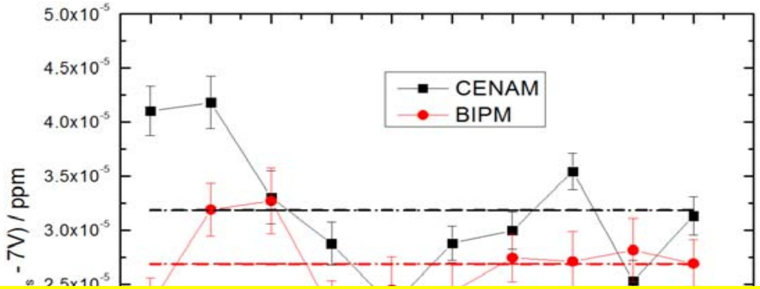
stepwise approx. sinewave at 50 Hz





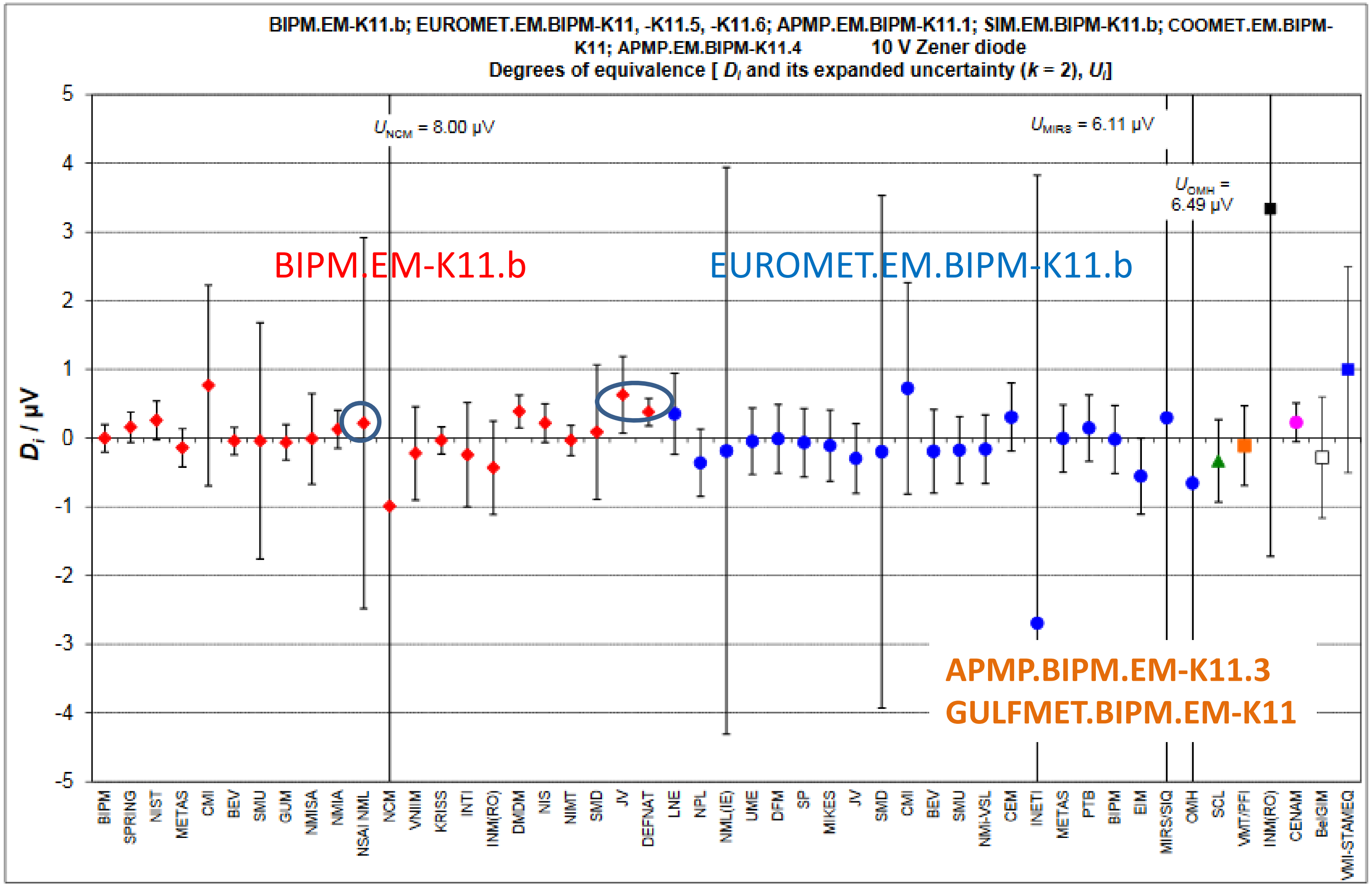
differential sampling with a continuous sinewave





In 2017 comparisons with NPL and PTB, in framework of EMPIR project ACQ-PRO

Secondment from KRISS being planned to develop this further
Start: September 2017



Red diamonds: participants in BIPM.EM-K11.b

Blue circles: participants in EUROMET.EM.BIPM-K11

Black square: participant in EUROMET.EM.BIPM-K11.6 only

Green triangle: participant in APMP.EM.BIPM-K11.1 only

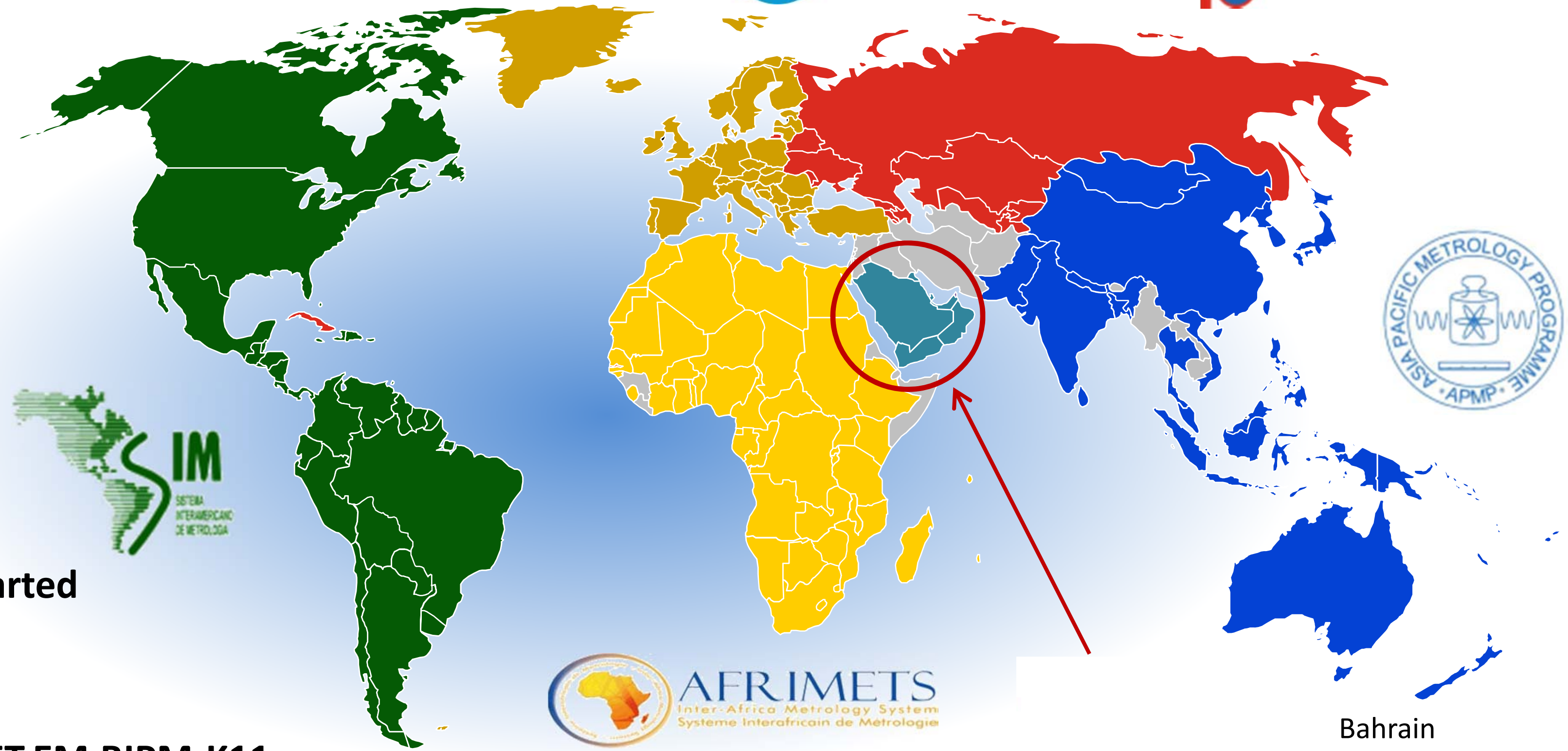
Orange square: participant in EUROMET.EM.BIPM-K11.5 only

Pink circle: participant in SIM.EM.BIPM-K11.b only

White square: participant in COOMET.EM.BIPM-K11 only

Blue square: participant in APMP.EM.BIPM-K11.4 only

New RMO provisionally accepted by CIPM for participation in MRA



4 SCs started

First KC:

GULFMET.EM.BIPM-K11
(SCL, SASO, EMI, KRISS, BIPM)

- attend JCRB meetings (without voting right)
- be invited to CC WG meetings
- minimum waiting period for full membership of 1 year (technical competence essential, eg. comparisons)

Bahrain
Kuwait
Oman
Qatar
Saudi Arabia
UAE
Yemen

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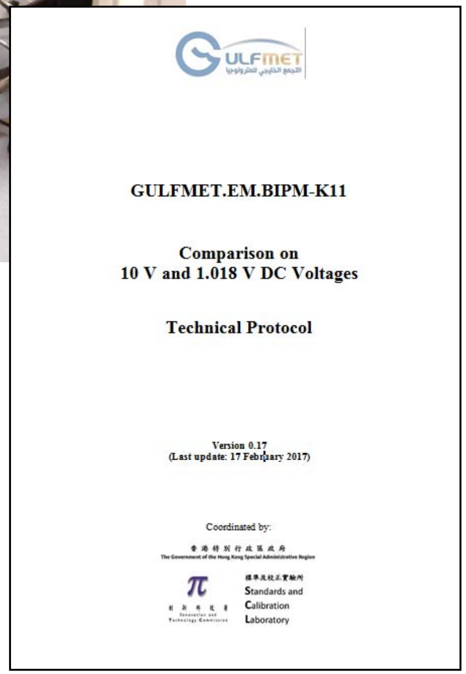
GULFMET.EM.BIPM-11, Zener voltage

Pilot lab: SCL Hong Kong (Steven Yang)

Participants
- BIPM
- KRISS, Rep. of Korea
- QCC EMI, UAE
- SASO, Saudi Arabia

BIPM contribution
- member of support group
- 2 measurement periods
- determination of sens. coeff. of Zeners (T, p)
- Steven Yang on secondment at BIPM for 2 months



GULFMET.EM.BIPM-K11

Comparison on
10 V and 1.018 V DC Voltages

Technical Protocol

Version 0.17
(Last update: 17 February 2017)

Coordinated by:

Standards and Calibration Laboratory

1. Example of CB&KT project in PMD

Capacity Building & Knowledge Transfer

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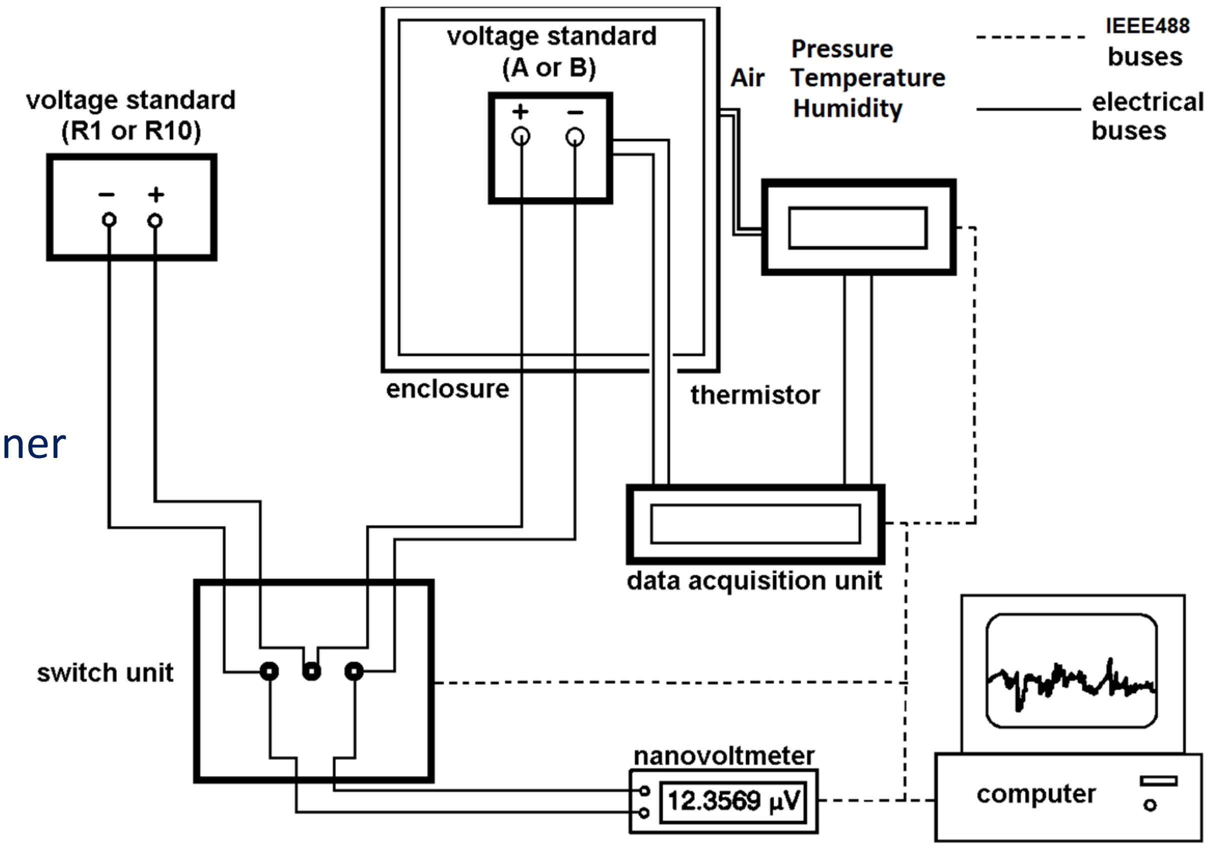
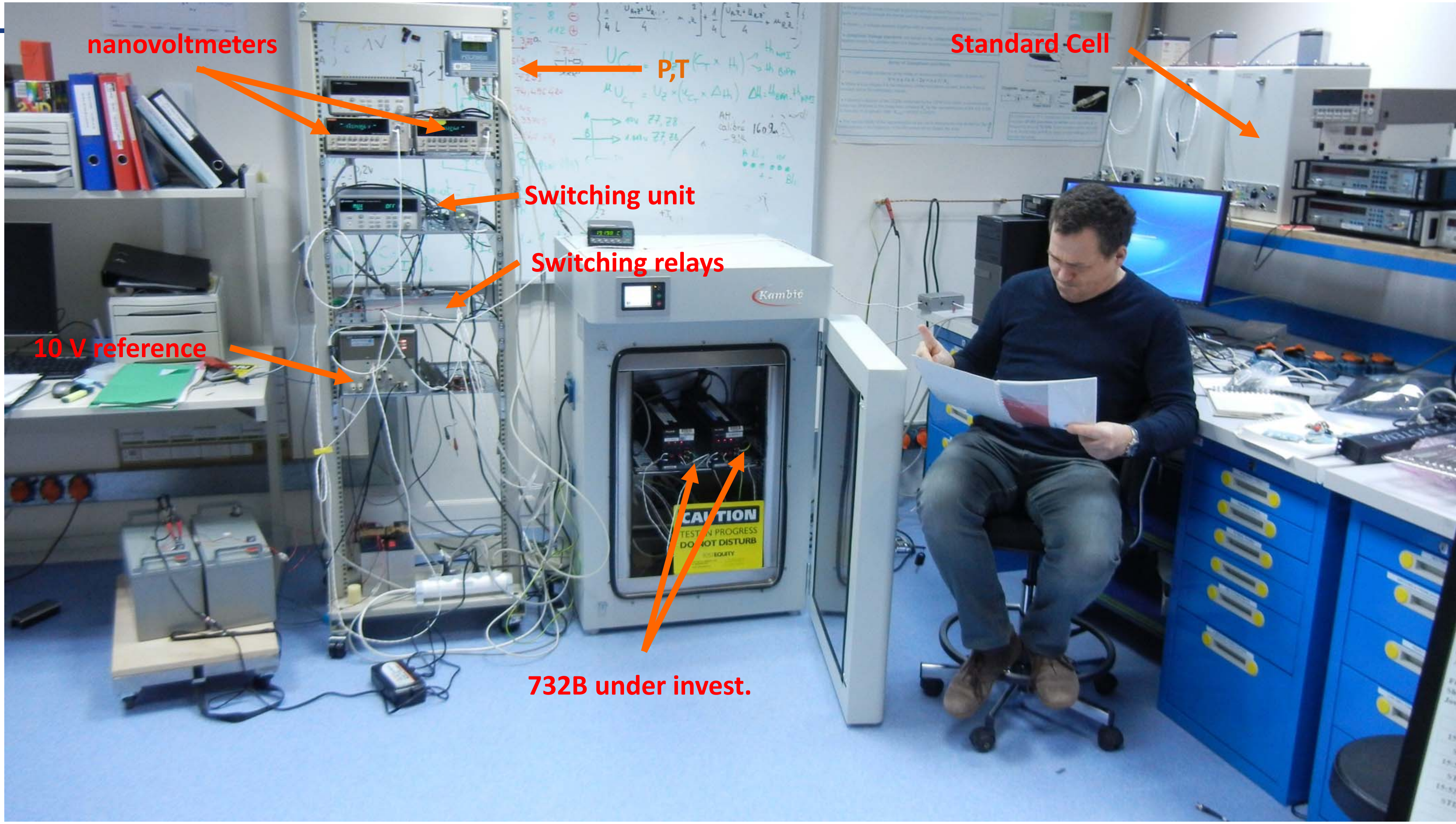
Re-determination of Zener temperature coefficients

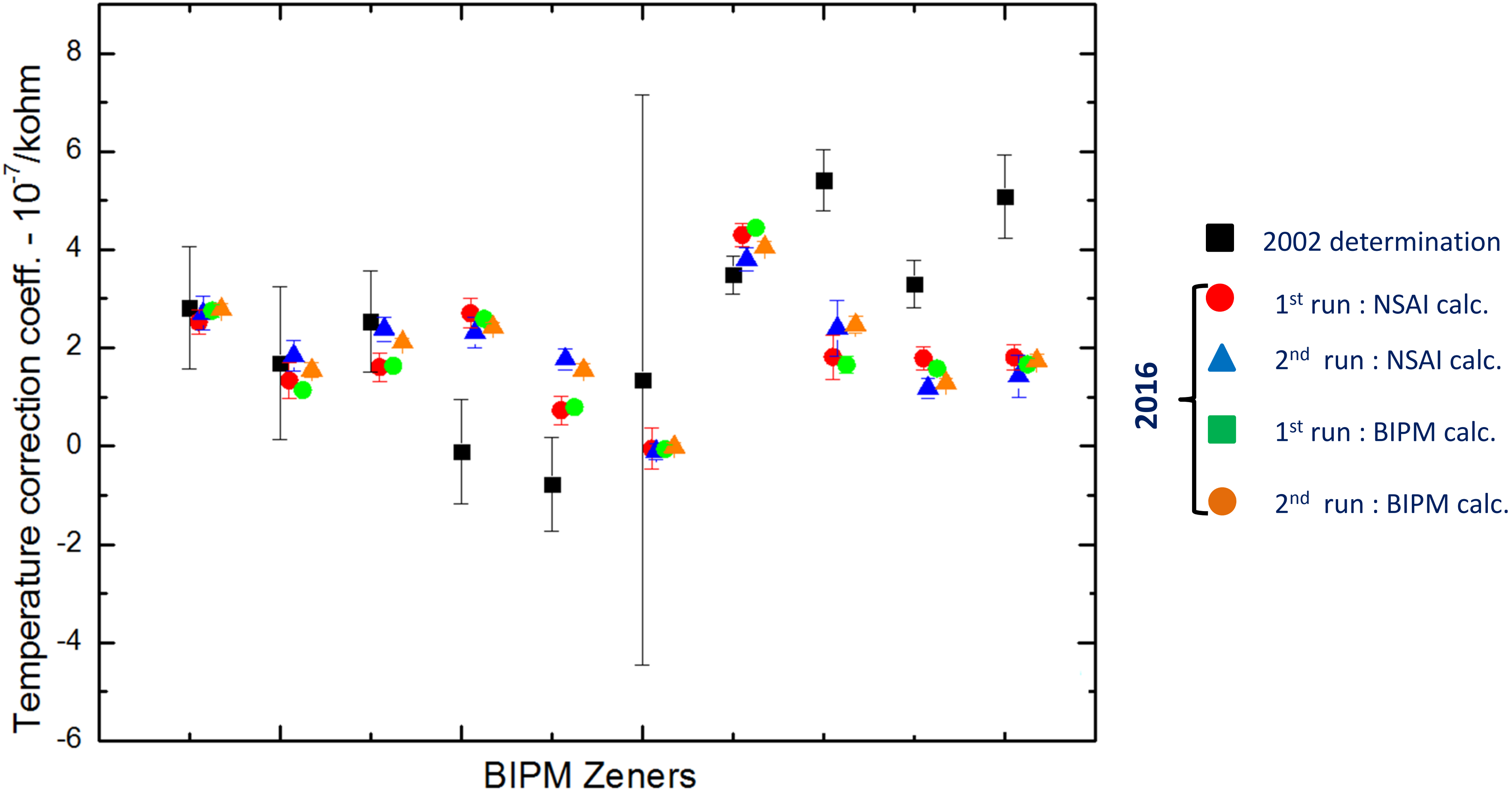
- 2 zeners in the enclosure
- 4 coefficients measured
- 10 V reference: 732A Fluke Zener
- 1 V reference: Weston cell



Measurement setup



Zener temperature coefficients for 10 V output



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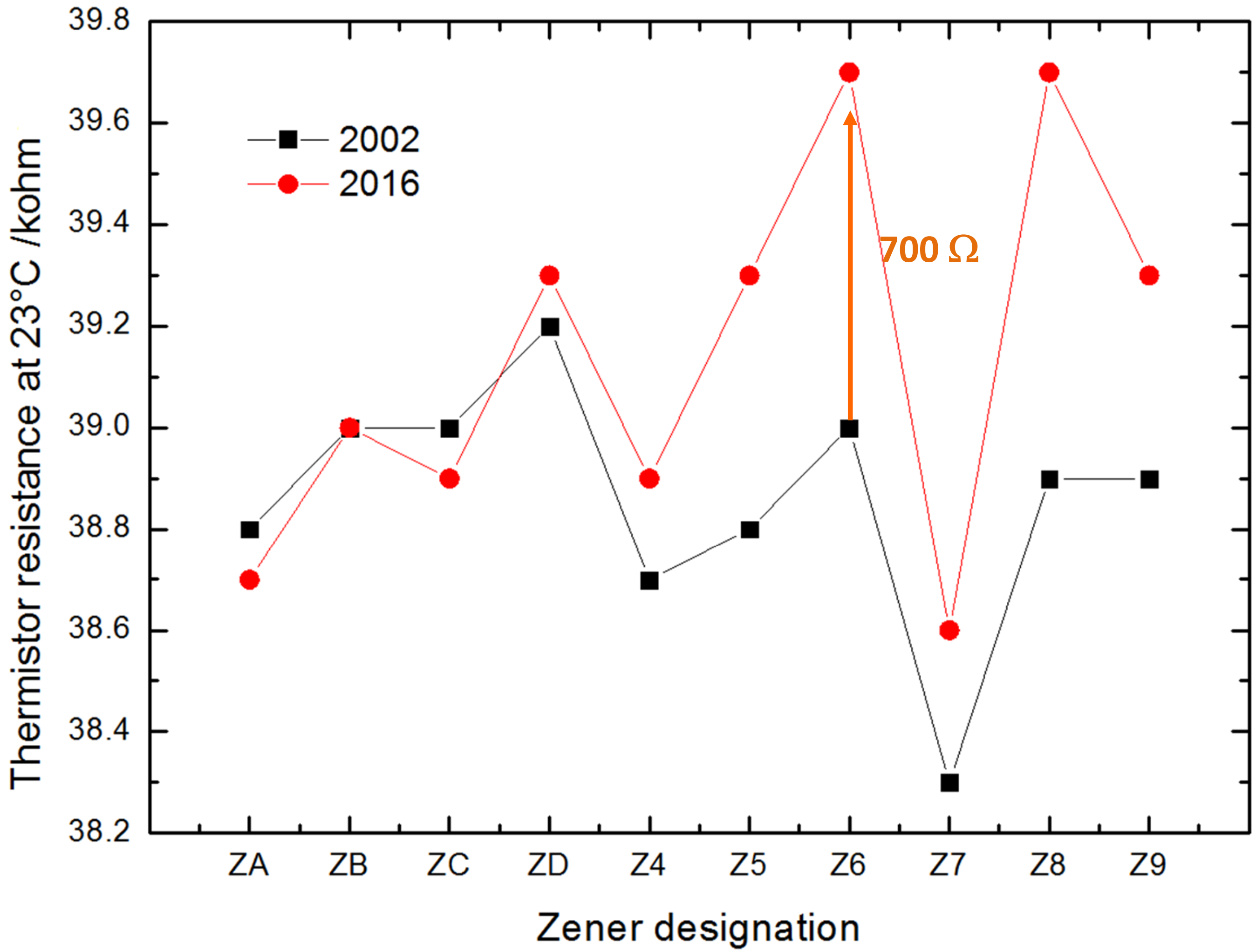
The uncertainty on all temperature coefficients has been reduced considerably (better temp. stability of chamber)

Zener thermistor reference value (at 23°C RT)



Most of the reference thermistor resistance values increased, indicating a lower oven temperature

- Normal operating range between 36.5 kΩ and 42.5 Ω
- Should not change by more than 900 Ω/year (manufacturer)

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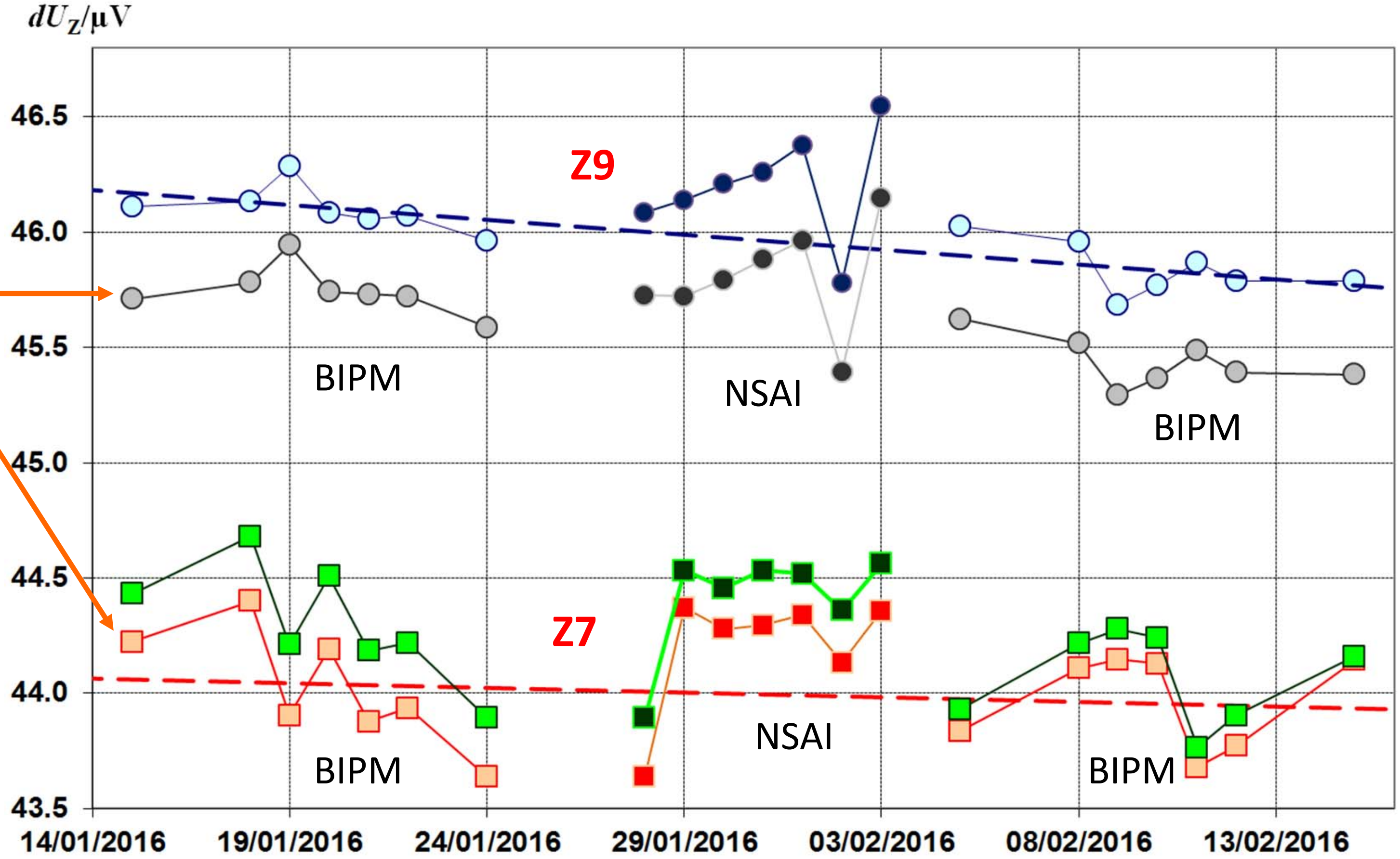
Conclusion

Applying New

Corr. Coeff.



NSAI- BIPM bilateral Zener comparison – 2016

- the change of Tc and R_{ref} has negligible effect: 20 nV (2 x 10^{-9})

Bilateral resistance comparisons, BIPM.EM-K13.a/b, 1 Ω and 10 kΩ

- **2013/2014: BIM-Bulgaria**
  published in 2017
- **2013/2014: NPL-India**
  Draft B under review
- **2014: NSAI-Ireland**
  published in 2017
- **2015: NIMT-Thailand**
  published in 2017
- **2015: CMI-Czech Republic**
  published in 2017
- **2016/17: SMD-Belgium**
  Draft A under preparation
- **2017: NMISA-South Africa**
  measurements under way at NMISA

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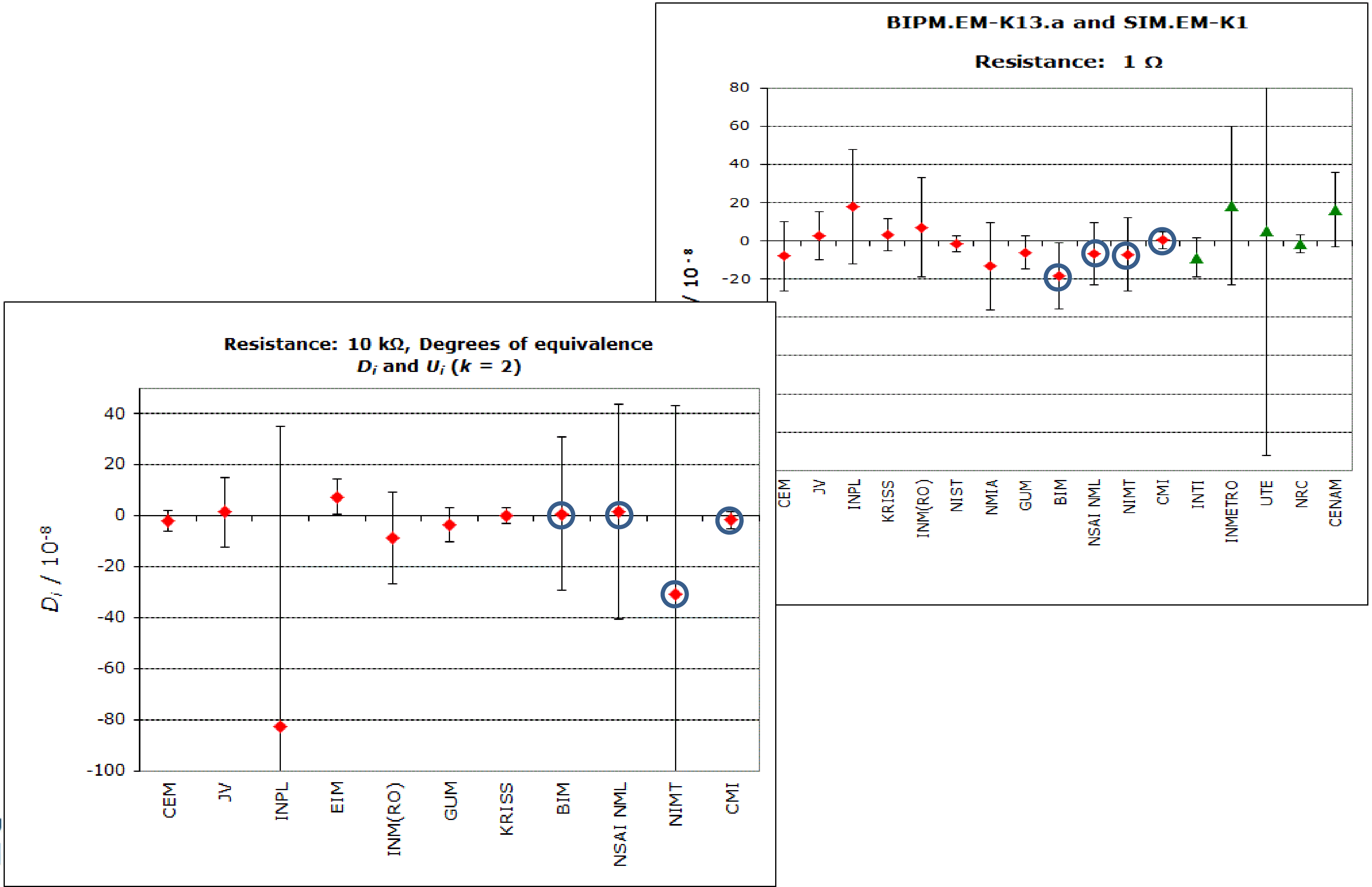
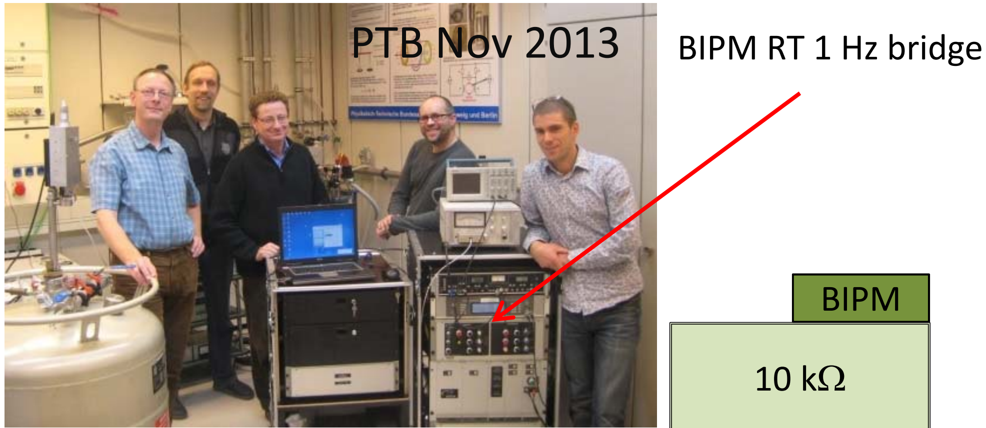
Bilateral resistance comparisons, BIPM.EM-K13.a/b, 1 Ω and 10 kΩ

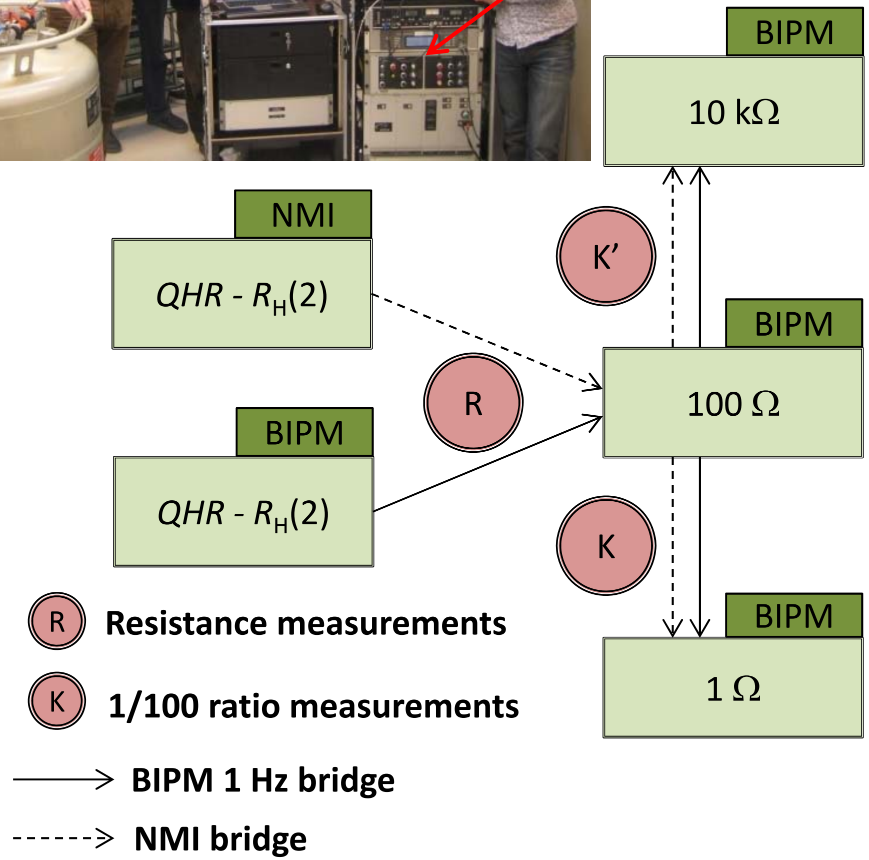


Bu… Poids et Mesures

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

- To verify international coherence of primary resistance standards by comparing quantum Hall effect based standards of the NMIs with that of the BIPM
- Five such comparisons have already been carried out in the period 1993 to 1999. This comparison has been resumed in 2013 at the request of the CCEM
- A first comparison has been carried out with the PTB in Nov 2013
- 15 new comparisons are expected for the coming years





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

October 2015: comparison at VSL
- unexpected behavior of VSL equipment
- no publishable result

December 2016: comparison at METAS
- Resistors brought to METAS in September
- Postponed by METAS until unknown date

Next try: CMI in April 2017

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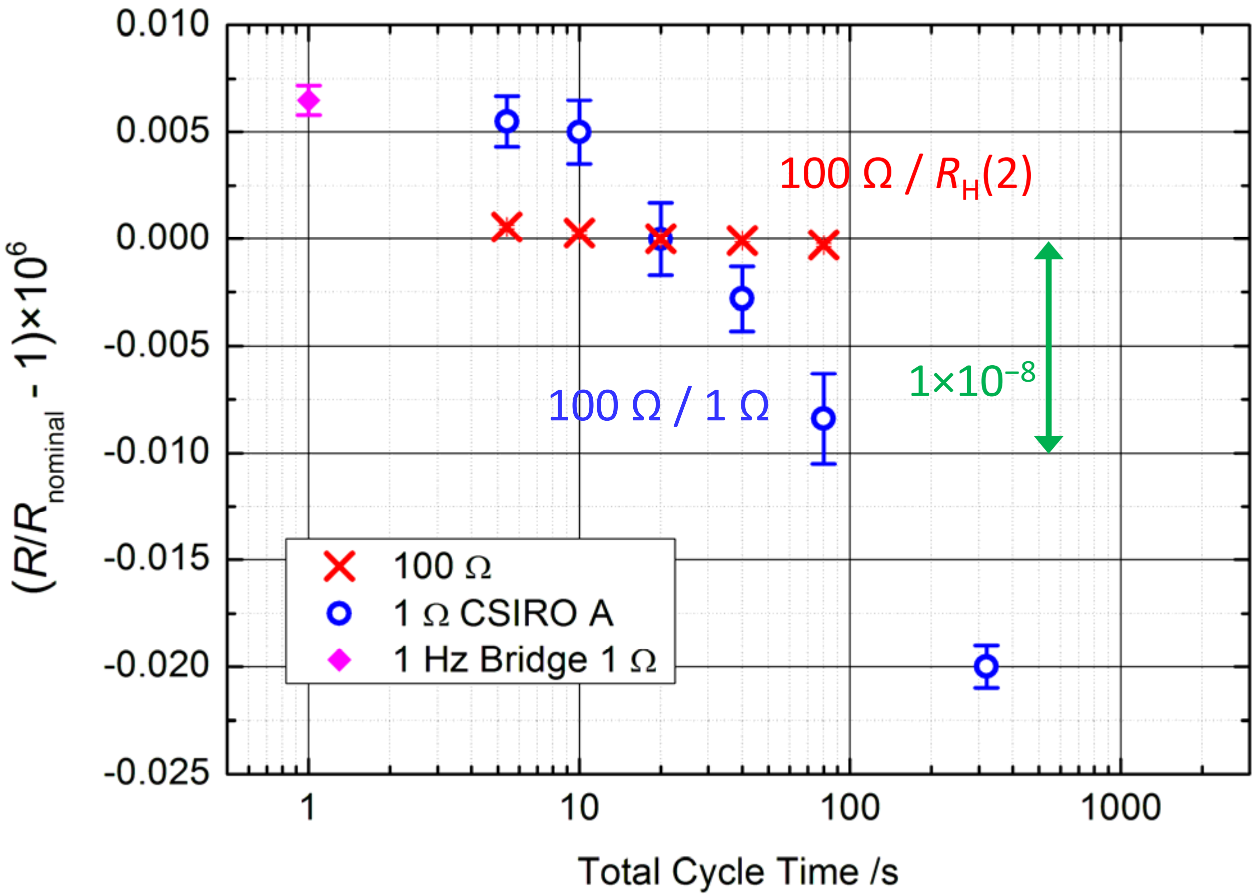
Behaviour of 1 Ω resistors

Typical frequency dependence for 1 Ω and 100 Ω standard resistors



Value of 1 Ω res. increases with cycle time

Origin: Peltier effect

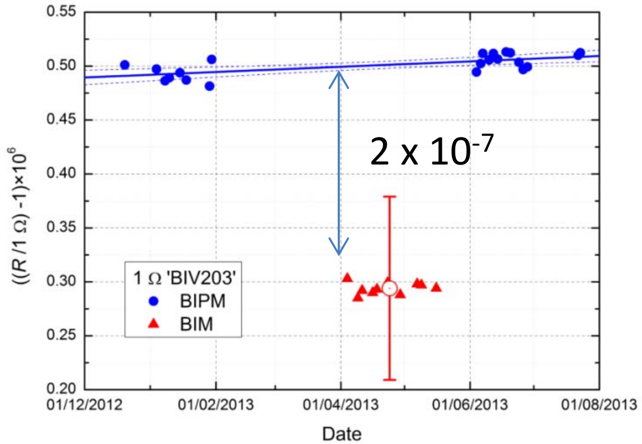
Magnitude of effect resistor dependent

Which is “true” (dc) value ?

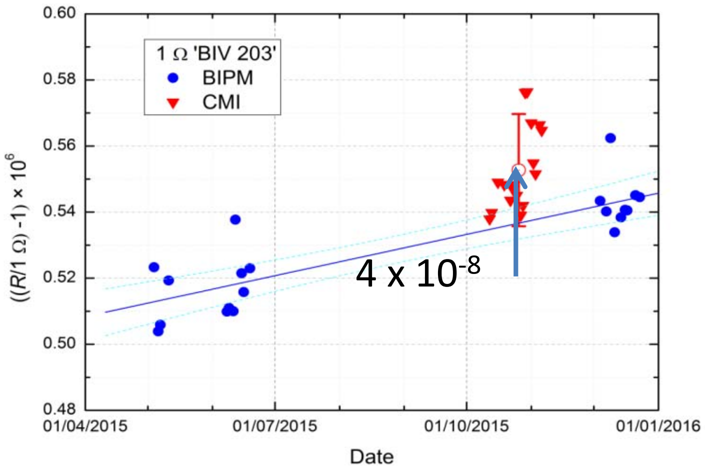
International des Poids et Mesures

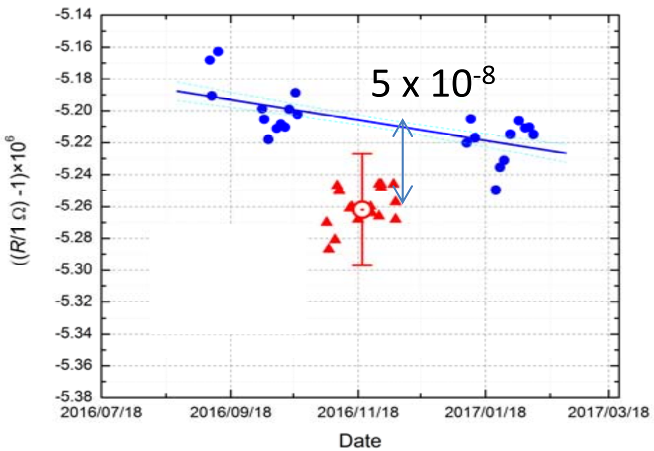
Metrologia **52** (2015) 509-513

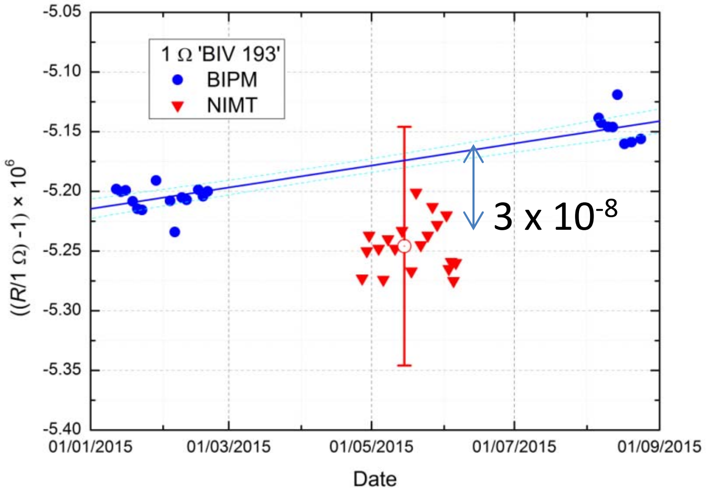
Some evidence from resistance comparisons (BIPM.EM-K13)



CMI investigated the effect and applied a correction (24s, 340 s)







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Investigations towards a compact next-generation QHR reference

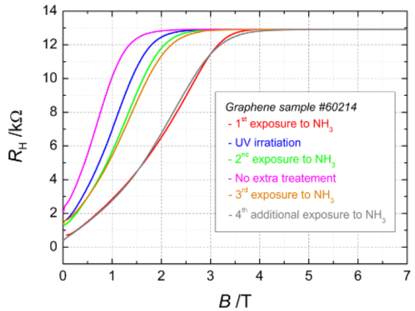
Graphene QHR samples

- lower field (5 T)
- Higher temperature (4-5 K)

Carrier density of new G-SiC devices usually too high, needs to be adjusted

Investigation of techniques for n_e adjustment:

- UV light
- electrost. discharge
- NH_3 gas



Poster at CPEM 2016 (with PTB, MIKES, Aalto Univ.)

LFCC bridge at room temperature

- cryogen free
- operating << 1Hz, small ac-dc correction

Investigation of LFCC operating below 1 Hz, based on new high permeability materials (nanocrystalline mat.);

Comparison between two new LFCCs and the 1 Hz BIPM LFCC

Poster at CPEM 2016 (with PTB, MIKES)

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Bilateral capacitance comparisons, BIPM.EM-K14.a/b

- ► 2016: **NIS-Egypt,** 10 pF and 100 pF
  Draft B under review

- ► 2016: **NMISA-South Africa,** 10 pF and 100 pF
  Draft B under review

- ► 2016: **NSAI-Ireland,** 100 pF
  Final Report, to be published soon

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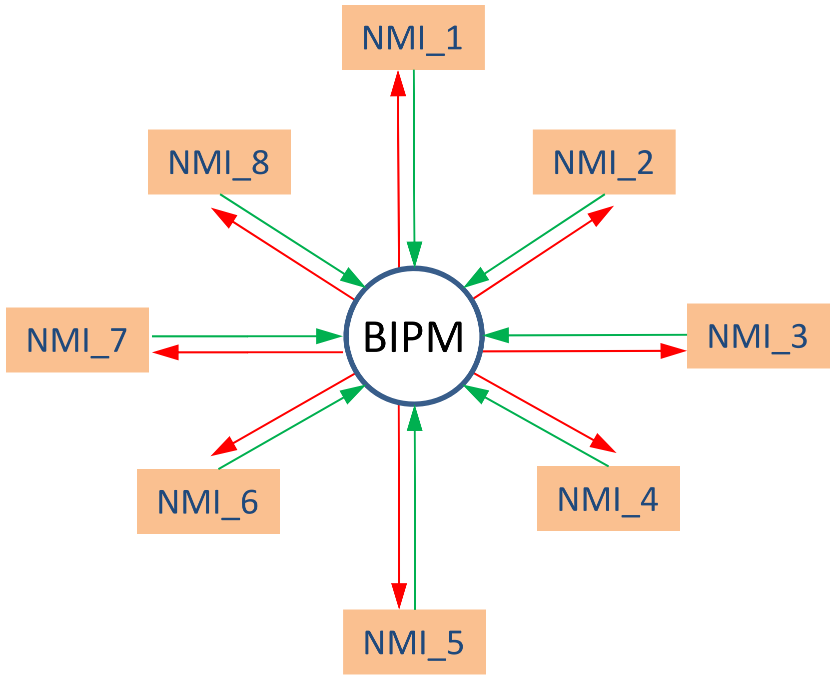
CCEM-K4: capacitance, 10 pF at 1592 Hz (opt. 100 pF, 1233 Hz)

Comparison scheme:

→ star scheme, *N* bilateral comparisons carried out simultaneoulsy

→ advantage to shorten considerably the time duration of the comparison



BIPM meas.: May-June 2017
Draft A: December 2017

NMIs

1- Each NMI measure its own standards
→ measurements carried out simultaneously in all NMIs

BIPM

2- All NMIs send their standards to BIPM
→ measurement by BIPM of all standards simultaneously

NMIs

3- Again, each NMI measure its own standards
→ measurements carried out simultaneously in all NMIs

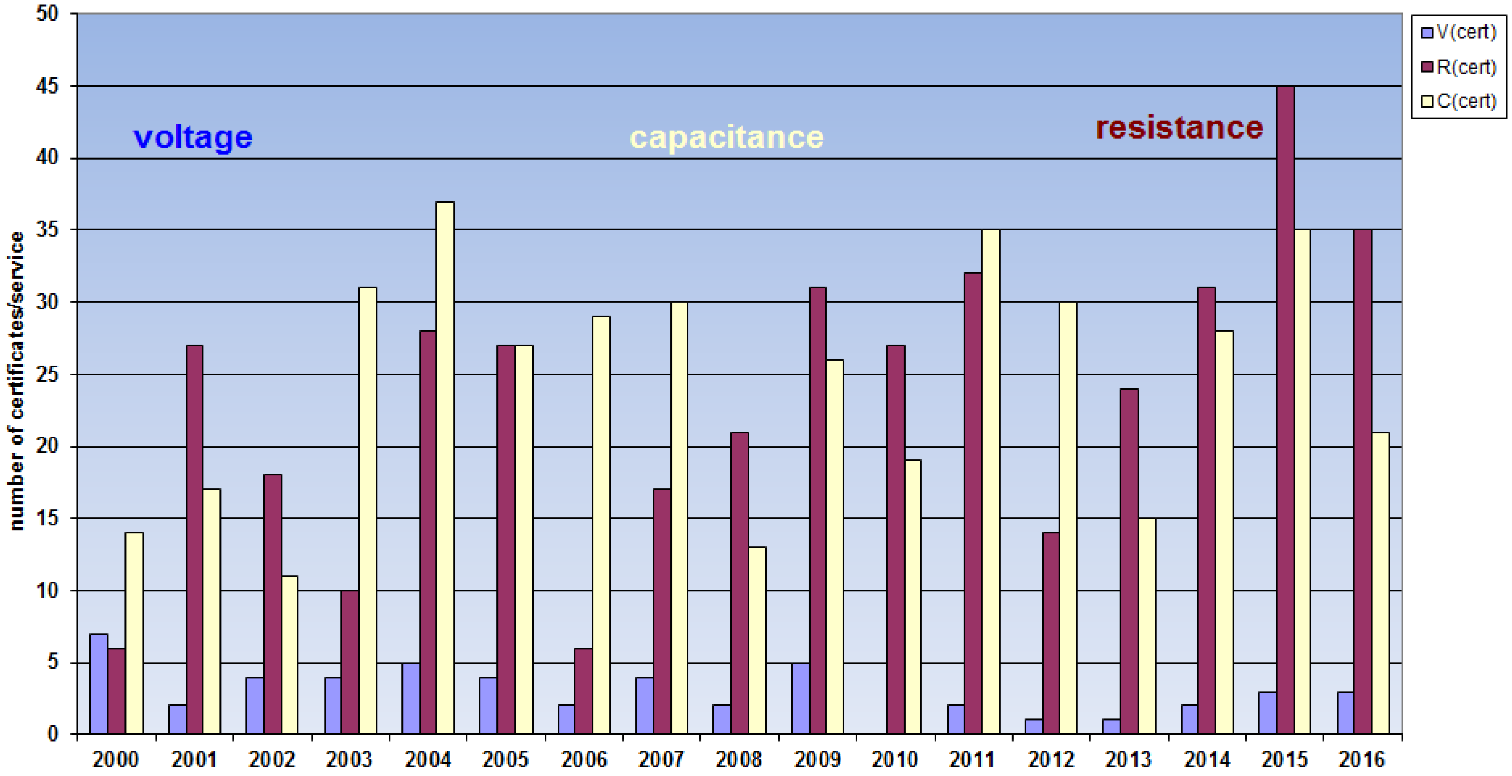
Comparisons in capacitance: EURAMET-S31

- EURAMET.EM-S31 comparison of 10 pF and 100 pF standards for measurements traceable QHR – piloted by PTB, participation of LNE, METAS, VSL and BIPM. Circulation of standards 2010-2011.
- First round revealed significant frequency-dependent discrepancies.
- A supplementary circulation of ac-dc resistors in 2013 gave excellent results and eliminated one suspected cause of errors.
- Some participants discovered systematic bridge errors and submitted corrections.
- A new circulation of capacitance standards has started end 2014, this time to include calculable capacitor traceability from NMIA.
- Draft A: All results found in agreement.

➢ "…the ac measuring technique is prone to delicate systematic effects and a comparison is a proper instrument to rectify the ac measuring bridges of the participants. "

Calibrations

voltage:	Zeners at 1.018 V, 10 V	2-3 per year
resistance:	1 Ω, 100 Ω, 10 kΩ	25-30 per year
capacitance:	1 pF, 10 pF, 100 pF	25-30 per year



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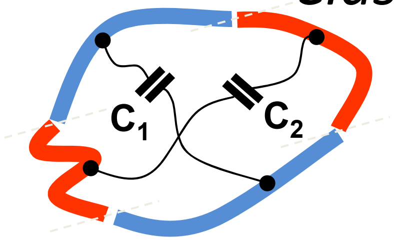
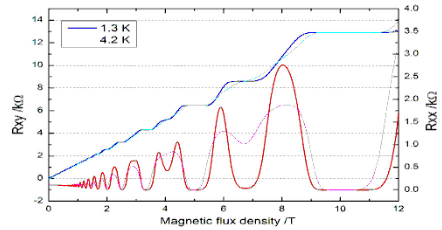
Determining R_K with a calculable capacitor with best unc. ever

Capacitance — Quadrature bridge — Resistance

$$\omega^2 C_1 C_2 R_1 R_2 = 1$$

Classical | *Quantum*



Calculable capacitor

$$\Delta C = \frac{\varepsilon_0 \log_e 2}{\pi} \Delta l$$

For $\Delta l \approx 0.2$ m, $\Delta C \approx 0.4$ pF
To compare C to R, we also have to chose a frequency, f
(in our case, $f \approx 1$ kHz)

Quantum Hall effect

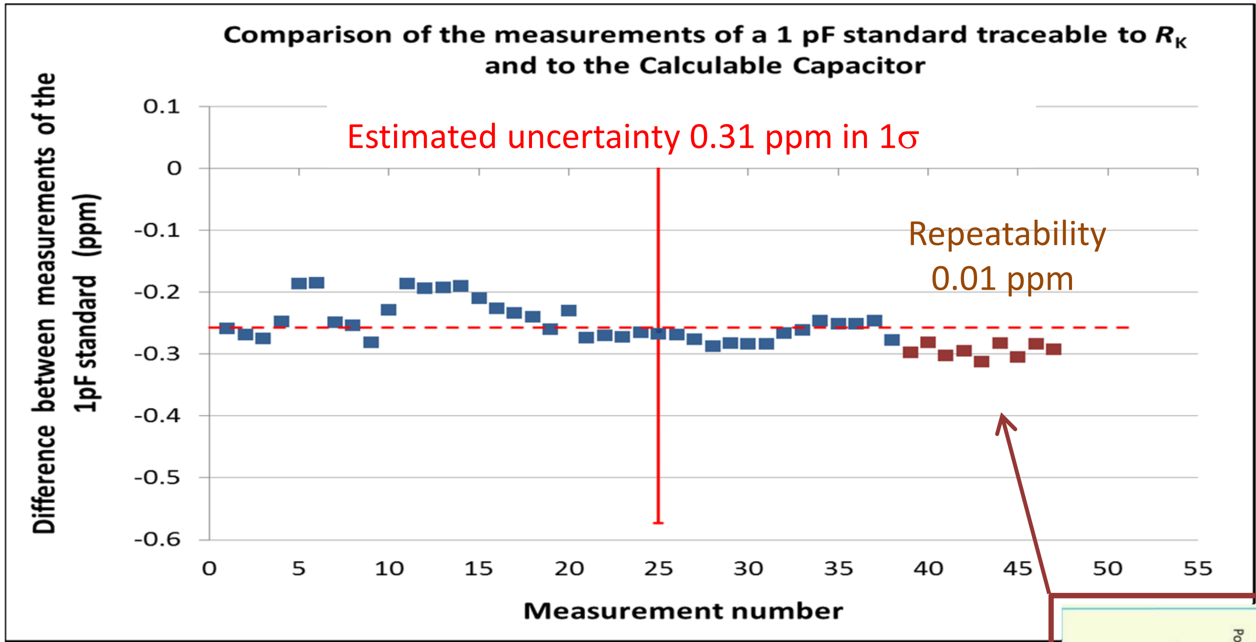
(2-d electron gas, $B \approx 10$ tesla, $T < 1$ K)

$R_{hall} = R_K / i \quad (i = 1,2,4\ldots)$
$R_K = h / e^2 \approx 25.8$ kΩ

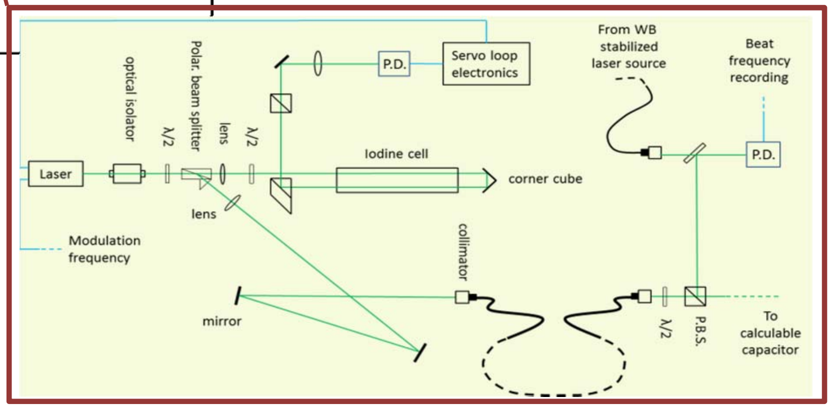
for $i = 2$ plateau: $R \approx 13$ kΩ

Target uncertainty for R_K: 1×10^{-8}

First measurements with calculable capacitor



New iodine-stabilized laser source



Offset of 0.26 ppm due to imperfect electrode alignment

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Status of calculable capacitor

- New stabilized laser source has been built to fix the laser frequency instabilities detected during measurements

- The CC has been disassembled, relocated in a new room offering a floor of much better stability and, then, realigned with geometrical error of the order of 3×10^{-9} (sub-µm accuracy)

- Better alignment thanks to new precision alignment probe, for residual skew and diagonal spacing of main electrode bars

- The completion of the reassembling and the start of new series of measurements are planned for the coming months

- Target uncertainty: 1×10^{8}

mobile clean room cabin

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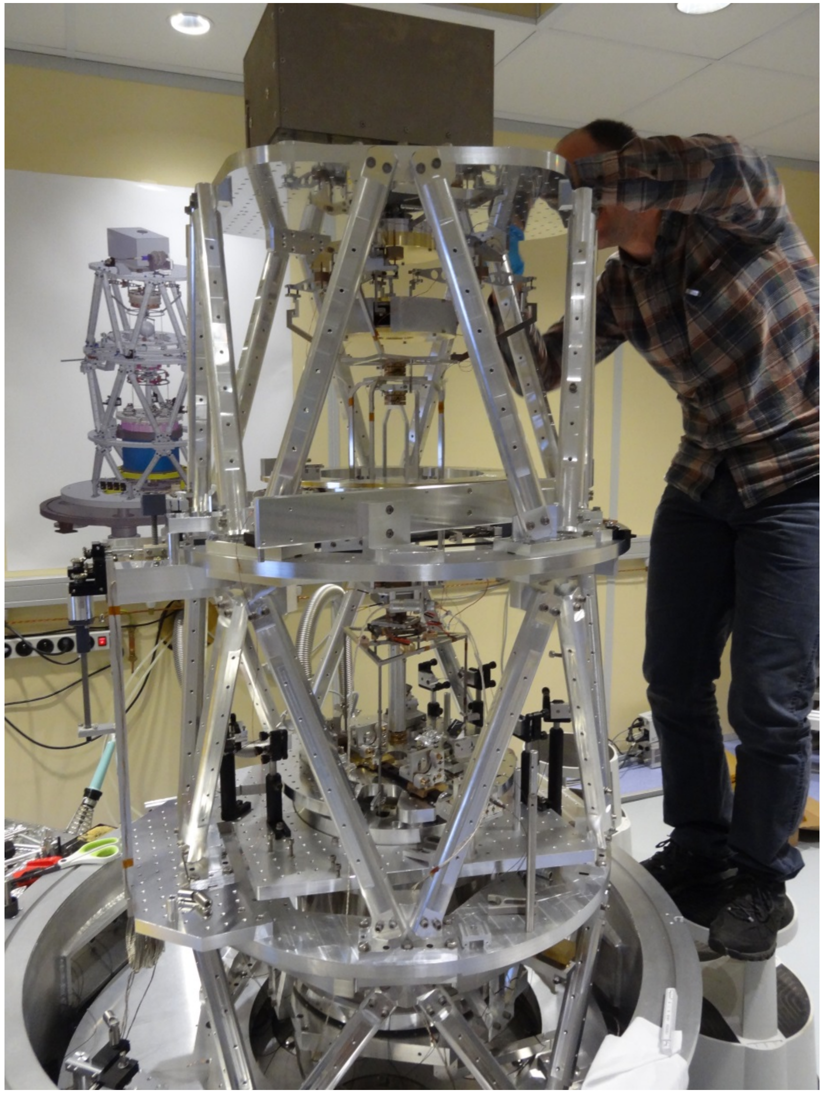
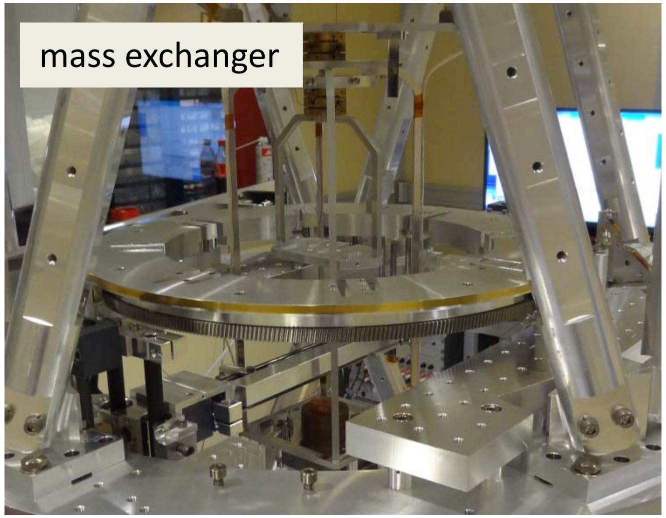
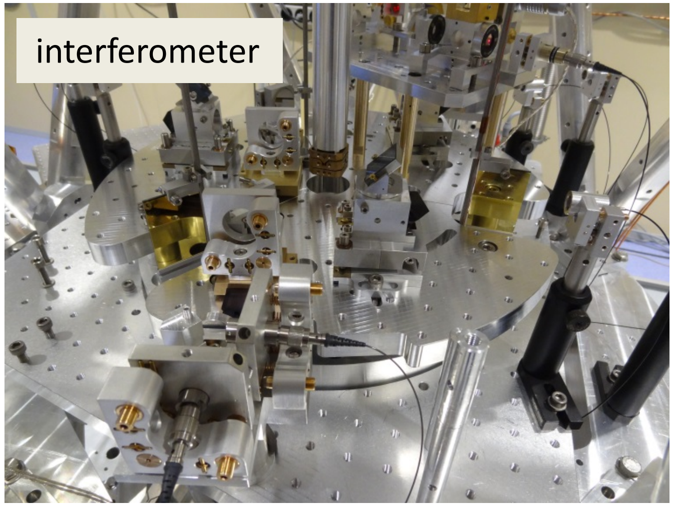
Watt balance: Major achievements during 2014-2016

- precision alignment of the magnetic circuit, publ. in *Metrologia*
- assembly of the improved apparatus on a new open support structure
- integrated mass exchanger
- re-arrangement of control and measurement units; electrical, optical links and vacuum feedthroughs
- completion and integration of the new interferometer
- new control and acquisition programs using FPGA & data synchronization scheme
- compact and vacuum compatible mechanical mounts for optics
- detailed study of effect of current on magnetic field profile (reluctance force), submitted to *Metrologia*

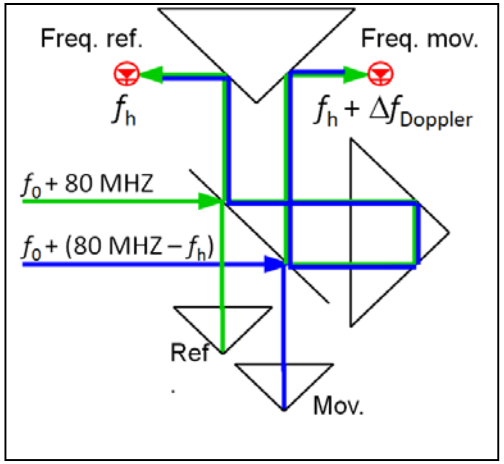
Assembly of the improved apparatus completed

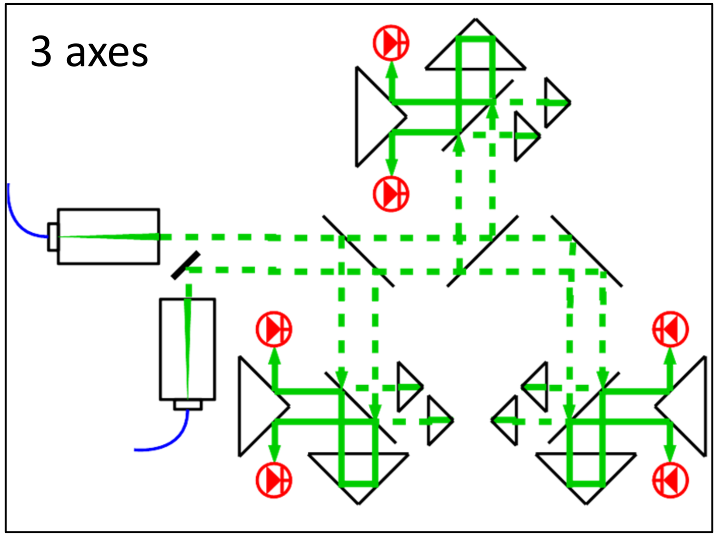


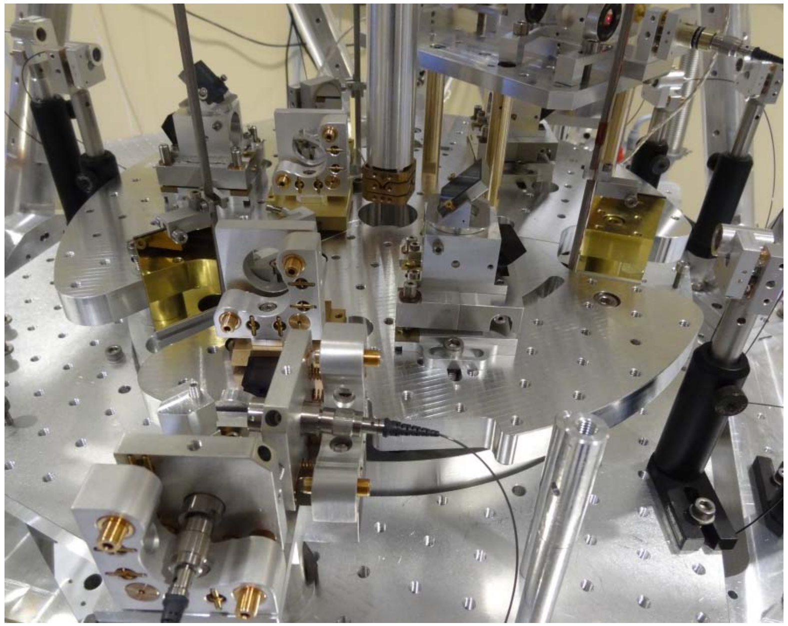




New interferometer







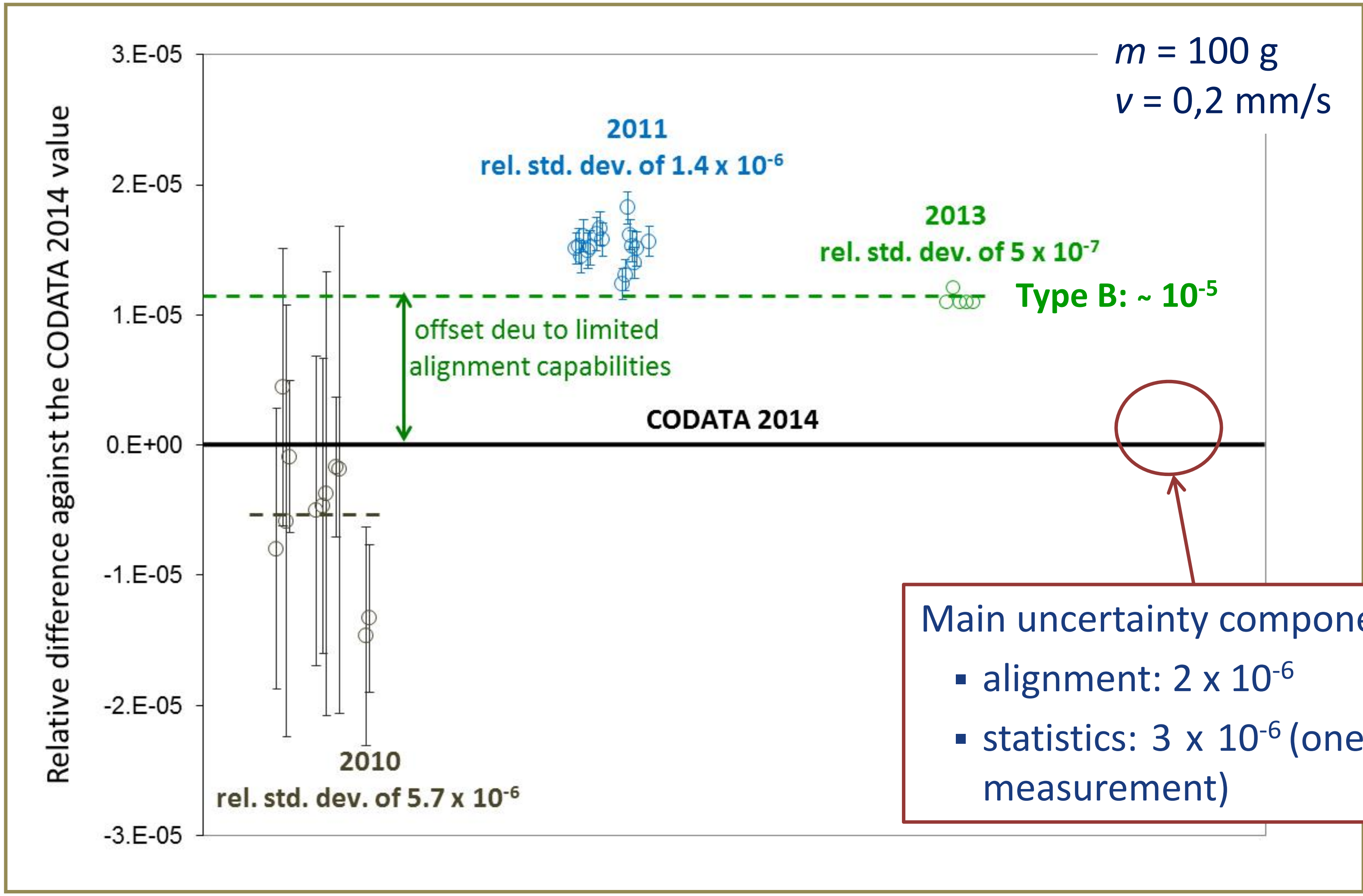
Objective: minimize periodic non-linearity observed previously

- Heterodyne frequency of about 3 MHz
- Spatially separated beams
- Non-polarizing elements
- Differential output

➢ noise level: 1/6000 fringe

➢ S/N level improved by factor of 5

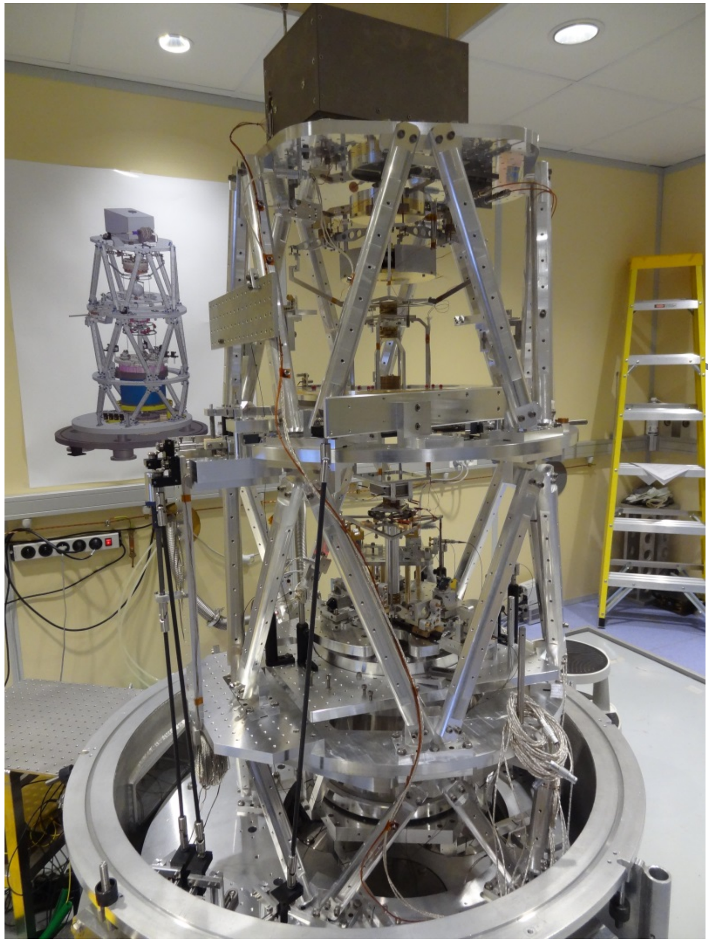
Last measurements, early 2016



Main uncertainty components:

- alignment: 2×10^{-6}
- statistics: 3×10^{-6} (one night measurement)

Outlook



1 July 2017

closing date
for new data

- bifilar coil
- better alignment
- possibly 1 kg
- PJVs
- noise reduction in force meas.
- vacuum

target uncertainty
$u_r(h) = 1 \times 10^{-7}$

design of a new suspension (motor & alignment mechanism) to further improve alignment & operation

Outlook in to the future

- Maintain travelling quantum standards which eliminates need for some CCEM comparisons

- Development of more versatile and more efficient quantum standards

  - ❑ - acJVS for comparison of ac voltages
  - ❑ - table-top QHR system using graphene samples and new LFCCs at room temperature
  - ❑ - acQHR as impedance standard

- Calibration service for ac/dc transfer standards using acJVS ?

- Replace 1 Ω comparisons and calibrations by higher values (> 10 kΩ) ? Which values (1 MΩ) ?