CCM Pilot Study of future realizations of the kilogram

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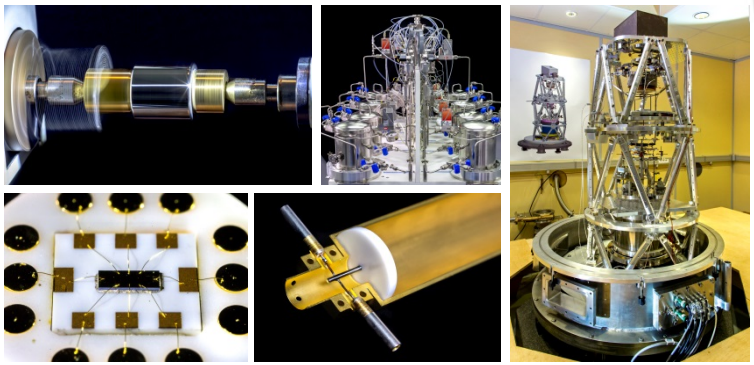
CCM

18-19 May 2017



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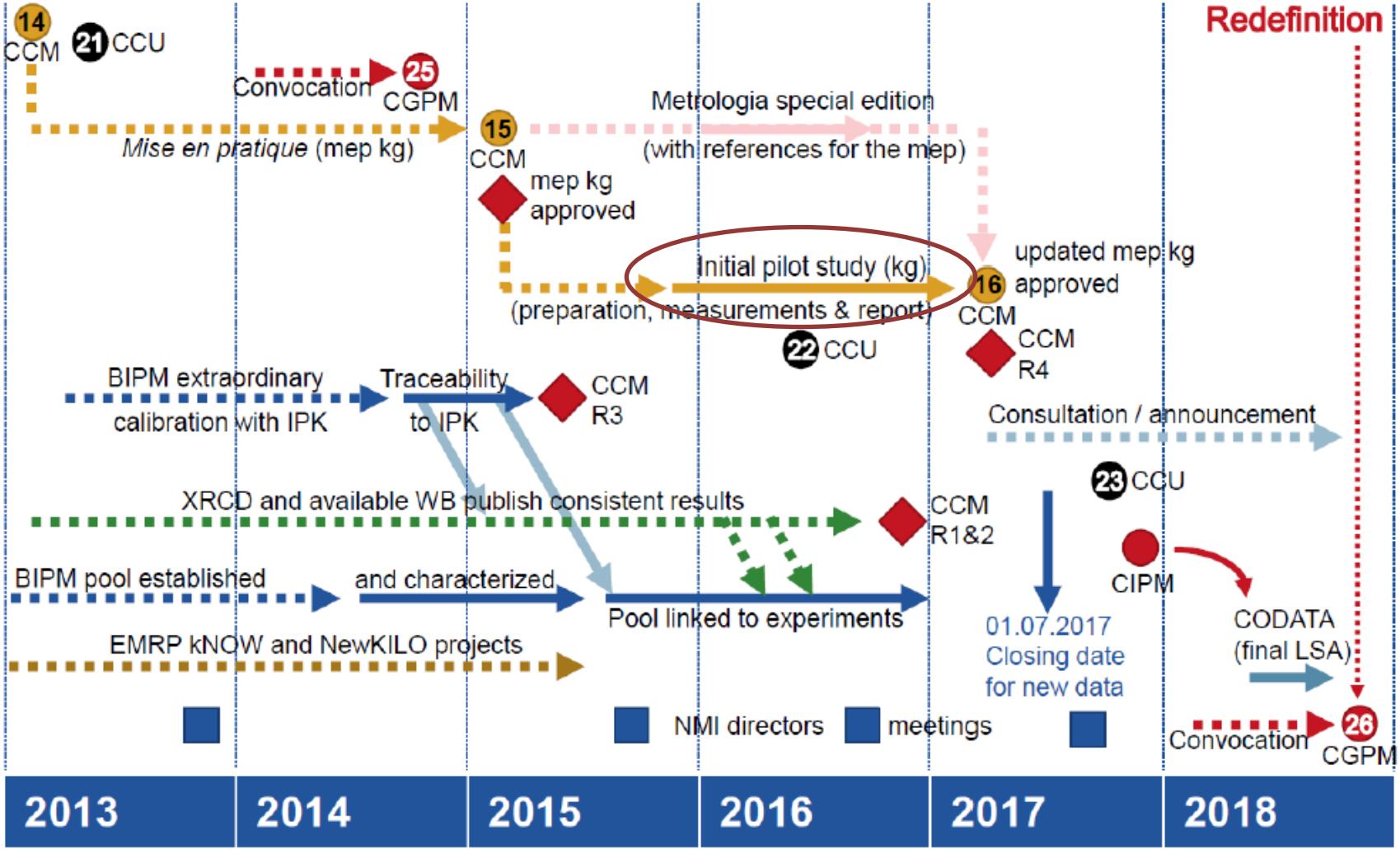
Joint CCM-CCU roadmap towards the redefinition



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Pilot Study: comparison of realizations of the kilogram

Objectives:

- test the uniformity of future kg realizations based on different realization experiments (Kibble balances, XRCD)
- test the continuity between the present and the future kg realizations
- provide recommendations for future key comparisons

Pilot laboratory: BIPM

Condition for participation: u_r (1 kg) < 2 x 10^{-7}, u < 200 µg

Participants: Kibble balances: LNE, NIST, NRC
AVO28 spheres: NMIJ, PTB

Technical Protocol: completed Nov 2015

Draft A report sent on 9 December 2016

Draft A-2 approved last week with some minor changes → Draft B very soon

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Pilot Study: travelling standards

Two sets of 1 kg travelling standards, to be provided by each participant

Set 1: **1 Pt-Ir standard**
1 optional standard (Pt-Ir, stainless steel, Si-sphere, none)

to be calibrated using realization experiment (Kibble balance, Avo sphere), under vacuum: test of the realization

using: $h = 6.626\ 070\ 040 \times 10^{-34}$ Js (CODATA 2014)

Set 2: **2 stainless steel standards**

to be calibrated in air, traceable to the realization experiment
test of the dissemination (incl. vacuum-air transfer and buoyancy correction)

Standards of Set 1 were compared at BIPM under vacuum, of Set 2 in air

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Pilot Study: travelling standards

	Set 1	Set 2	Method	Unc. for Set 1 / Set 2
LNE	1 Pt-Ir	2 st.st.	Kibble balance (in air)	140 µg / 140 µg
NIST	1 Pt-Ir 1 st.st.	2 st.st.	Kibble balance (NIST 4)	36 µg / 37 µg
NMIJ	2 Pt-Ir	2 st.st.	XRCD (AVO28-S5c)	24 µg / 26 µg
NRC	1 Pt-Ir	2 st.st.	Kibble balance	15 µg / 15 µg
PTB	1 Pt-Ir 1 ^{nat}Si sphere	2 st.st.	XRCD (AVO28-S8c)	19 µg / 19 µg

- **All travelling standards arrived at the BIPM between 25 March and 26 April 2016**

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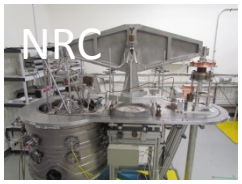
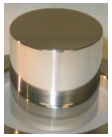
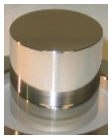
Pilot Study: principle of the comparison of kilogram realizations



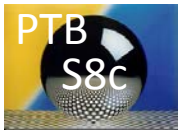
vacuum



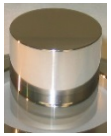
vac.

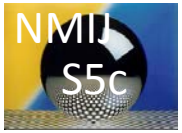


travelling standards

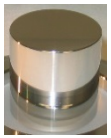


vac.

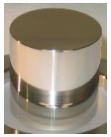




vac.

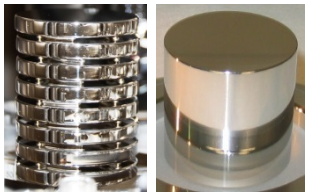


air

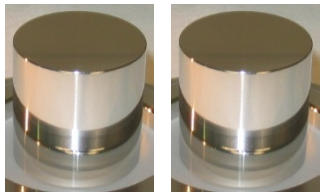


cal.

BIPM Pt-Ir sorption standards (vacuum)



vac.-air transfer



cal.

BIPM working standards (air)

IPK (Extraord. Cals. 2014)

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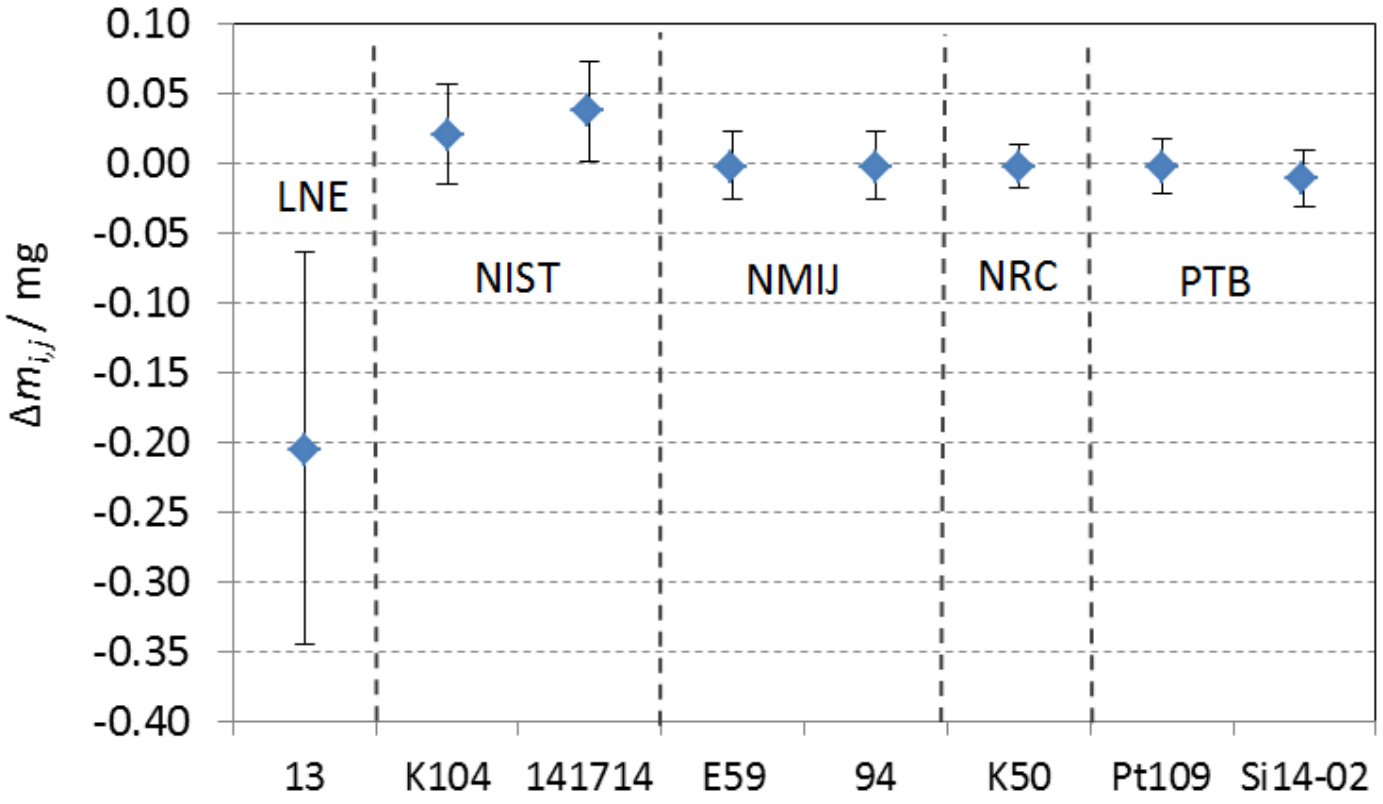
Results for standards of Set 1

$$\Delta m_{i,j} = m_{i,j}^{\mathrm{NMI}} - m_{i,j}^{\mathrm{BIPM}}$$



uncertainty includes:

- NMI calibration with primary method (dominating)
- transport (0.004 mg, exc. 141714: 0.021 mg)
- vacuum-air cycling (0.002 – 0.005 mg)

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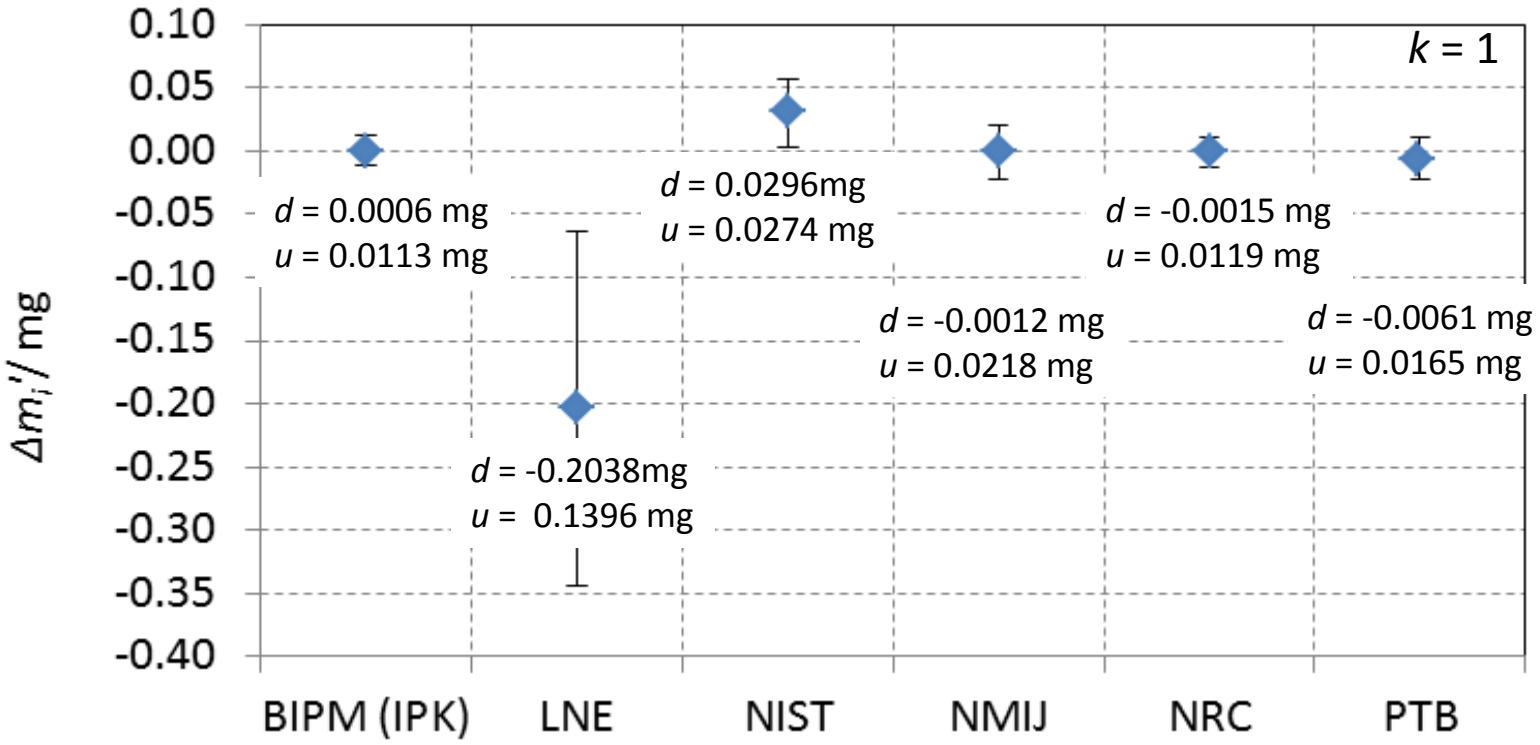
Results for standards of Set 1

Deviations from reference value (weighted mean of NMI results):



u (CRV) = 0.010 mg

Birge ratio = 0.90

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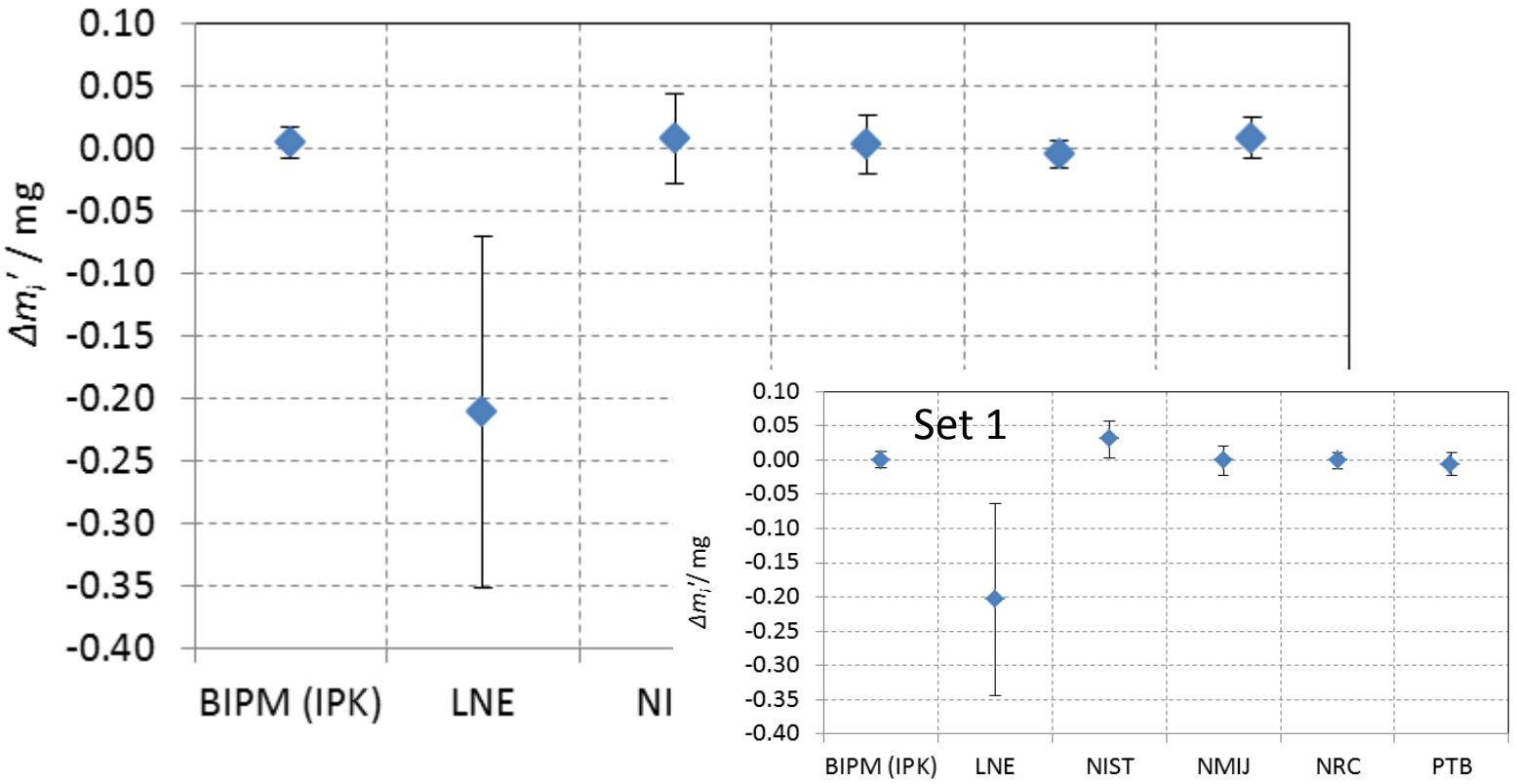
Results for standards of Set 2

Deviations from reference value (weighted mean of NMI results):



u (CRV) = 0.010 mg

Birge ratio = 0.80

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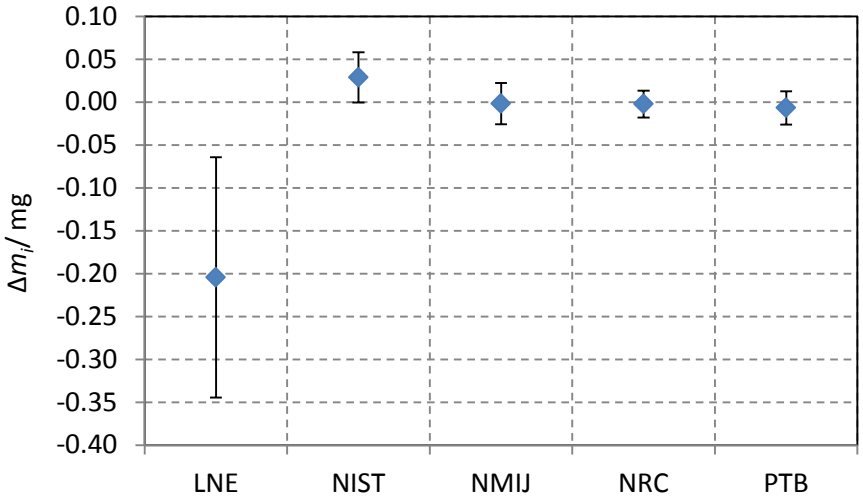
Comparison of mass calibration *versus* comparison of Planck constant

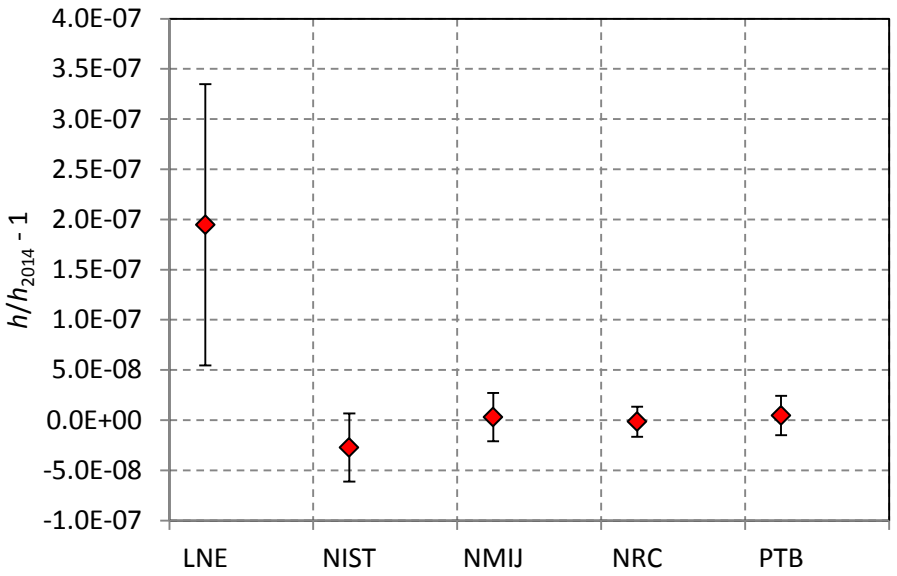
Calibrations of 1 kg standards



Results for the Planck constant and mass calibrations are highly consistent

Pilot Study results not dominated by behavior of travelling standards

Determinations of Planck constant during Pilot Study



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Pilot Study: Summary and Conclusions (I)

- Calibrations of 1 kg standards of Set 1 from the NIST, NMIJ, NRC and the PTB agree to within their standard uncertainties, the LNE is in agreement at the level of $k = 2$. The standard uncertainty of the weighted mean of the five laboratories is 0.010 mg.
- The weighted mean agrees with the BIPM calibration based on the IPK to within 0.001 mg.
- The calibrations of 1 kg standards of Set 2 from the NIST, NMIJ, NRC and the PTB agree to within their standard uncertainties, the LNE is in agreement at the level of $k = 2$. The standard uncertainty of the weighted mean of the five laboratories is 0.010 mg.
- The weighted mean of the calibrations of the standards of Set 2 agrees with the BIPM calibration based on the IPK to within 0.0045 mg.
- The result of the comparison of mass calibrations is highly consistent with the comparison of the determinations of the Planck constant carried out during this study.

Pilot Study: Conclusions (II)

- The mass calibrations (using h_{2014}) carried out by four participants in this study are consistent with relative standard uncertainties below 5 parts in 10^8 (0.050 mg). Two of these results have relative standard uncertainties not larger than 2 parts in 10^8.

- The values of the Planck constant (traceable to IPK) obtained by four participants during this study are consistent with relative standards uncertainties below 5 parts in 10^8. Two of these results have relative standard uncertainties not larger than 2 parts in 10^8.

- The conditions 1 and 2 of the CCM Recommendation G1 (2013) are fulfilled.

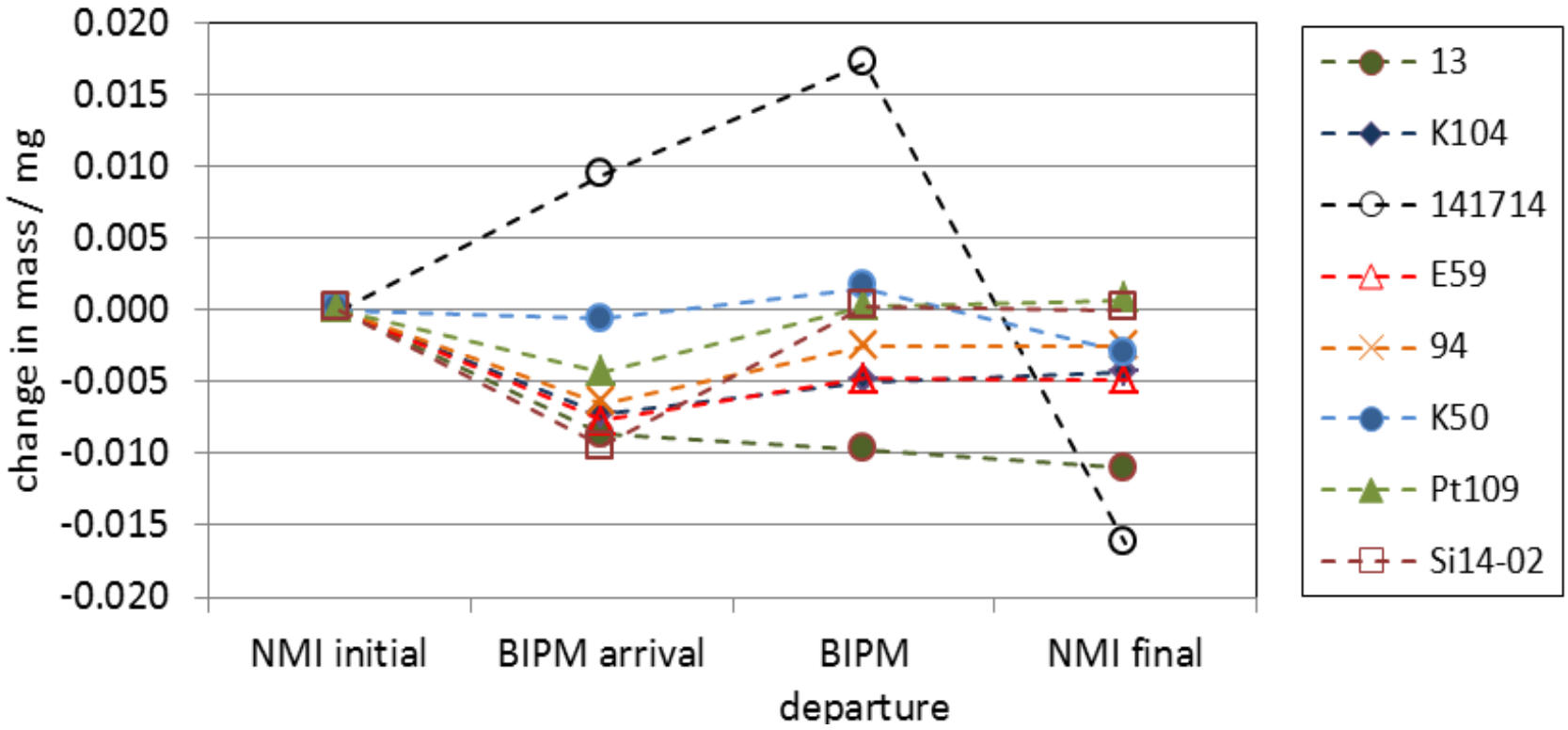
- Although the CCM has to make the final judgement, it is the opinion of the pilot that the procedures for the future realization and dissemination of the kilogram, as described in the *mise en pratique*, have been validated in accordance with the principles of the CIPM MRA (condition 4 of CCM Recommendation G1 (2013)).

Recommendations for future key comparisons

- Definition of a more rigorous approach for verifying the mass stability of the stainless steel standards (similar as for Set 1)
- Participants shall carry out a number of vacuum-air cycles to stabilize the mass and to estimate the related uncertainty
- The vacuum and air calibrations led to very similar results. Do we need to repeat both?

Stability of the travelling standards of Set 1

Calibrations traceable to IPK at NMIs and the BIPM



$$u_{\text{transport}} = \frac{1}{2}\left(\left|m_{\text{BIPM}}^{\text{arrival}} - m_{\text{NMI}}^{\text{initial}}\right| + \left|m_{\text{NMI}}^{\text{final}} - m_{\text{BIPM}}^{\text{departure}}\right|\right)$$

≈ 0.004 mg for all standards except 141714 (0.021 mg)

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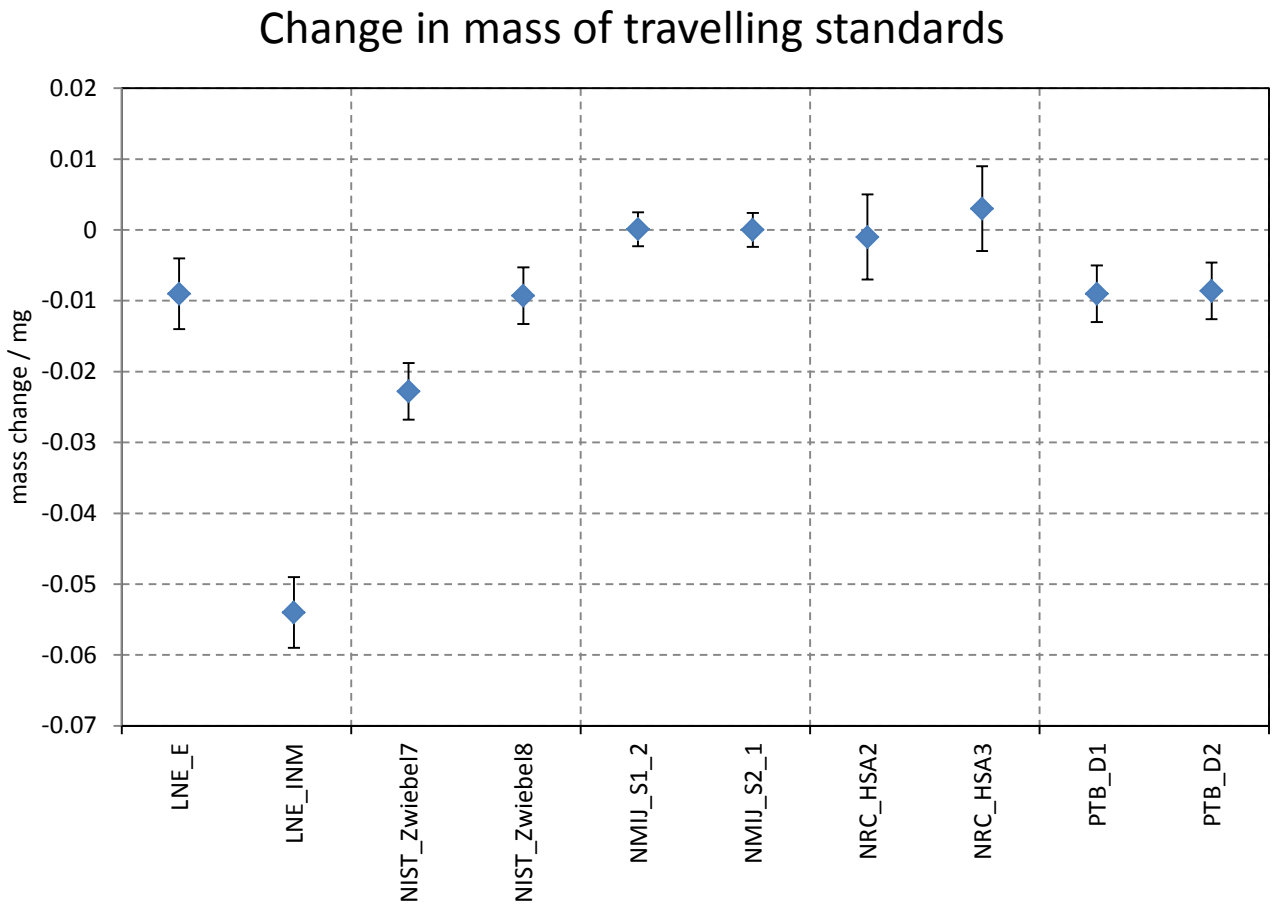
Stability of the travelling standards of Set 2



$$u_{\text{transport}} = \frac{1}{\sqrt{3}} |m_{\text{after}} - m_{\text{before}}|$$

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