



Status of Photon Calibrator global effort for O4 (LVK Calibration Joint F2F)

Virgo, KAGRA, LIGO Pcal teams

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NIST and PTB collaborators

LVK September 2022

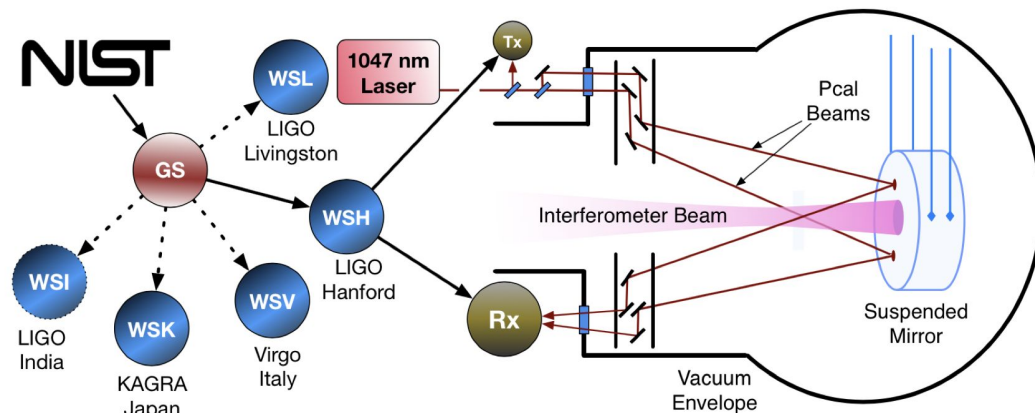
Global Pcal effort during O3 run

- Single “gold standard” calibrated by NIST
 - 1-sigma relative uncertainty of 0.32 %
- Virgo, KAGRA, and LIGO “working standards” calibrated at LIGO Hanford Observatory
- 0.32 % -> 0.41 % for LIGO Pcal fiducial displacements

[D. Bhattacharjee et al. 2021 *Class. Quantum Grav.* 38 015009](#)

- NIST/PTB bilateral comparison of O3-style sensor confirmed calibration accuracy
 - Consensus rel. uncertainty = 0.10 %

[M. Spidell et al. 2021 *Metrologia* 58 055011](#)



Sensor upgrades for O4 run

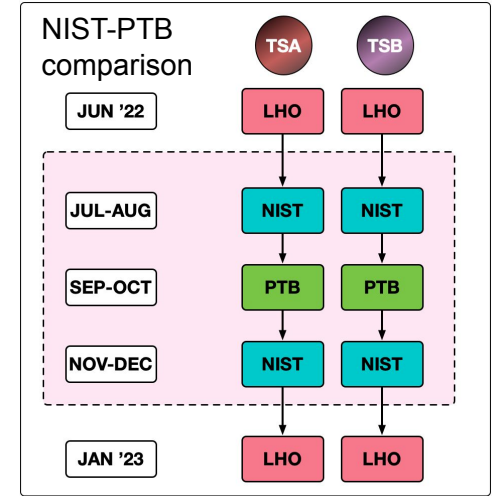
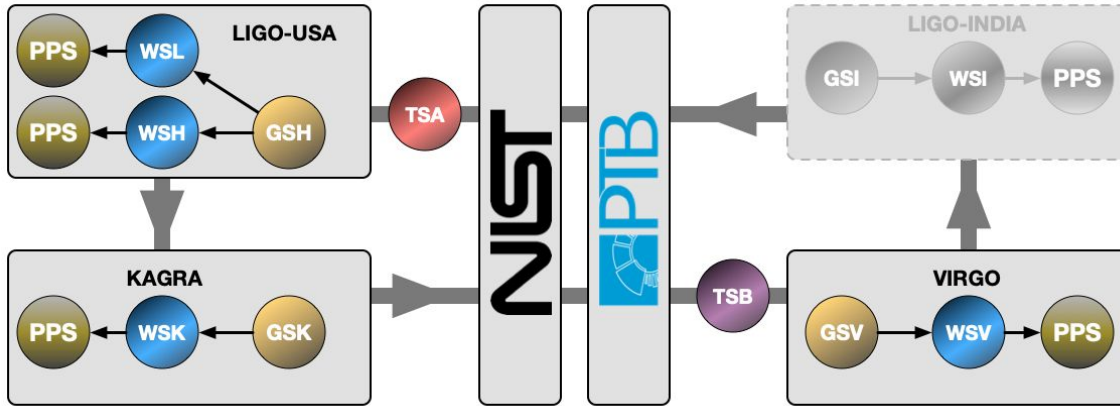
- Updated power sensors for all observatories
 - Reduced temperature dependence of responsivity
 - On-board temperature sensor
 - **Global calibration:** TSA and TSB
 - **Virgo:** GSV and WSV
 - **KAGRA:** GSK, PD assy. for WSK
 - **LIGO:** GSHL, WSH, WSL
 - **LIGO India (LAO):** GSA, WSA
 - Sensor characterization
 - Responsivity, temperature dependence
- [LIGO-T2200158](#)



Global Pcal plan for O4

- Two “transfer standards” calibrated by NIST and PTB
 - ~ 0.1 % 1-sigma uncertainty: NIST/PTB **bilateral comparison** using new NIST primary standard and upgraded O4 power sensors
 - Circulating between observatories and NIST and PTB
 - Completing loop once per year - calibrated standard arriving at each observatory every six months

S. Karki et al. 2022 *Galaxies* 10 42

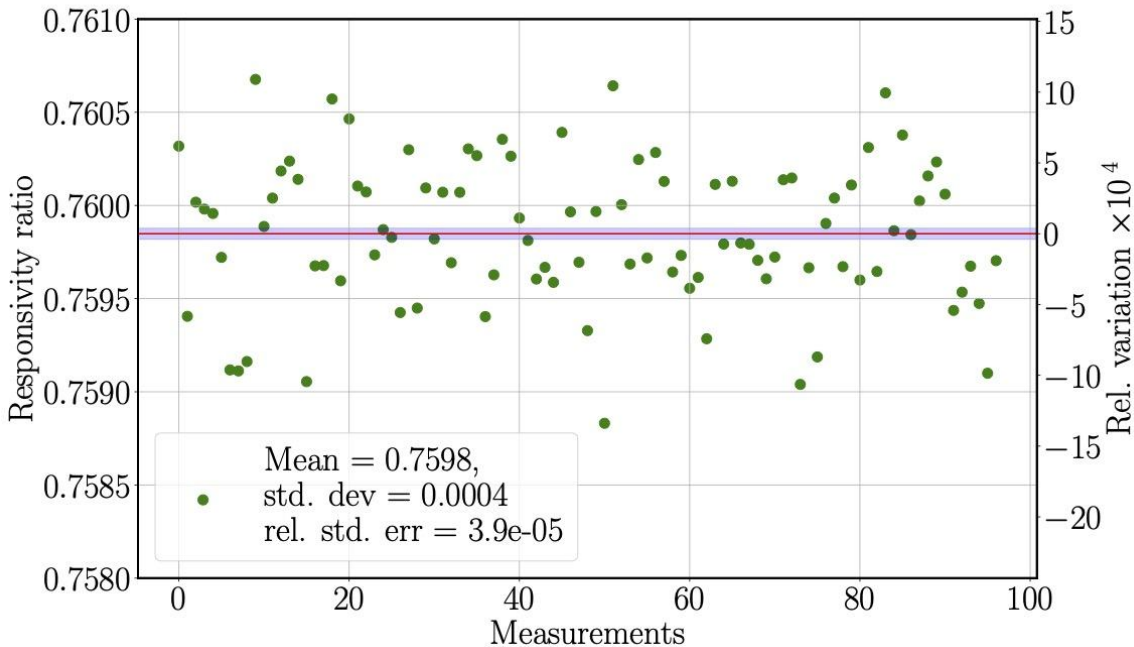
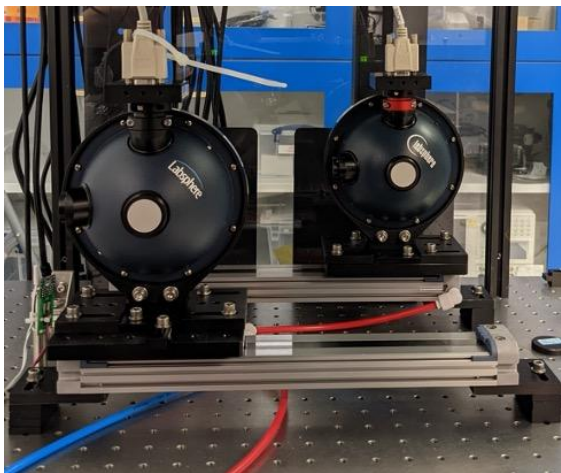


- **Challenge for observatories** - propagating TS calibration to Pcal Power Sensors at end stations

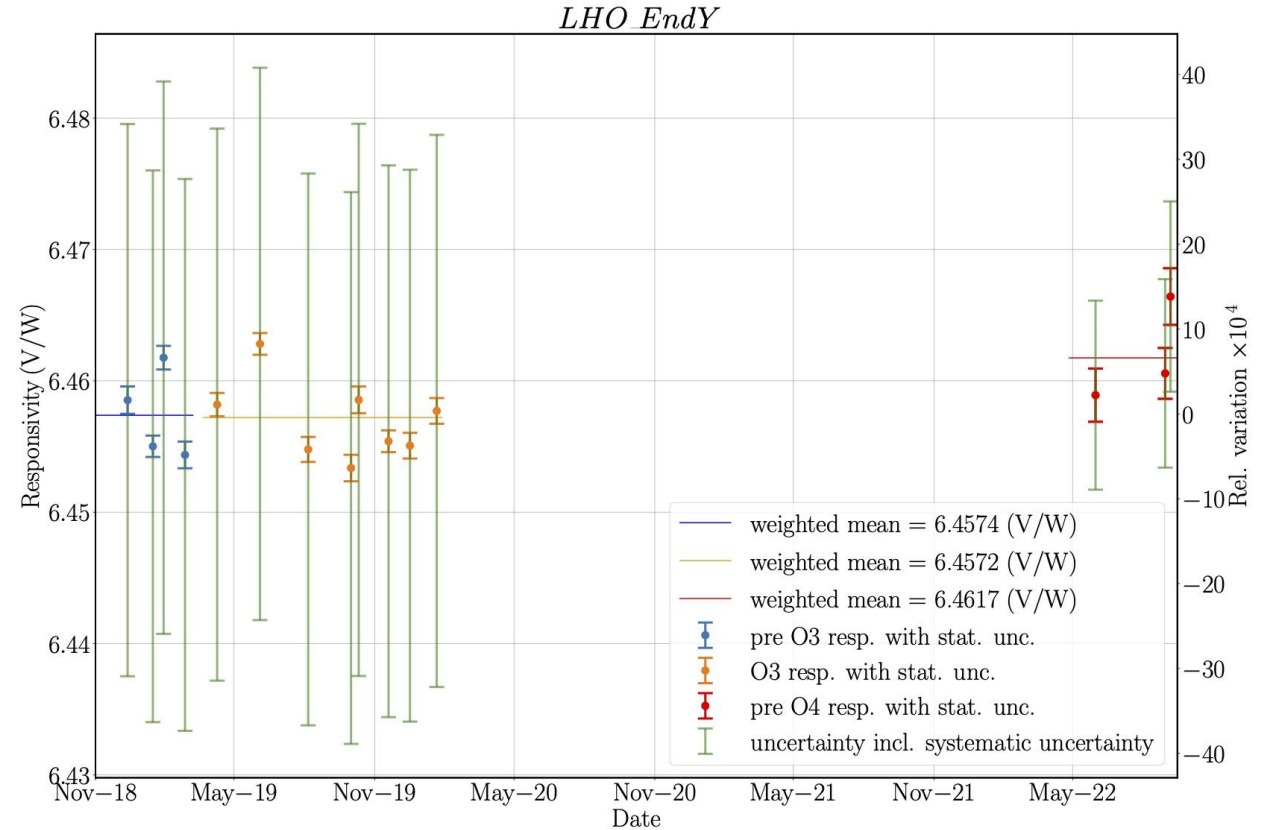
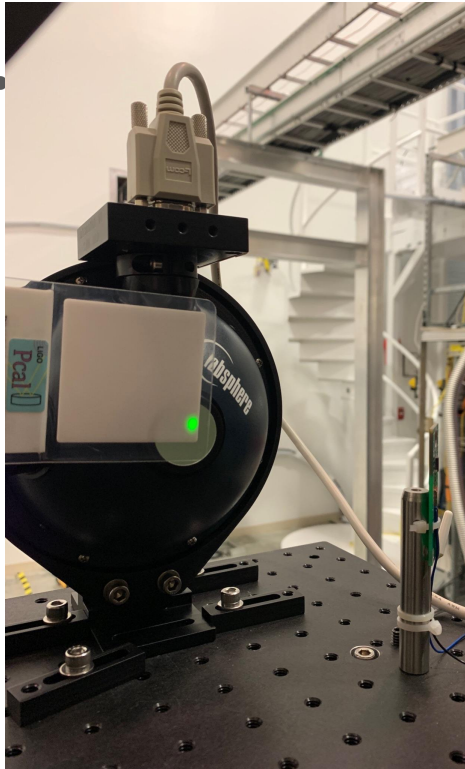
Transferring calibration to “gold” and “working” standards

- **Responsivity ratio measurements in Pcal laboratories**

- TS -> GS
- GS -> WS
- **Virgo:** LAPP in Annecy
- **KAGRA:** Toyama University
- **LIGO:** Hanford Observatory



Transferring calibration to end station sensors



Summary

- Pcal Gold and Working standards for LIGO, Virgo and Kagra have been upgraded.
 - Responsivity and temperature dependence have been characterized
- Upgraded standards have been delivered to Virgo and KAGRA
- Pcal transfer standards have been characterized and delivered to NIST for the bilateral comparison with PTB
- Transfer of calibration to the Pcal power sensors at the end stations has begun.
 - Success of ongoing effort to reduce absolute and relative calibration errors will hinge on these efforts carried out at each Pcal laboratory and at each observatory