NIST-PTB bilateral comparison, GW detectors calibration plan

NIST, PTB, LIGO Hanford

06/13/2023

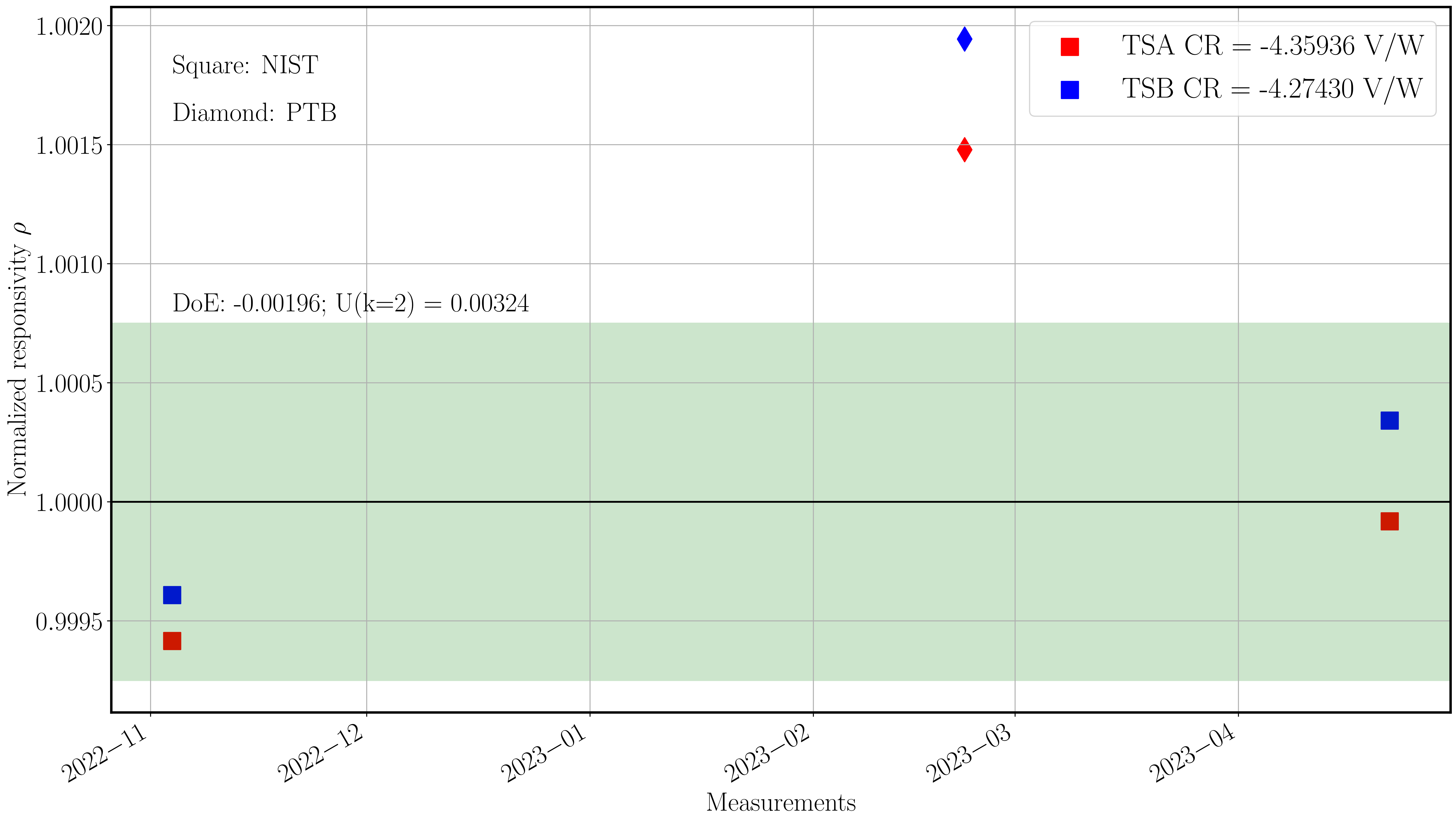
Agenda

- NIST-PTB bilateral study, 2022-2023
  - Calculation of consensus responsivity and bilateral DoE (Matt Spidell's spreadsheet)
  - NEWRAD conference in September 2023
  - Potential publication
- Implementation of the calibration subway map

Bilateral comparison study

- Matt Spidell prepared a spreadsheet to calculate the consensus responsivity and the Degree of Equivalence
- Modified Matt Spidell's spreadsheet to include
    - Values from the second round measurement at NIST
    - Uncertainty of the pilot lab in calculation of $u_{rel}(\Delta_{i,j})$ in accordance to the following document by BIPM: https://www.bipm.org/documents/20126/30126060/CCPR-G2+(rev.+4)+Guidelines+for+CCPR+key+comparison+report+preparation/ad4d6e1a-bbdb-e272-7d37-73ac80005805

Bilateral results



Previous bilateral comparison
M. Slidell, et al.,
Metrologia **58** (2021) 055011

100 mW: DoE = -0.07% U (k=2)= 0.91 %
300mW : DoE = -0.23% U (k=2)= 0.91 %

Composite: DoE= -0.15% U (k=2) = 0.87 %

NEWRAD, 2023

- Abstract has been accepted for oral presentation

Calibrating the global network of gravitational wave observatories via laser power calibration at NIST and PTB.

D. Bhattacharjee[1], R. L. Savage[2], S. Karki[3], A. Sanchez[2], F. Llamas[4], J. Betzwieser[5], J. Lehman[6], M. Spidell[6], M. Stephens[6], S. Kück[7], H. Lecher[7], M. López[7], L. Rolland[8], P. Lagabbe[8], D. Chen[9], R. Bajpai[9], and S. Fujii[10]

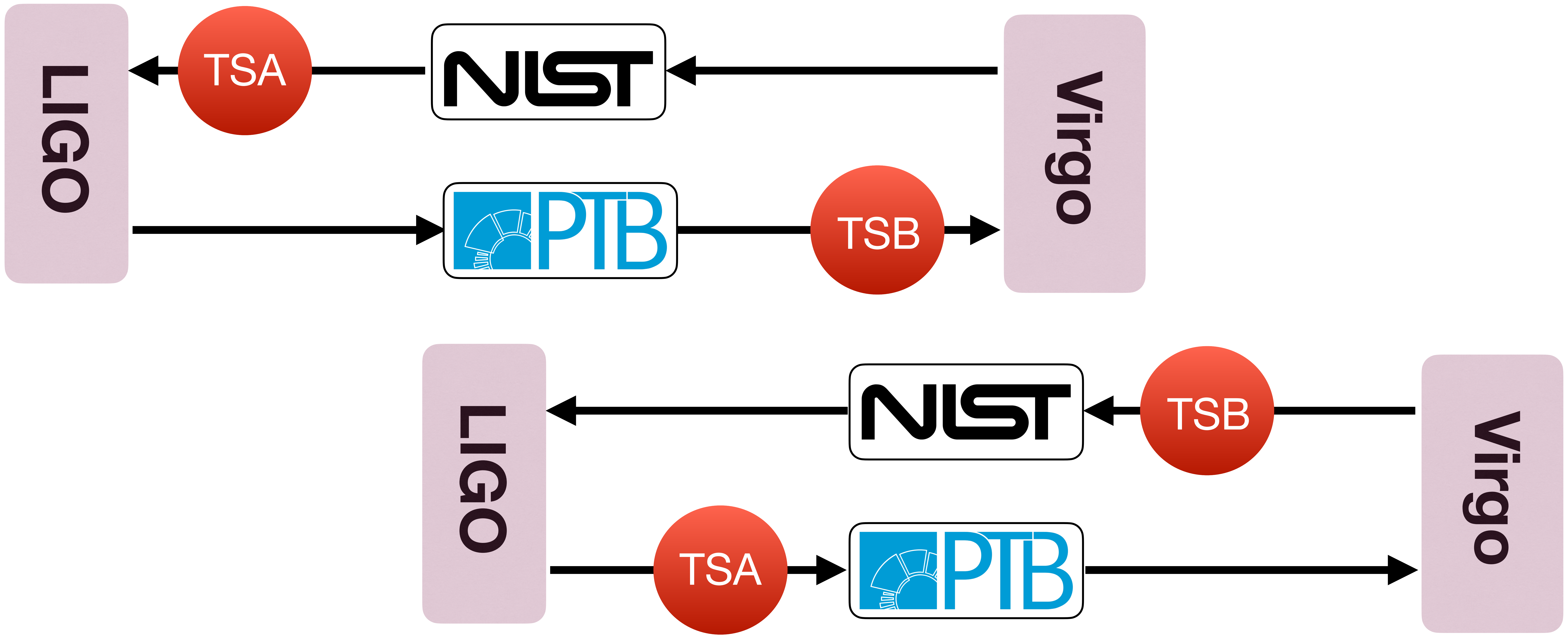
[1]Kenyon College, Gambier, USA, [2]LIGO Hanford Observatory, Richland, USA, [3]Missouri University of Science and Technology, Rolla, USA, [4]University of Texas Rio Grande Valley, Brownsville, USA, [5]LIGO Livingston Observatory, Livingston, USA, [6]National Institute of Standards and Technology, Boulder, USA, [7]Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany, [8]Laboratoire d'Annecy de Physique des Particules, Annecy, France, [9]National Astronomical Observatory of Japan, Mitaka, Japan, [10]Institute for Cosmic Ray Research, Kashiwa, Japan

Corresponding e-mail address: bhattacharjee1@kenyon.edu

DCC link: https://dcc.ligo.org/LIGO-G2300653/public

Calibration subway map

Both transfer standards currently at LIGO Hanford



Modification to the spreadsheet

From the document

For each NMI i for each lamp j, the relative difference $\Delta_{i,j}$ between NMI measurement (as an average of two rounds) and Pilot measurement is given by,

$$\Delta_{i,j} = \frac{\bar{E}_{i,j}}{E^{\mathrm{P}}_{i,j}} - 1 \quad (4)$$

and its uncertainty by

$$u(\Delta_{i,j}) = \sqrt{u_{\mathrm{rel}}^{2}(\bar{E}_{i,j}) + u_{\mathrm{rel}}^{2}(E^{\mathrm{PR}}_{i,j}) + u_{\mathrm{rel,add}}^{2}(E_{i,j})}. \quad (5)$$

where $\boldsymbol{u_{\mathrm{rel,add}}(E_{i,j})}$ is an additional uncertainty in the comparison of lamp j of NMI i, arising from those components such as changes of the artifact due to transportation (if identified) and different measurement conditions between Pilot and participants that affected comparison results (if applicable) – often related to characteristics of the artifacts.

From the spreadsheet

$\Delta_{i,j} = 0;\ u(\Delta_{i,j}) = 0.1061\ \%$ for NIST

$\Delta_{i,j} = 0.00181;\ u(\Delta_{i,j}) = 0.12476\ \%$ for PTB (TSA)

$\Delta_{i,j} = 0.00210;\ u(\Delta_{i,j}) = 0.12075\ \%$ for PTB (TSB)

$\bar{E}^{P}_{i,j} = -4.35572$ V/W for TSA; $\bar{E}^{P}_{i,j} = -4.27073$ V/W for TSB

$\bar{E}_{i,j} = -4.3636$ V/W for TSA; $\bar{E}_{i,j} = -4.27970$ V/W for TSB

$u_{rel,add} = 0.001\ \%$

$u_{rel}(E^{PR}_{i,j}) = 0.075\ \%$ **This term added for calculating $u(\Delta_{i,j})$**

$u_{rel}(\bar{E}_{i,j}) = 0.075\ \%$ for NIST

$u_{rel}(\bar{E}_{i,j}) = 0.09969\ \%$ for PTB (TSA)

$u_{rel}(\bar{E}_{i,j}) = 0.09946\ \%$ for PTB (TSB)

LIGO-G2301163

Δ_{KCRV}

From the document

The KCRV is calculated using weighted mean with cut-off. The cut-off value $u_{\text{cut-off}}$ is calculated by

$$u_{\text{cut-off}} = \text{average}\{u_{\text{rel}}(\bar{E}_i)\} \quad \text{for} \quad u_{\text{rel}}(\bar{E}_i) \le \text{median}\{u_{\text{rel}}(\bar{E}_i)\} \quad ; i = 0 \text{ to } N \tag{12}$$

The reported uncertainty $u_{\text{rel}}(\bar{E}_i)$ of each NMI i is adjusted by the cut-off,

$$\begin{aligned} u_{\text{rel,adj}}(\bar{E}_i) &= u_{\text{rel}}(\bar{E}_i) \quad \text{for} \quad u_{\text{rel}}(\bar{E}_i) \ge u_{\text{cut-off}} \\ u_{\text{rel,adj}}(\bar{E}_i) &= u_{\text{cut-off}} \quad \text{for} \quad u_{\text{rel}}(\bar{E}_i) < u_{\text{cut-off}} \end{aligned} \quad i = 0 \text{ to N} \tag{13}$$

The weights w_i for NMI i is determined by

$$w_i = u_{\text{adj}}^{-2}(\Delta_i) / \sum_{i=0}^{N} u_{\text{adj}}^{-2}(\Delta_i) \tag{16}$$

The KCRV, Δ_{KCRV}, is determined by

$$\Delta_{\text{KCRV}} = \sum_{i=0}^{N} w_i \Delta_i \tag{17}$$

The uncertainty of the KCRV (weighted mean with cut-off) is given by

$$u(\Delta_{\text{KCRV}}) = \sqrt{\sum_{i=0}^{N} \frac{u^2(\Delta_i)}{u_{\text{adj}}^4(\Delta_i)}} \Bigg/ \sum_{i=0}^{N} u_{\text{adj}}^{-2}(\Delta_i) \tag{18}$$

From the spreadsheet

$\text{median}\{u_{\text{rel}}(\bar{E}_i)\} = 0.114\,\%$

$u_{\text{cut-off}} = 0.1061\,\%$

$u_{rel,adj}(\bar{E}_i) = 0.1061\,\%$ for NIST

$u_{rel,adj}(\bar{E}_i) = 0.1228\,\%$ for PTB

$w_i = 57.3\,\%$ for NIST

$w_i = 42.7\,\%$ for PTB

$\Delta_{KCRV} = 0.0836\,\%$

$u(\Delta_{KCRV}) = 0.0803\,\%$

Consensus responsivity and DoE

From the spreadsheet

$$CV_j = (\Delta_{KCRV} + 1)\,.\,R_{\text{pilot,j}} = -\,4.35936\ V/W\ \text{(TSA)};\ \ \text{u(CV}_\text{j}) = 0.075\,\%$$

$$CV_j = (\Delta_{KCRV} + 1)\,.\,R_{\text{pilot,j}} = -\,4.27430\ V/W\ \text{(TSB)};\ \ \text{u(CV}_\text{j}) = 0.075\,\%$$

From the document

The bilateral DoE between NMI *i* and NMI *m* is given by

$$D_{i,m} = \Delta_i - \Delta_m \qquad (24)$$

$$U_{i,m} = k\sqrt{u^2(\Delta_i) + u^2(\Delta_m)} \quad ; k=2 \qquad (25)$$

From the spreadsheet

$$\Delta_i = 0\,\%\ ;\ \ \Delta_m = 0.196\,\%$$

$$u(\Delta_i) = 0.1061\,\%\ ;\ \ u(\Delta_m) = 0.1228\,\%$$

$$D_{i,m} = -\,0.196\,\%\ ;\ \ U_{i,m} = 0.324\,\%$$