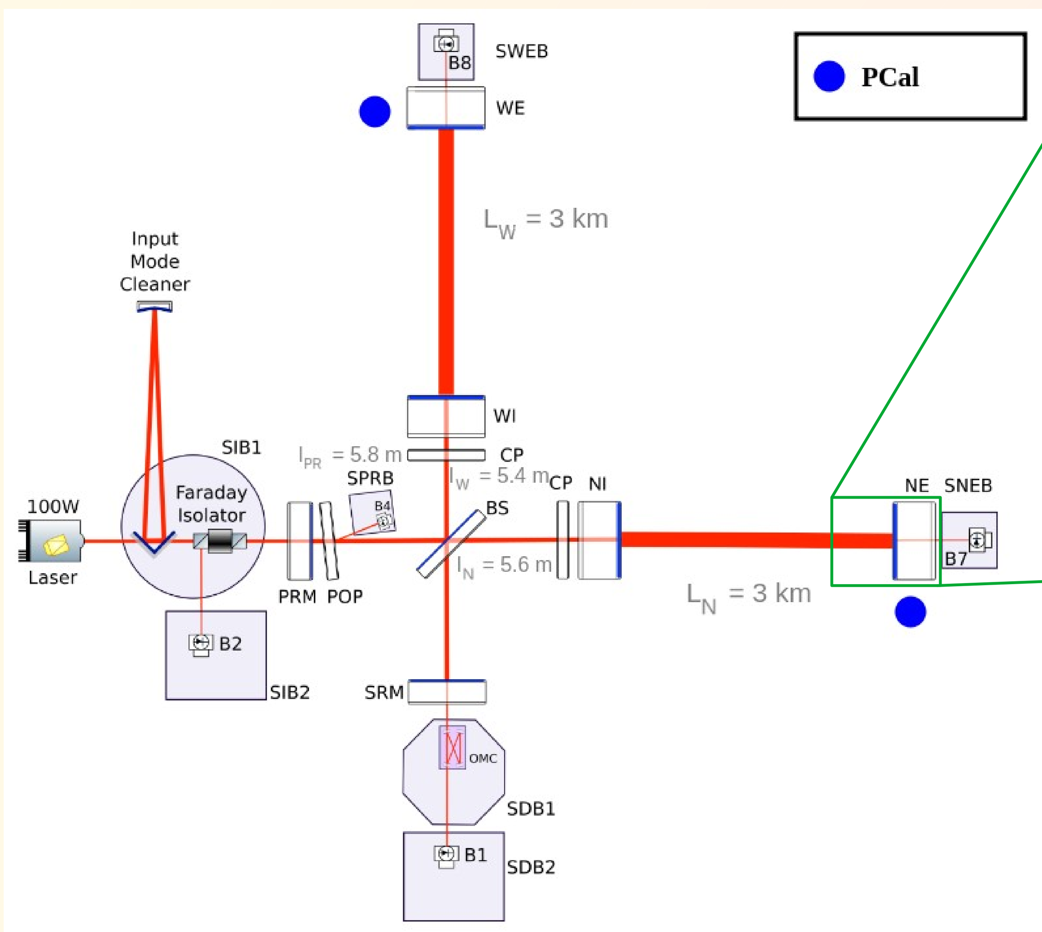
Upgrades of the reference actuator for the calibration of Advanced Virgo+

LAGABBE Paul, ROLLAND Loïc, GRIMAUD Cervanne, VERKINDT Didier
Laboratoire d'Annecy de physique des particules

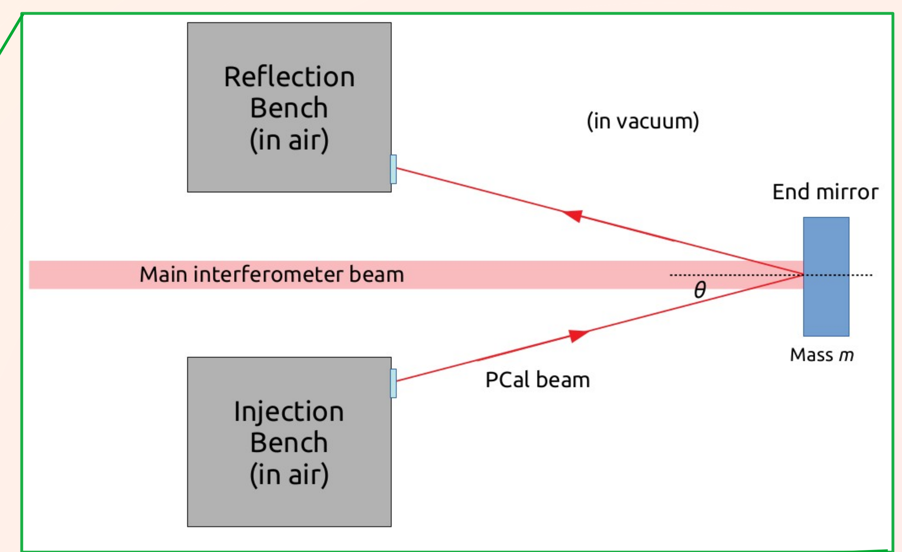
To reconstruct the interferometer strain signal h(t), calibrated models of the frequency-dependent response of the mirror electromagnetic actuators are needed. The photon calibrator (PCal) is being used as a reference actuator for the Virgo calibration since the O3 run with an uncertainty on the induced mirror motion of 1.34%. The design of the PCal has been improved in preparation of the O4 run in order to reduce the uncertainties on the induced mirror motion to below the percent level. In addition, further upgrades will be needed to adapt the PCal to the O5 bigger mirrors and to further reduce the uncertainties.

Sources:

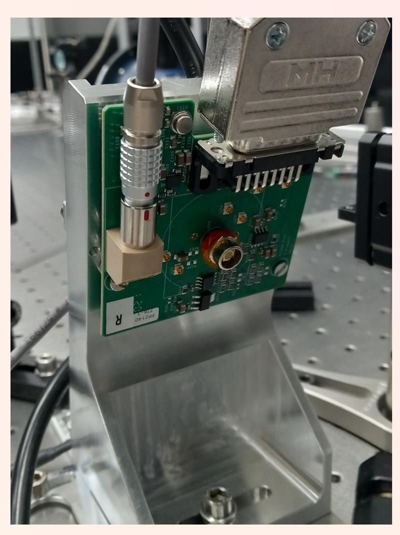
Calibration of Advanced Virgo and Reconstruction of the detector strain h(t) during the Observing Run O3, 17 Nov 2021, arXiv:2107.03294v3
The Advanced Virgo Photon Calibrators, 29 Jan 2021, arXiv:2009.08103v2
AdV+ Phase II TDR review document - CAL.04: CAL - Photon Calibrators, https://tds.virgo-gw.eu/ql/?c=18806
Toward Calibration of the Global Network of GravitationalWave Detectors with Sub-Percent Absolute and Relative Accuracy, Galaxies 2022, 10, 42. https://doi.org/10.3390/galaxies10020042



Scheme of the interferometer Virgo, the PCal are located in front of the end mirrors



Simplified scheme of the photon calibrator. The PCal laser is generated from the injection bench, sent to the end mirror, and reflected to the reflection bench



Photodiode, used for the laser power monitoring

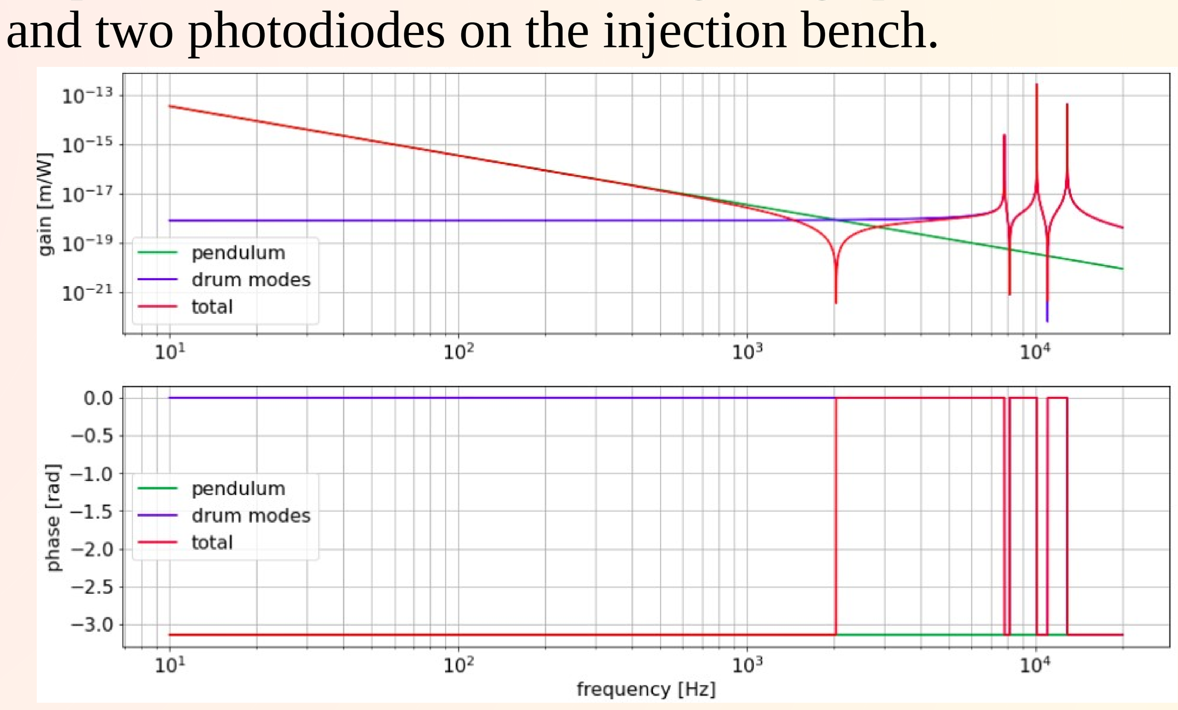
LIGO-like integrating sphere

Working principle of the photon calibrator:

The PCal uses the radiation pressure of an auxiliary laser to push the end mirror by a known motion. This motion is estimated from the laser power reflected by the end mirror using a sum of models:

- Model of the mirror suspension system:
- Model of the deformation of the mirror coated surface (drum modes)

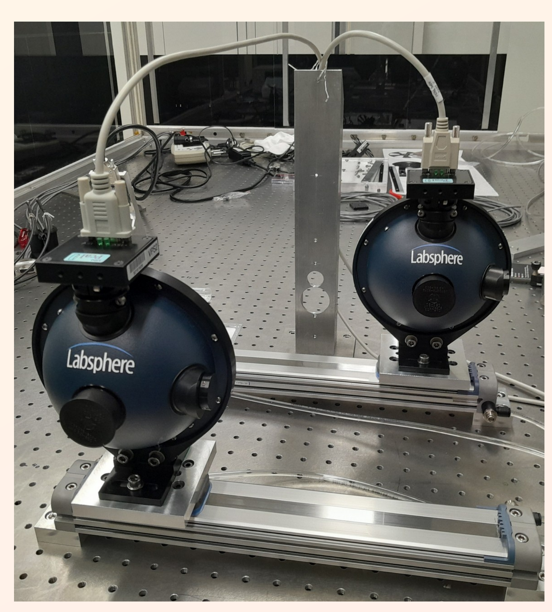
Reflected power measured with an integrating sphere on the reflection bench, and two photodiodes on the injection bench.



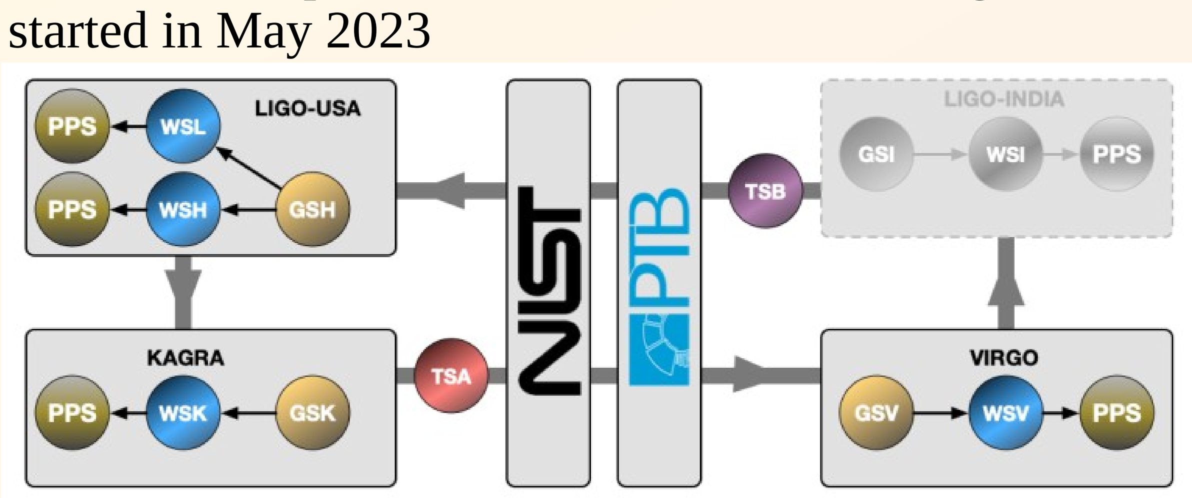
Mechanical response of the PCal, The pendulum and the deformation compensate each other at 2 kHz, so there is a notch at this frequency

Power calibration of the power sensors:

The calibration of the sensors has to be absolute and common with LIGO and Kagra collaborations.
Procedure implemented between LIGO Virgo and Kagra and started in May 2023



Picture of the sphere intercalibration bench at LAPP



Scheme of the inter-calibration procedure between LIGO, Virgo and Kagra.

All the standards are integrating spheres, and each collaboration has:

- A gold standard (GSx)
- A working standard (WSx), the PCal Power Sensors (PPS) are calibrated with respect to it

Two transfer standards (TSA/B) travel from one site to another in order to make sure that the calibration every other standard remains constant.

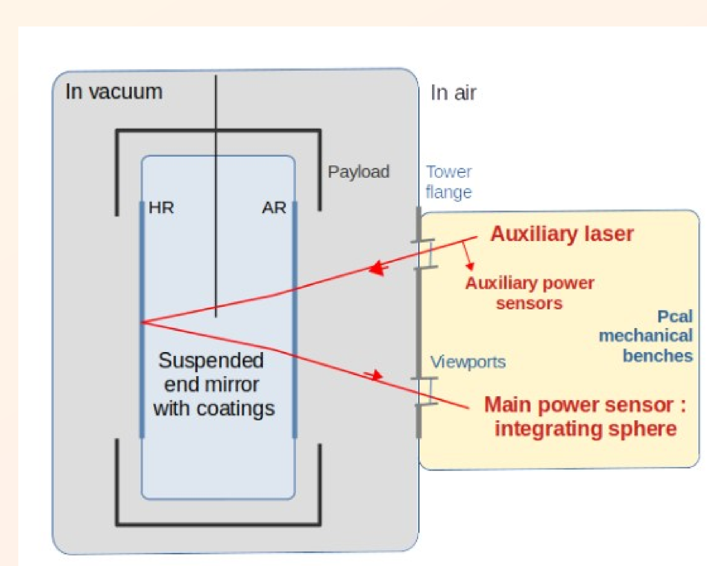
WSV and GSV spheres built and calibrated with respect to LIGO standards in May-June 2022, WSV/GSV response ratio stable within 0.01%

Prospects for the O5 run

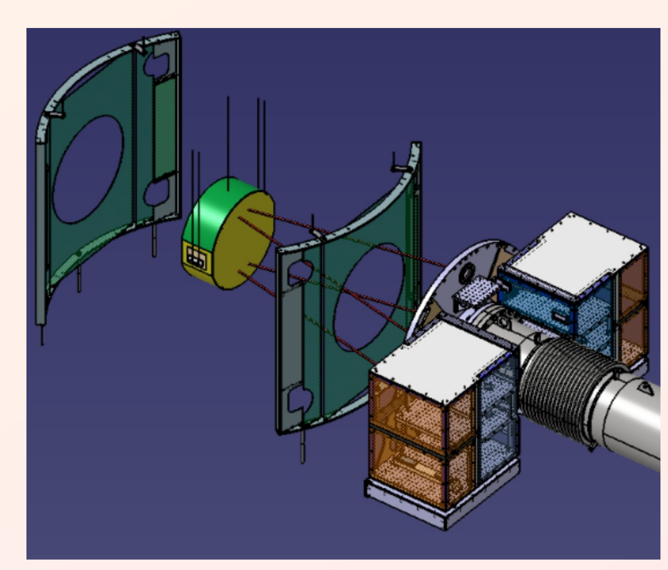
The O5 end mirrors are larger, the notch due to the surface deformation of the mirror is expected to be at ~300 Hz

New characteristics of the Virgo PCal:

- PCal installed in front of the anti-reflection surface of the mirror because of the space contraint
- Two symmetric laser beams at +/- 175 mm from the center of the mirror vertically
- Viewports with better antireflect coating



Scheme of the PCal bench design of O5



Sketch of the back flange of the mirror with the future PCal bench installed on it

Characterization of the sphere responsivity stability

The stability of the response of the sphere has been characterized as a function of:

- The temperature, it is is measured and corrected
- The position of the beam (angle of incidence & lateral position) with respect to the sphere
- The size of the beam
- The power of the input beam

Source	Values
Sphere calibration	0.123%
Beam position	0.012%
Beam size	0.012%
Linearity	0.113%
Total	0.167%

Uncertainty budget on the sphere response. The uncertainties have been characterized in April 2023

Source	Values
Response of the WSV	0.167%
Power sensors calibration	0.01%
Viewport losses	0.2%
Mechanical response	0.13%
Stability through time	0.4%
Total	0.5%

Preliminary uncertainty budget on the mirror displacement due to the PCal. The values are theoretical and have to be characterized

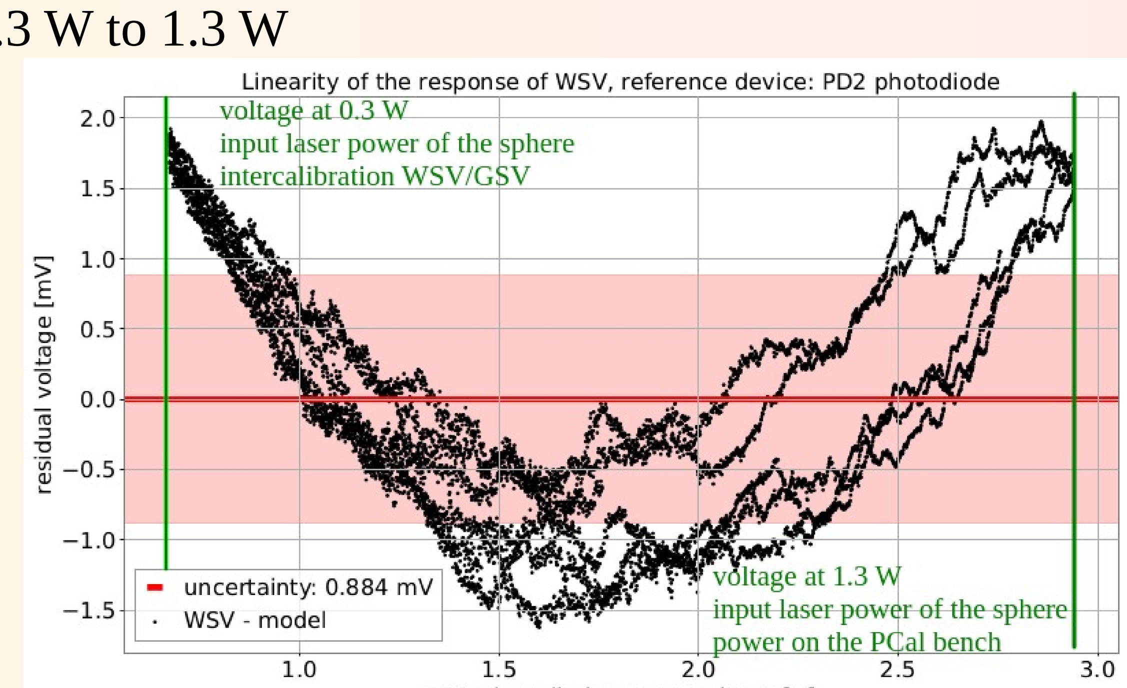
Characterization of the linearity of the sphere with respect to a photodiode.

Laser power signal = ramps signal:

- Duration 500 s
- From 0.3 W to 1.3 W

Model:

$$V_{WSV,i} = A \times V_{PD,i} + \epsilon_i$$



Residual ε as function of output voltage of the photodiode V_{PD}