News from the Working Group on Fluid Flow

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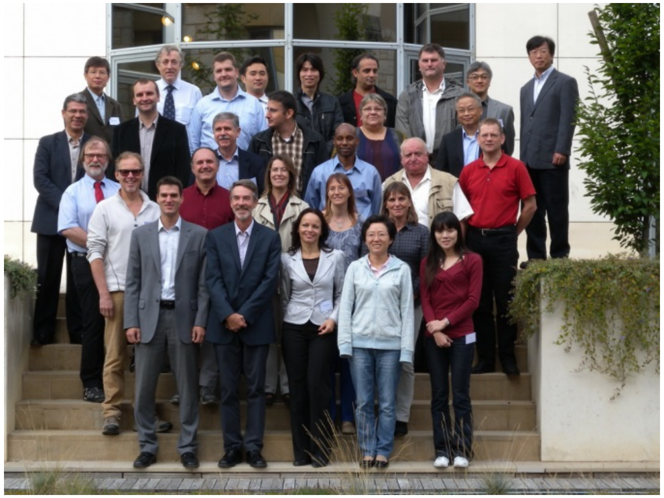
NIST Fluid Metrology Group
February 26, 2015

WGFF Meetings



September 18 and 19, 2013 at FLOMEKO, Poitiers, France

Chair: John Wright (NIST)
Vice Chair: Bodo Mickan (PTB)
Both since 2010

June 18 and 19, 2014 by teleconference, 16 participants (thanks Richard Davis)

April 13 and 14, 2015 at ISFFM, Washington D. C., USA

Global Update of Flow CMCs

RMO	Updated CMCs	New CMCs	Deleted CMCs
APMP	77	12	15
EURAMET	168	91	108
SIM	16	2	25

CMCs for New Measurands

- Water speed
- Cryogenic liquid flow (liquid N2, surrogate for LNG)

WGFF Guidance Documents

- *WGFF Guidelines for CMC and Calibration Report Uncertainties*, completed October 21, 2013, posted on WGFF web page
- *Review Protocol for Fluid Flow CMCs*, completed September, 2014
- *WGFF Comparison Calculations*, including KC pass / fail / inconclusive criteria (in process)

Review Protocol for Fluid Flow CMCs

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5.1 General criteria ....
5.2 Specific criteria ....

6. **REFERENCES** ....

Three levels of scrutiny for 4 measurands (volume, gas flow, liquid flow, air speed)

Table 4 – Gas flow CMC review criteria

Instrument/method	Detailed uncertainty analysis review and consistent comparison results required	Consistent comparison results required	Internal documents, publications, or other proof required
Piston prover	< 0.1 %	0.1 % up to 0.25 %	> 0.25 %
Bell prover	< 0.1 %	0.1 % up to 0.25 %	>0.25 %
PVTt or gravimetric standard	< 0.1 %	0.1 % up to 0.25 %	> 0.25 %
Secondary standard flow devices (i.e. turbine,coriolis, ultrasonic).	< 0.15 %	0.15 % up to 0.3 %	> 0.3 %

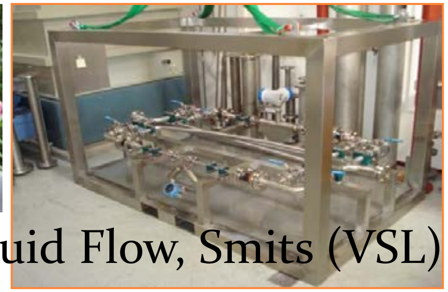
Completed Comparisons

Comparison	Measurand	Date published
CCM.FF-K4.2.2011	Liquid volume (100 μL)	Feb 2013
CCM.FF-K5.a.2	Natural gas flow	Feb 2013
CCM.FF-K6.2011	Low Pressure Gas Flow	May 2014

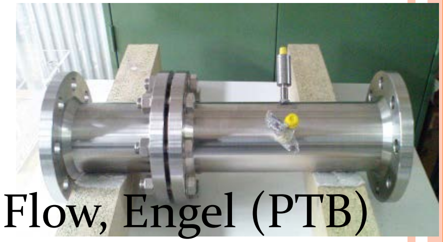
Planned or In Process Comparisons

Comparison	Measurand
CCM.FF-K2.1.2011	Hydrocarbon liquid flow, Testing complete
CCM.FF-K2.2.2011	Hydrocarbon liquid flow, Protocol
CCM.FF-K5.2011	High pressure gas flow, Planned
CCM.FF-K4.1.2011	Volume (100 mL and 20 L), Draft B
CCM.FF-K1.2015?	**Water flow, For CCM approval**

WGFF Status of Key Comparisons

K2.1: Hydrocarbon Liquid Flow, Smits (VSL)

K1: Water Flow, Engel (PTB)


K3: Air Speed, Care (LNE), Mueller (PTB)


K2.2: Hydrocarbon Liquid Flow, Shimada (NMIJ)


K4.2: Volume, Batista (IPQ)

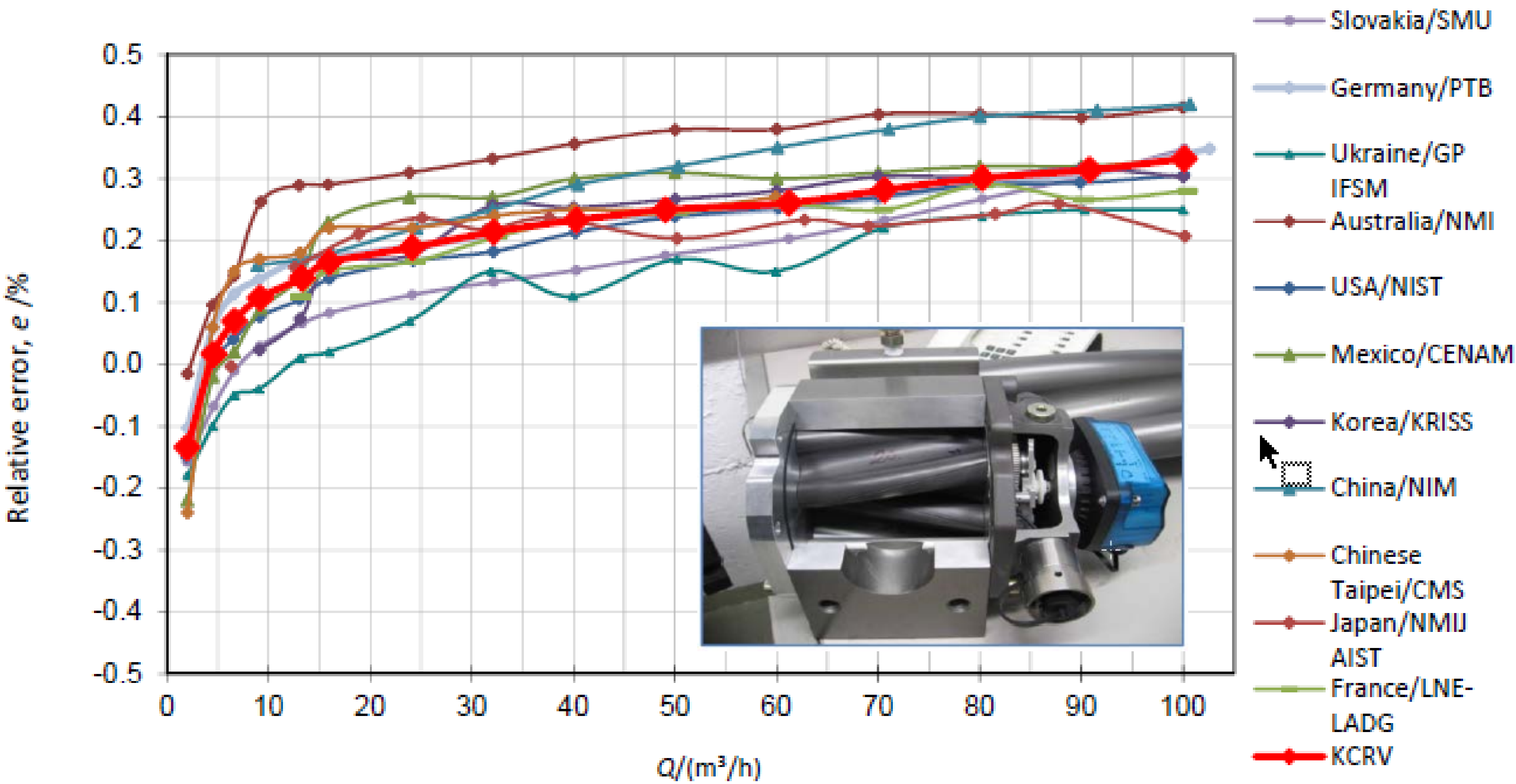

K4.1: Volume, Arias (CENAM)


K5: High Pressure Gas Flow, Mickan (PTB)


K6: Low Pressure Gas Flow, Benkova (CMI) & Makovnik (SMU)

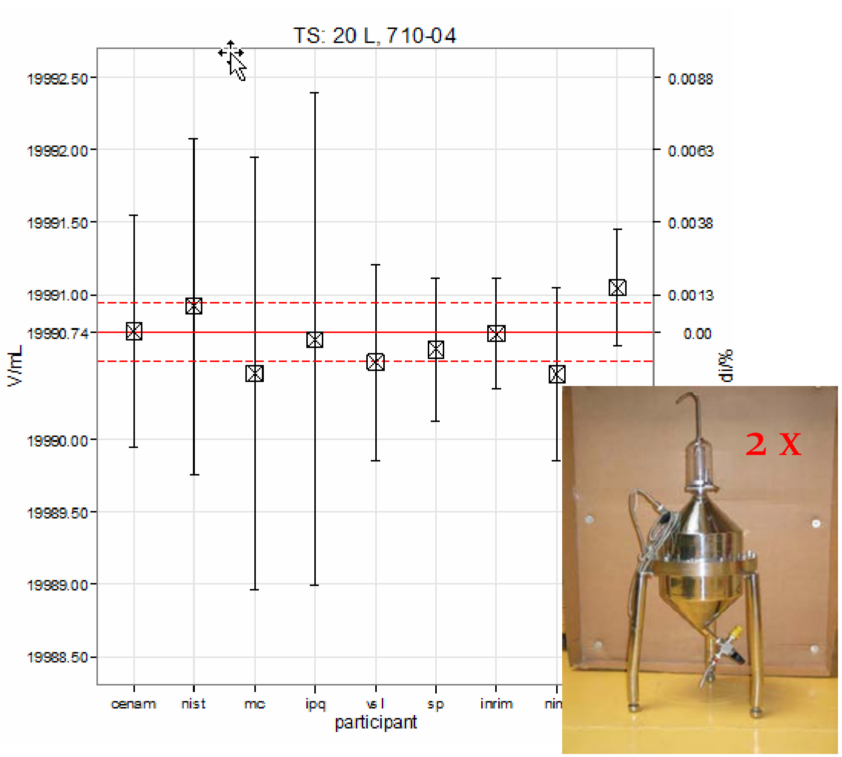
CCM.FF-K6.2011: Low Pressure Gas Flow, 2 to 100 m³/h, Benkova (CMI) & Makovnik (SMU)

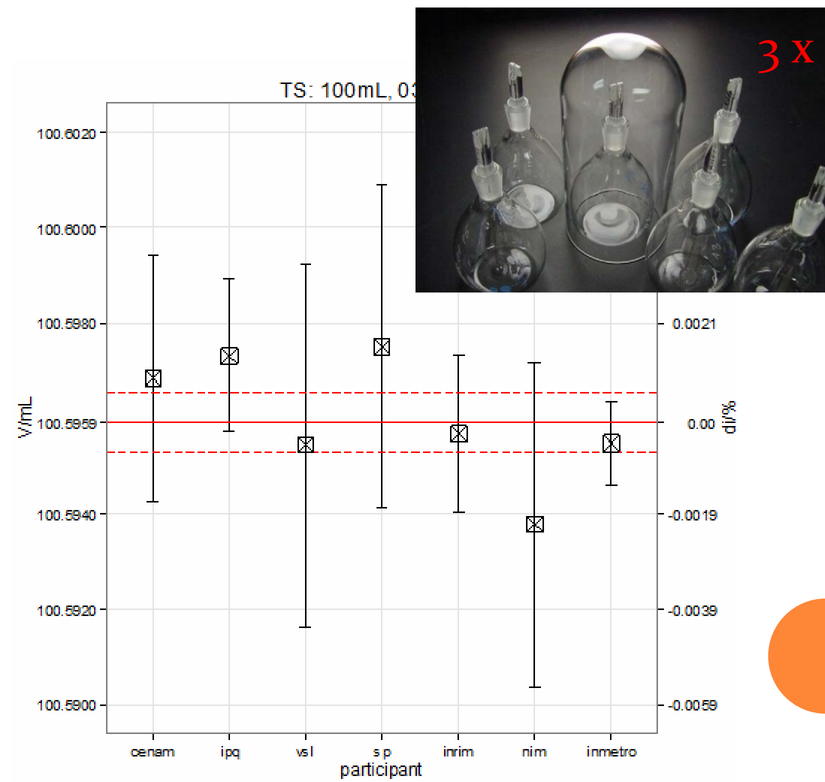
- Posted May, 2014
- Used a uncertainty weighted Calibration Reference Curve
- Linked to EURAMET.M.FF-K6 (same TS and Pilot labs)
- Clear statements about whether results support CMCs



CCM.FF-K4.1.2011: Liquid Volume 100 mL and 20 L, Arias (CENAM)

- Draft B submitted December 2014, MC results in a separate report
- KEBS results were not taken into account for computing KCRV but are included in an Appendix





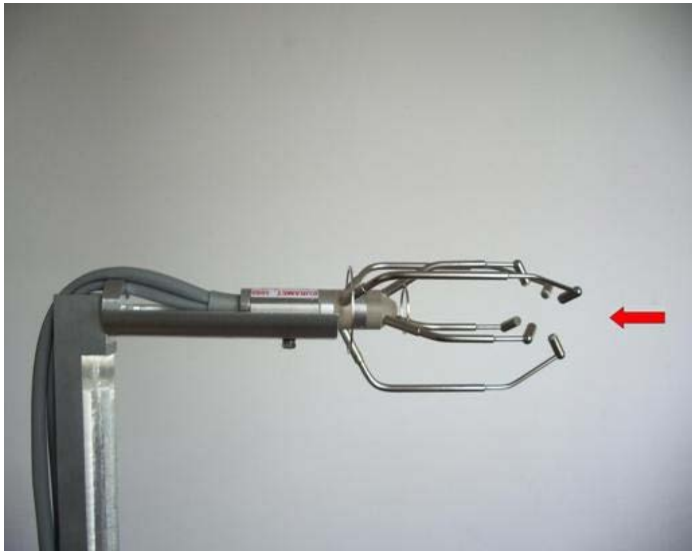
CCM.FF-K2.1.2011: Liquid Flow 10 to 60kg/min, Smits (VSL)

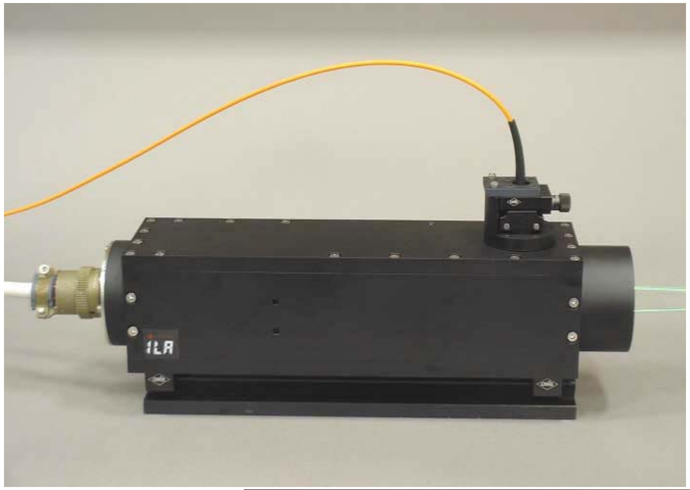
- Micromotion and Krohne coriolis meters
- Merging hydrocarbon liquid and water
- Preliminary tests show TS stability of < 0.03 %
- Started August 2013, testing completed last week
- If TS performs well, will be used for proficiency tests (after KC conclusion)

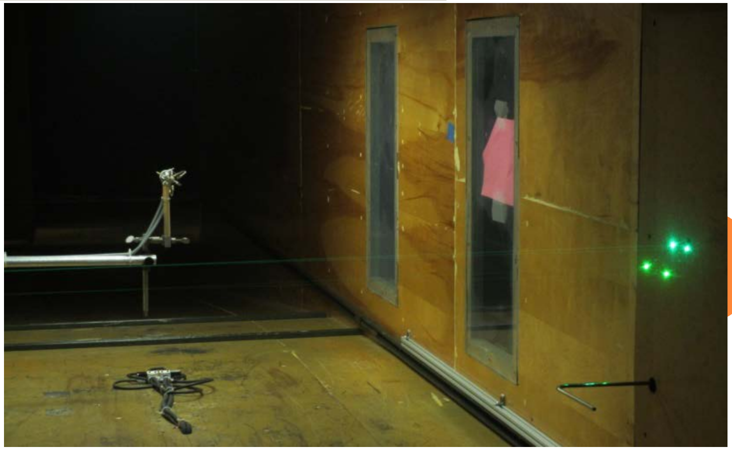
At BEV

CCM.FF-K3.2011: Air Speed, 0.5 to 40 m/s Care (LNE-CETIAT) and Mueller (PTB)

- Started July 2013, 9 of 10 labs done
- Comparison of spinning disks, assessment of labs' handling of blockage effects

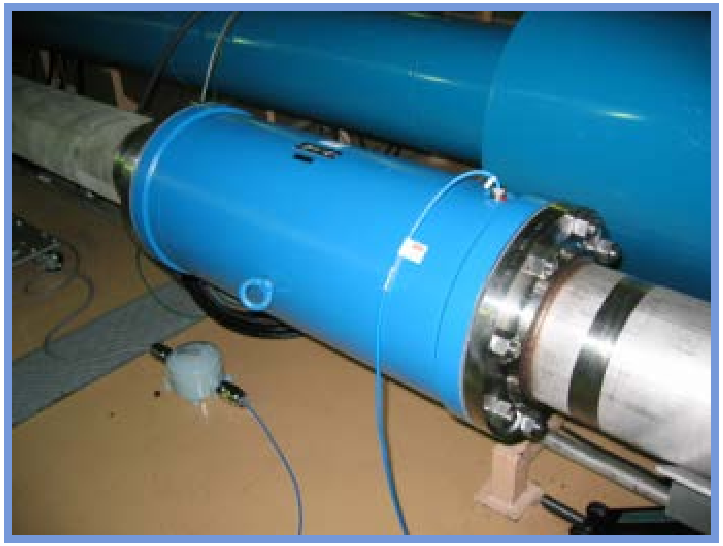


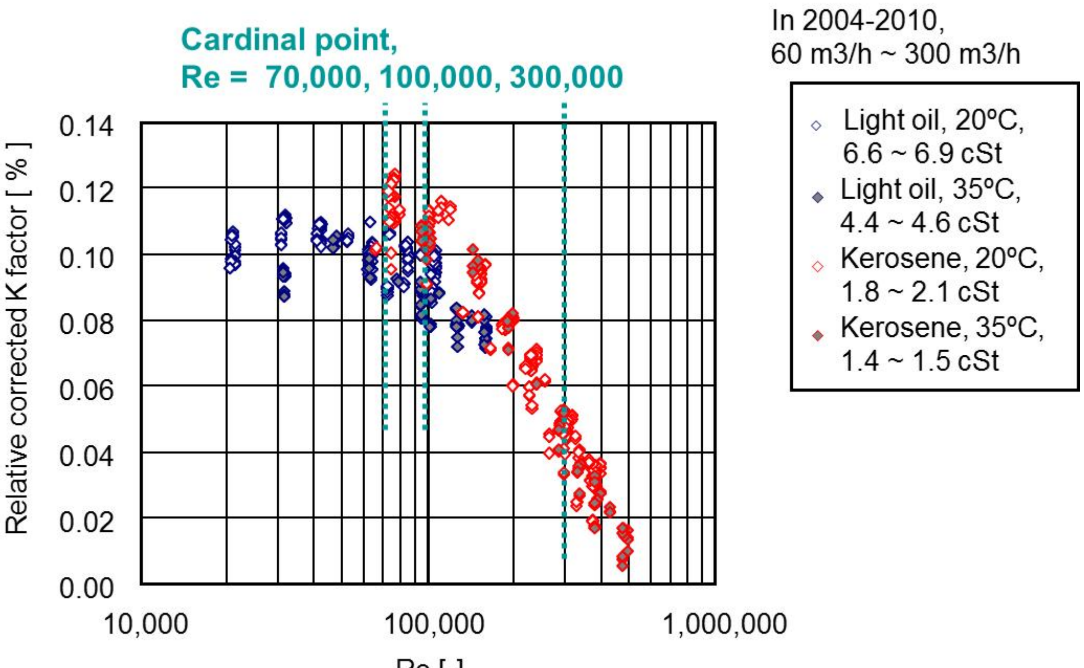


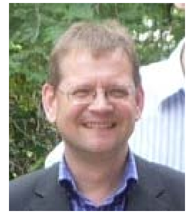


CCM.FF-K2.2.2011: Hydrocarbon Liquid Flow, 13 to 67 kg/s, Shimada (NMIJ))

- Positive displacement meter, hydrocarbon liquid only
- Preliminary tests show TS stability of < 0.03 %
- Same TS used in APMP comparison







K5 High Pressure Gas Flow

Bodo Mickan (PTB)

2 Turbine meters and 6 critical flow venturis

Merging FF-K5a (natural gas) and K5b (air and nitrogen)

Protocol due July 2014

K1 Water Flow (requesting CCM approval)

Rainer Engel (PTB)

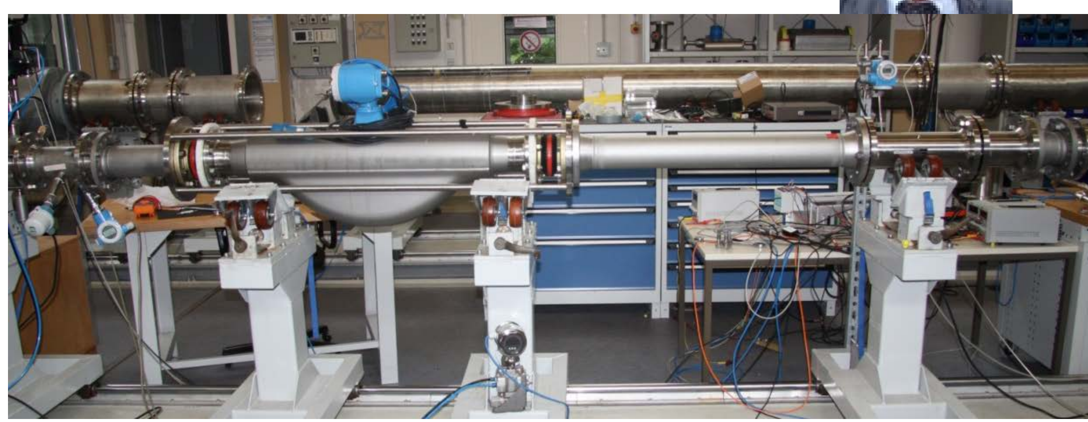
Turbine + Coriolis meter

30 m^3/h to 200 m^3/h

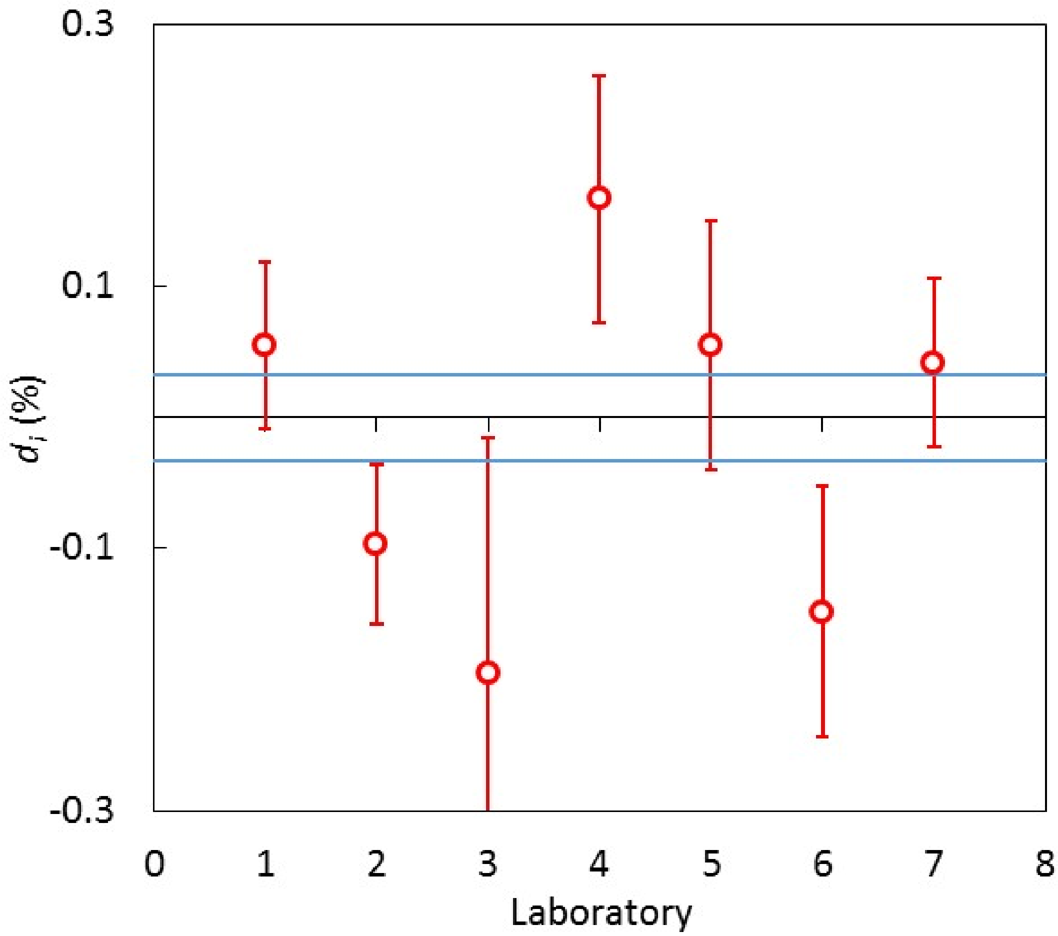
PTB, TUV NEL, VSL, SP,

CENAM, NIST, NMIJ,

KRISS, ITRI, NIM, UME



Pass / Fail / Inconclusive?



WGFF COMPARISON CALCULATIONS

Purpose of a KC: do the comparison results support each participant's uncertainty claims for $u_{\mathrm{LAB}\,i}$?

standard uncertainty of the reported value from the participating laboratory

$$u_{xi} = \sqrt{u_{\mathrm{LAB}\,i}^2 + u_{\mathrm{TS}}^2 + \frac{s^2}{n}}$$

transfer standard uncertainty

$$u_{\mathrm{TS}} = \sqrt{u_{\mathrm{drift}}^2 + u_{\mathrm{T}}^2 + u_{\mathrm{P}}^2 + u_{\mathrm{prop}}^2 + \cdots}$$

PRESENT TOOLS

degree of equivalence for laboratory i $$d_i = x_i - x_{\mathrm{CRV}}$$

standardized degree of equivalence $$E_{n\,i} = \frac{d_i}{U(d_i)}$$

- $|E_n| \leq 1$ indicates that the agreement is within the 95 % confidence level uncertainty expectations of the lab and comparison.
- $|E_n| > 1.2$ indicates that the agreement is outside of uncertainty expectations.
- $|E_n|$ values between 1 and 1.2 are treated as a warning level to the participant.

A Review of CIPM and RMO Comparisons…

$^{u_{\mathrm{TS}}}/_{u_{\mathrm{LAB}_i}}$ is sometimes > 5!

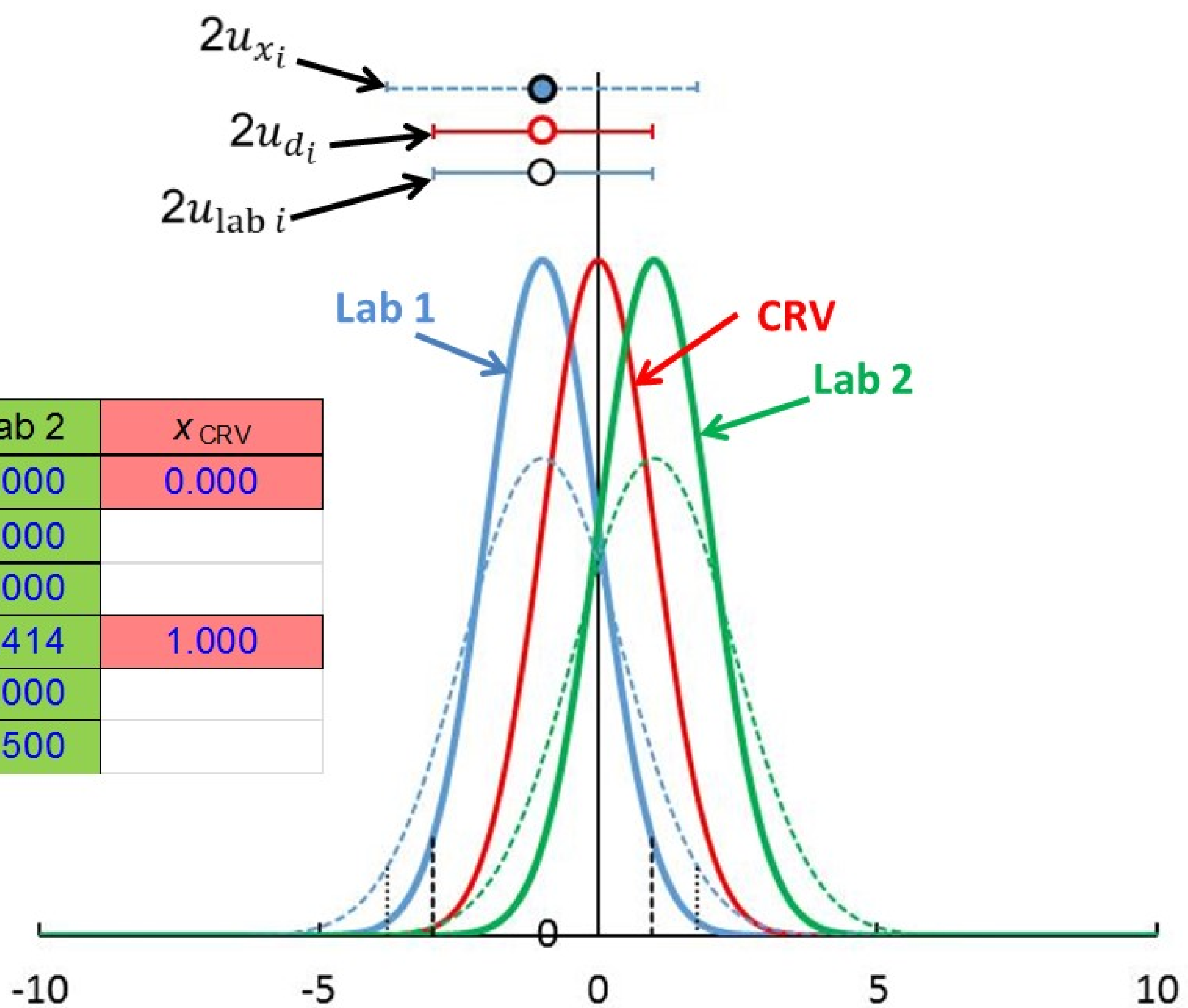
Problem Statement

A large transfer standard uncertainty (u_{TS}) leads to inconclusive comparison results, even when $|E_n| < 1$.

Some graphical examples for a bilateral comparison help to explain…

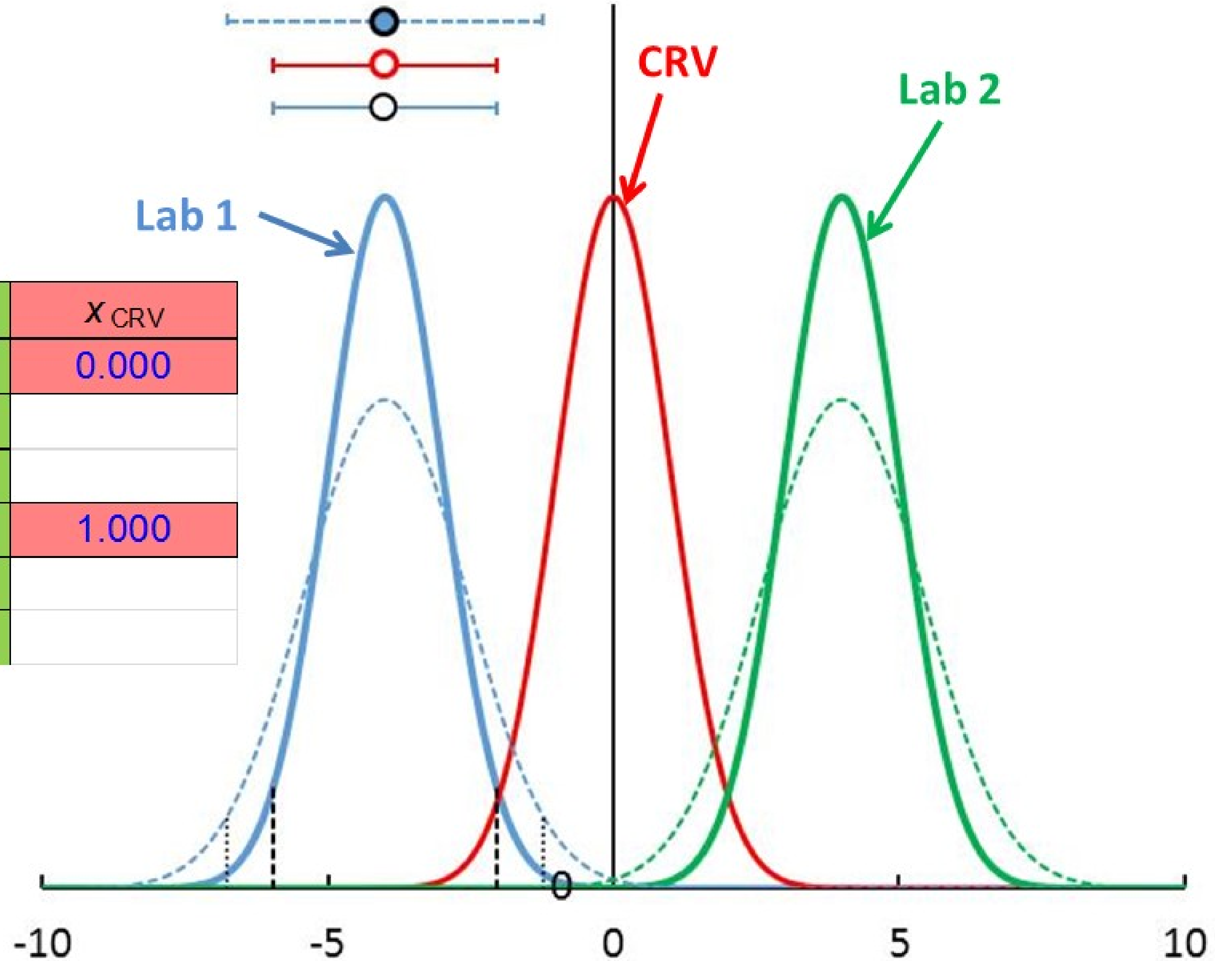
$u_{\mathrm{TS}}/u_{\mathrm{LAB}\ i} = 1$, CLEAR EQUIVALENCE

	Lab 1	Lab 2	x_{CRV}
x_i	-1.000	1.000	0.000
$u_{\mathrm{lab}\ i}$	1.000	1.000	
u_{TS}	1.000	1.000	
$u_{x\ i}$	1.414	1.414	1.000
$u_{d\ i}$	1.000	1.000	
En_i	-0.500	0.500	



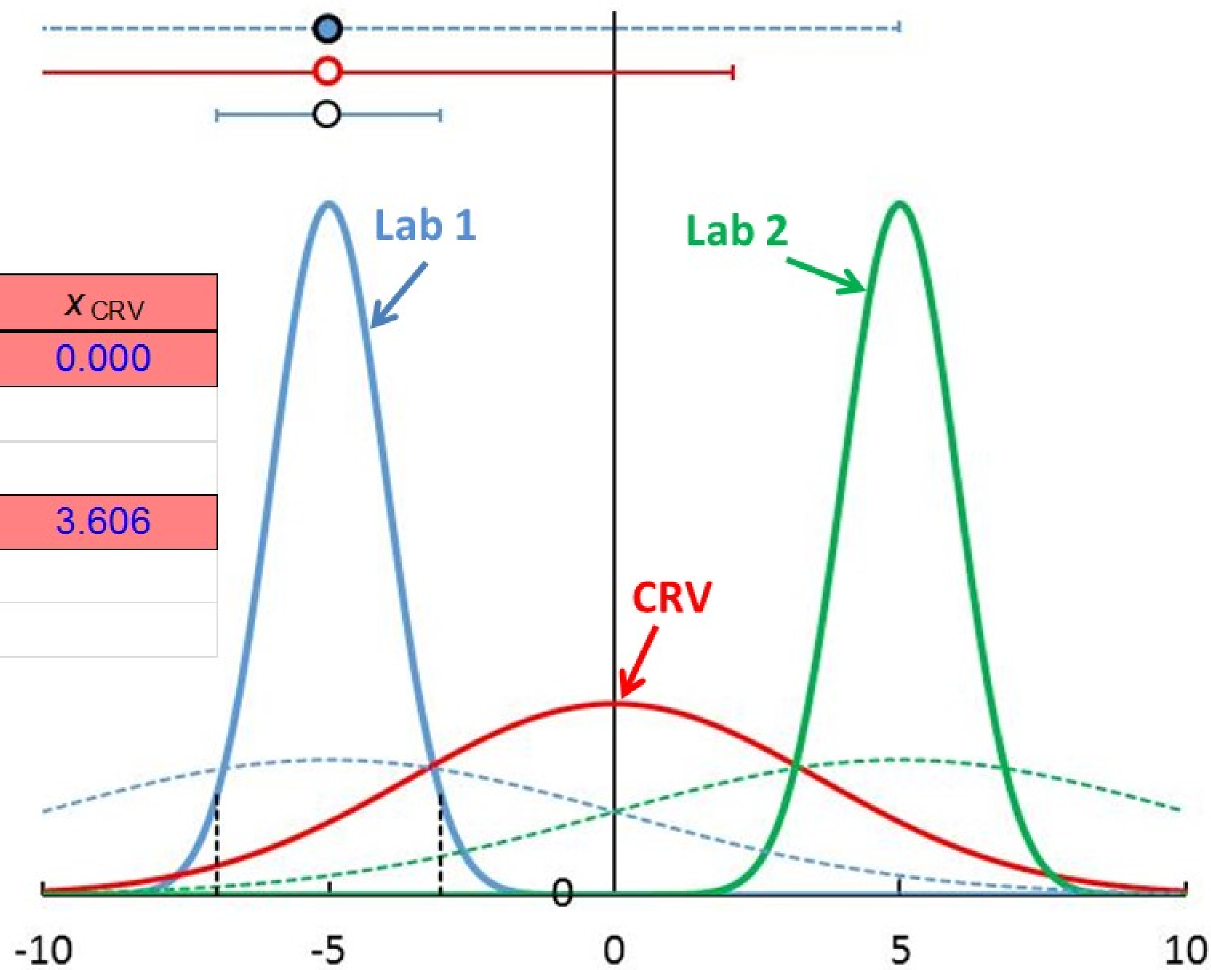
$u_{\mathrm{TS}}/u_{\mathrm{LAB}\ i} = 1$, CLEAR *NON*-EQUIVALENCE

	Lab 1	Lab 2	x_{CRV}
x_i	-4.000	4.000	0.000
$u_{\mathrm{lab}\ i}$	1.000	1.000	
u_{TS}	1.000	1.000	
$u_{x\ i}$	1.414	1.414	1.000
$u_{d\ i}$	1.000	1.000	
En_i	-2.000	2.000	

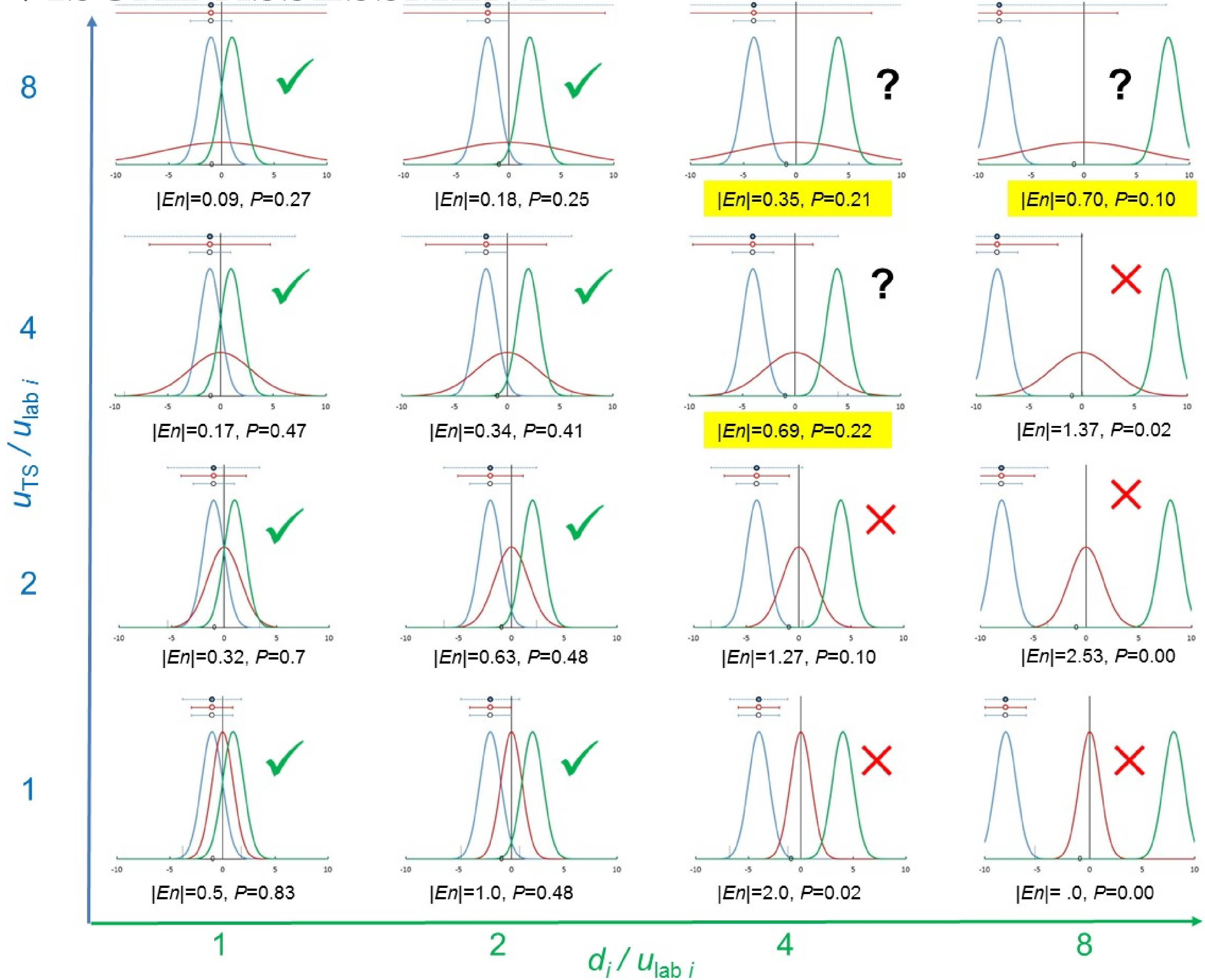


$u_{\mathrm{TS}}/u_{\mathrm{LAB}\ i} \gg 1$, INCONCLUSIVE

	Lab 1	Lab 2	x_{CRV}
x_i	-5.000	5.000	0.000
$u_{\mathrm{lab}\ i}$	1.000	1.000	
u_{TS}	5.000	5.000	
$u_{x\ i}$	5.099	5.099	3.606
$u_{d\ i}$	3.606	3.606	
En_i	-0.693	0.693	



Visual assessment



Explanatory Power of the Test

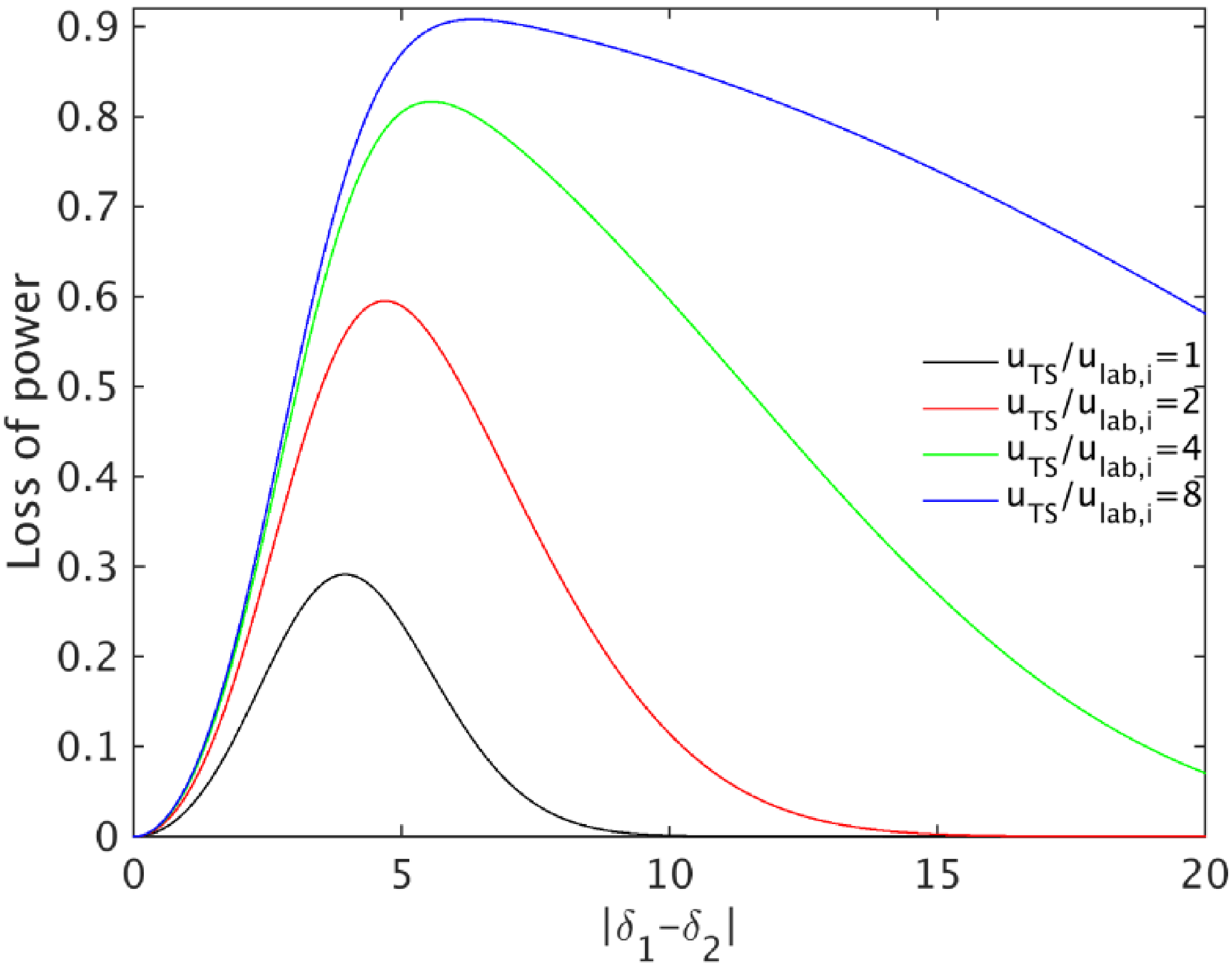
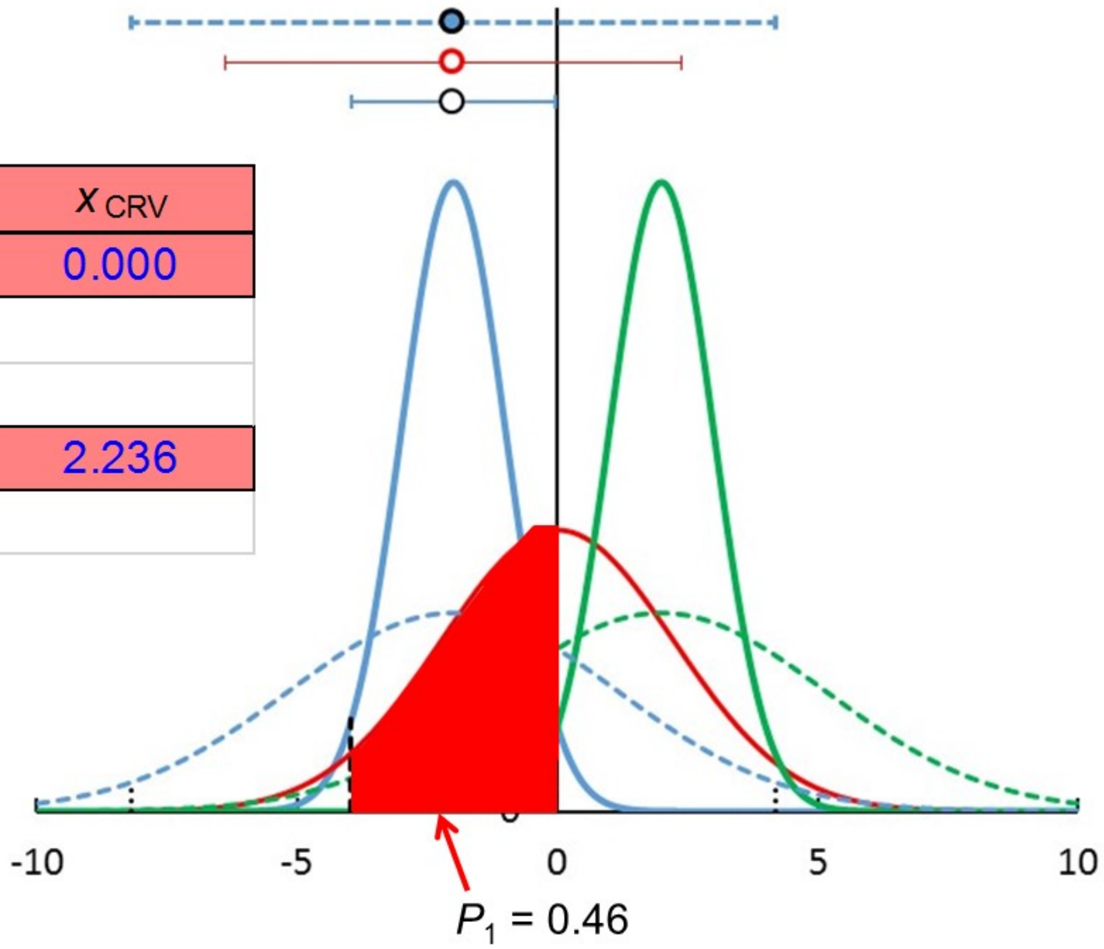


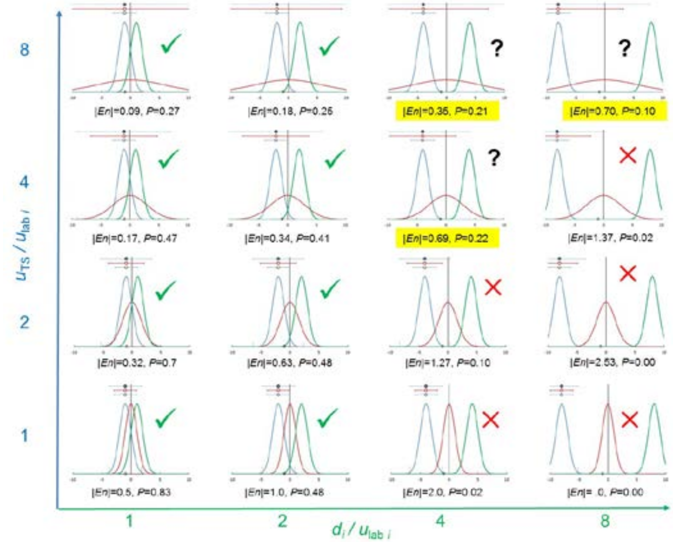
Figure 6. Loss in explanatory power in a bilateral comparison as a function of $|\delta_1 - \delta_2|$ for various $u\mathrm{TS} / u_{\mathrm{lab}\ i}$ values where the uncertainties quoted by the two laboratories are assumed to be equal.

Coverage Probability, P_i

	Lab 1	Lab 2	x_{CRV}
x_i	-2.000	2.000	0.000
$u_{\text{lab } i}$	1.000	1.000	
u_{TS}	3.000	3.000	
$u_{x\,i}$	3.162	3.162	2.236
En_i	-0.447	0.447	



BEHAVIOR OF $|En_i|$ AND P_i



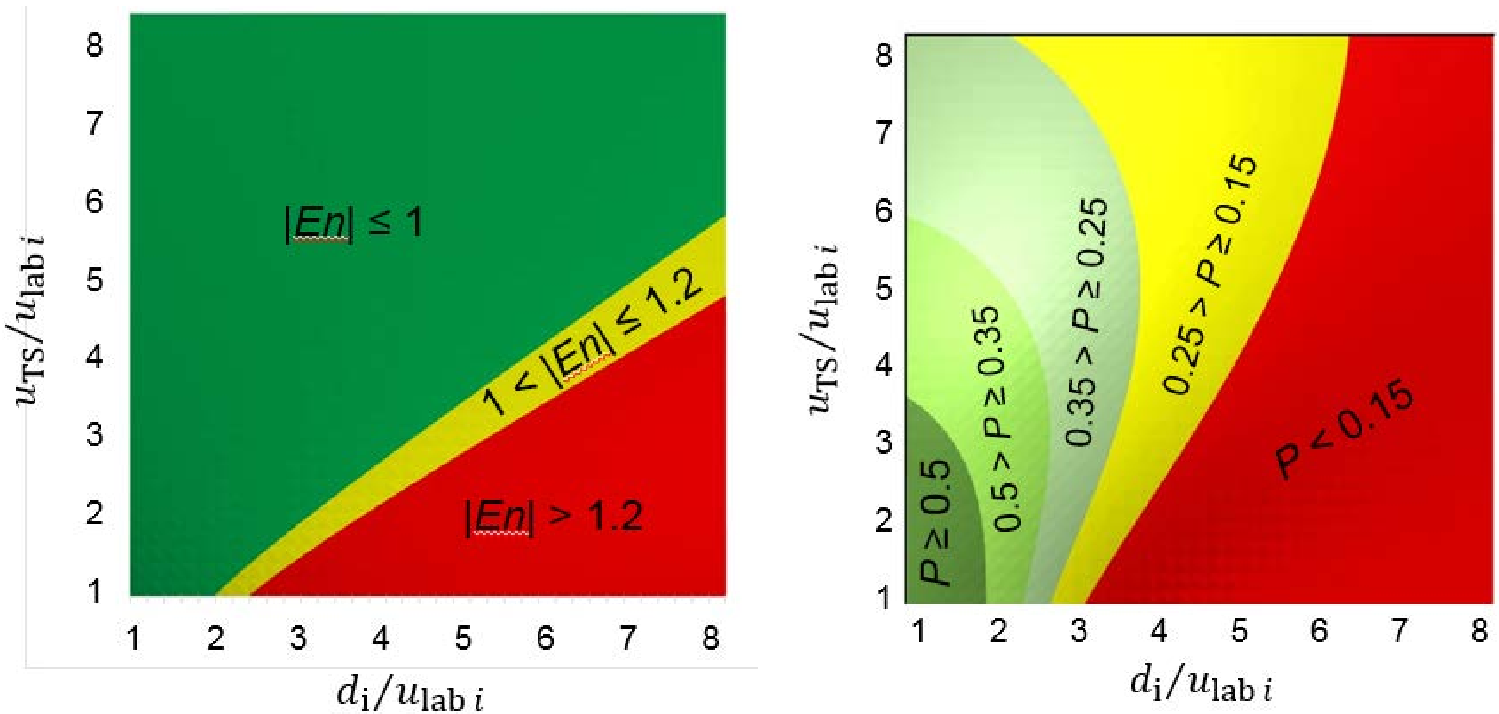


Figure 10. Contour plots of $|En_i|$ and P_i for $d_{\mathrm{i}}/u_{\mathrm{lab}\ i}$ and $u_{\mathrm{TS}}/u_{\mathrm{lab}\ i}$ ranging from 1 to 8.

Tested 3 proposed Criteria…

Criteria "B":

1. Participant i passes if $|d_i/(2u_{\text{lab }i})| \leq 1$ or $P_i \geq 0.5$,
2. fails if $|En_i| > 1$, and
3. the comparison results are inconclusive for participant i if $|d_i/(2u_{\text{lab }i})| > 1$ or $P_i < 0.5$ and $|En_i| \leq 1$.
4. Average P_i and $|En_i|$ for multiple set points.

Behaves in the same manner as the visual assessment

Thank You
Questions?