Characterization of O4 Pcal power sensors

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Outline

Introduction

Overview

This slide stack, documents the math formalism, measurement and analysis methods, and experimental results that characterize the Pcal power standards that were updated in anticipation of LIGO's fourth observing run, O4.
Detector spacers were added to the power standards to reduce the temperature dependence of the responsivity by limiting the field of view of the sensor. The transimpedance amplifier circuits were also updated to incorporate AD590 temperature sensors soldered in place and to adjust the overall gain to compensate for the attenuation of the detector spacers. Measurements of the temperature dependence of both the dark voltages and the responsivities were realized by insulating one of the sensors and heating in an oven to about 15 K above the ambient laboratory temperature. Responsivity ratio measurements made in the standard fashion as the heated device cooled where then used to estimate the temperature-dependent dark voltage and the temperature dependent-responsivity ratio.

Key steps in Pcal power sensor characterization

1. Reference all measured parameters to device-specific AD590 temperature: $T^{'} = 300.15\,\mathrm{K}$ (27 °C)
2. Measure temperature dependence of dark voltages: $V_{dark} = V^{'}_{dark} + m_{dark}(T - T^{'})$
3. Measure temperature dependent responsivity ratios. Then:
   * subtract temperature-dependent dark voltages
   * divide denominator voltages by $[1 + \kappa_{dev2}(T_2 - T^{'})]$
   * plot and fit: $\rho_{dev1}/\rho^{'}_{dev2} = m\,(T_1 - T^{'}) + b$, where $b = \rho^{'}_{dev1}/\rho^{'}_{dev2}$
   * fit gives $\alpha^{'}_{dev1,dev2} = \rho^{'}_{dev1}/\rho^{'}_{dev2}$ and $\kappa_{dev1,\,insulated} = m\,/\alpha^{'}_{dev1,dev2}$
4. Correct voltages in standard responsivity ratio measurements to obtain estimates of $\alpha^{'}_{1,2} = \rho^{'}_{dev1}/\rho^{'}_{dev2}$ by subtracting a DC background
5. Using m in step 3 (last bullet) fit a straight line through the responsivity ratio measurements.
   * fit gives a new $\alpha^{'}_{dev1,dev2\,corr} = \rho^{'}_{dev1}/\rho^{'}_{dev2}$, used to calculate kappa corrected for the temperature shift due to insulation. $\kappa_{dev1,\,non-insulated} = m\,/\alpha^{'}_{dev1,dev2\,corr}$
6. Redo step 4.
7. Use temperature-corrected primary measurements from NIST and/or PTB ($\rho^{'}_{dev2}$) and temperature-corrected responsivity ratio measurements to estimate $\rho^{'}_{dev1}$: $\rho^{'}_{dev1} = \rho^{'}_{dev1}/\rho^{'}_{dev2} \times \rho^{'}_{dev2} = \alpha^{'}_{1,2} \times \rho^{'}_{dev2}$

O4 Pcal power sensors and intended uses

Device	Description/Intended use during O4 run
WSS	Used for 2020 NIST/PTB bilateral comparison, WSN (NIST)
PS1	TSA
PS2	TSB
PS3	GSA LAO gold standard, LAO RxX
PS4	GSHL LIGO gold standard
PS5	WSH LHO working standard
PS6	WSL LLO working standard
PS7	GSK KAGRA gold standard (previously WSK)
PS8	GSA LAO working standard, LAO RxY
VPS1	WSV Virgo working standard
VPS2	GSV Virgo gold standard
UTPS1	UGRGV power sensor 1
UTPS2	UTRGV power sensor 2

Table: O4 Pcal power sensors and intended usage during O4 run.

O4 Pcal analysis software

Path in SVN: /ligo/svncommon/CalSVN/aligocalibration/trunk/Projects/PhotonCalibratorPhotonCalibrator/scripts/O4/

Script	Description/comments
PS3PS2iter	Directory of files used for temperature dependence iteration
PS_resp.py	Script to plot the responsivity trends of the devices, generates rhoPrimePSx.pdf
alphaprime.py	Script to calculate $\alpha^{'}$, generates dev1dev2_avgratios_tcorr.pdf, dev1dev2_avgvoltage_tcorr.pdf and dev1_alphaprime.csv. It also generates a summary_tcorr.txt to be used by the end station analysis script.
alphatrends.py	Script to plot the responsivity ratio trends, generates dev1dev2_alphatrends.pdf and a csv file dev1dev2_alpha.csv.
darkVoltage.py	Script to calculate the dark parameters of the devices, generates dev1_darkparams.pdf and a csv file dev1_darkparams.pdf
generate_params.py	Script that creates a database for the devices O4params.csv
kappa.py	Script that calculates κ for the devices, generates a dev1_kappa.pdf or a dev1_kappa_woshift.pdf and a csv file dev1_kappa.csv

Dark voltages

Data directories

Path in SVN: /ligo/svncommon/CalSVN/aligocalibration/trunk/Projects/PhotonCalibrator/measurements/LabData/...

Device	Data directory
PS1	.../PS1_PS2/i2022-03-29T164919
PS2	.../PS2_PS1/i2022-03-25T104152
PS3	.../TSA_TSB/i2021-10-13T155703
WSS	.../WSS_PS2/i2022-04-01T165457
VPS1	.../VPS1_PS3/i2022-05-18T155744
VPS2	.../VPS2_PS3/i2022-05-20T083652
PS7	.../PS7_PS3/i2022-06-21T173031
PS4	.../PS4_PS7/i2022-06-22T192758
PS5	.../PS5_PS7/i2022-06-24T174415
PS6	.../PS6_PS3/i2022-06-28T193242
PS10	../PS10_PS3/i2022-08-12T143704
PS11	../PS11_PS3/i2022-10-31T102613

Table: Data directories for measurements and results of the calibration

Temperature-dependent dark voltages - Running the darkVoltage.py script

$V_{dark}(mV) = m_{dark}\,(T - T^{'}) + V'_{dark}$
path to script: /ligo/svncommon/CalSVN/aligocalibration/trunk/Projects/PhotonCalibrator/scripts/O4/darkVoltage.py

It plots the average of the voltage in transmitted and reflected for device 1 as a function of the AD590 temperature associated to device 1 and fits a straight line to give the slope and intercept.

Copy the script into the temperature dependent background measurement directory

Run python3 darkVoltage.py
 * Generates a plot dev1_darkparams.pdf and prints m_{dark} (slope) and V'_{dark} (intercept) in the legend
 * Generates dev1_darkparams.csv with columns Dev, slope (m_{dark}), intercept(V'_{dark})

Result Summary

Dev	m_{dark} (mV/K)	$V'_{dark}(mV)$
PS1	−0.11413	+2.2600
PS2	−0.14522	−0.1631
PS3	−0.12297	−1.0213
WSS	−0.01647	+0.0034
VPS1	−0.16674	−2.3886
VPS2	−0.13240	−2.5401
PS7	−0.1347	−0.9697
PS4	−0.1221	+3.0198
PS5	−0.1586	+1.3667
PS6	−0.1658	−0.4025
PS10	−0.1663	−1.2892
PS11	−0.1155	−2.4226

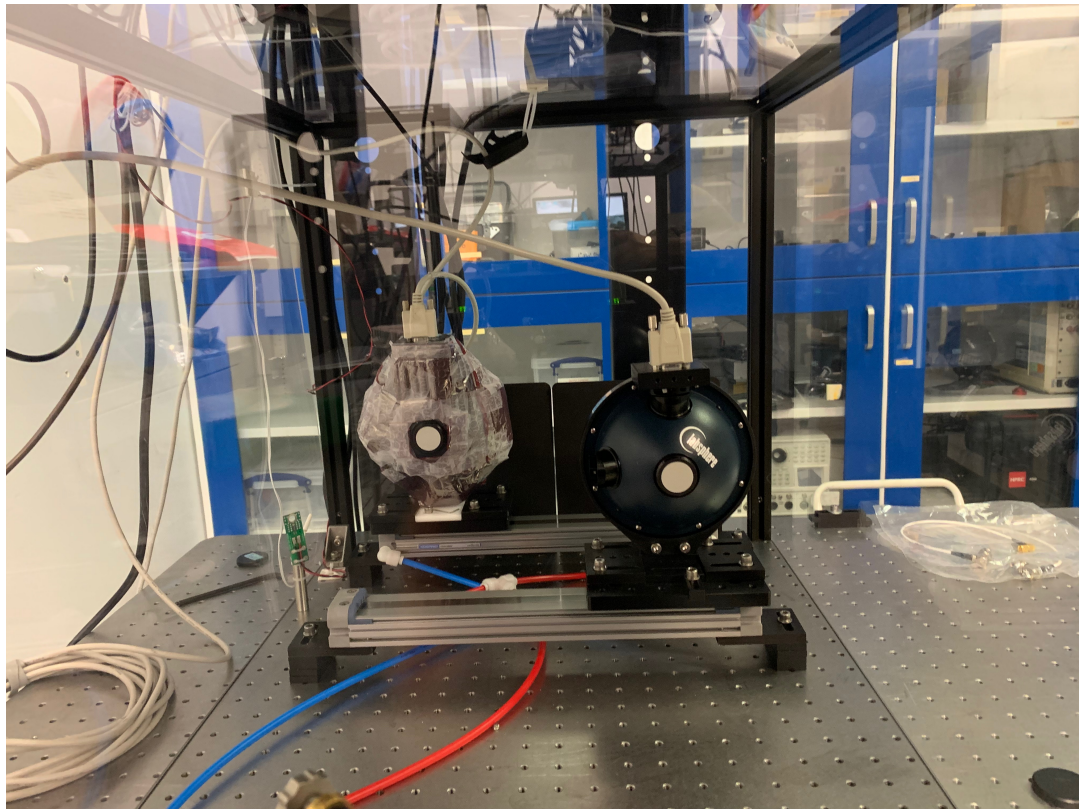
Table: Summary of dark voltage measurement results.

Device names are hyperlinked to plots generated by darkVoltage.py.

Measurement of temperature dependence of responsivity

Setup

The relative responsivity temperature coefficients, κ, are determined by insulating, then heating, one sphere in an oven before performing responsivity ratio measurements while it cools.



Data directories

Path in SVN: /ligo/svncommon/CalSVN/aligocalibration/trunk/Projects/PhotonCalibrator/measurements/LabData/...

Ratio	**Data directory**
PS3/PS2	.../PS3_PS2/i2022-04-27T093520
PS2/PS3	.../PS2_PS3/i2022-03-22T083532
PS1/PS3	.../PS1_PS3/i2022-03-17T083753
PS1/PS3	.../PS1_PS3/i2022-03-18T102237
WSS/PS2	.../WSS_PS2/i2022-04-01T094944
VPS1/PS3	.../VPS1_PS3/i2022-06-01T094342
VPS2/PS3	.../VPS2_PS3/i2022-06-01T123628
PS7/PS3	.../PS7_PS3/i2022-06-22T151042
PS4/PS3	.../PS4_PS3/i2022-06-23T094512
PS5/PS3	.../PS5_PS3/i2022-06-27T140251
PS6/PS3	.../PS6_PS3/i2022-07-13T104749
PS6/PS3	.../PS6_PS3/i2022-07-14T091034

Data directories

Path in SVN: /ligo/svncommon/CalSVN/aligocalibration/trunk/Projects/PhotonCalibrator/measurements/LabData/...

Ratio	**Data directory**
PS10/PS3	.../PS10_PS3/i2022-10-24T113020
PS10/PS3	.../PS11_PS3/i2022-10-28T113822

Temperature-dependent responsivity ratio - PS3-PS2 iteration steps

1. First estimate of κ_{PS3}, without compensating for PS2 responsivity temperature dependence.
2. First estimate of κ_{PS2}, using the first estimate of κ_{PS3} to correct for the temperature dependence of PS3 used as reference
3. Second (more accurate) estimate of κ_{PS3}, using first estimate of κ_{PS2} to correct for the temperature dependence of PS2 used as reference
4. Second (more accurate) estimate of κ_{PS2}, using second estimate of κ_{PS3} to correct for the temperature dependence of PS3 used as reference

Temperature-dependent responsivity ratio - Running the PS3PS2iter.py script

path to script: /ligo/svncommon/CalSVN/aligocalibration/trunk/Projects/PhotonCalibrator/scripts/O4/PS3PS2iter/PS3PS2iter.py

* The script follows the 4 steps listed in the previous slide.
* Temperature dependent background is subtracted from the voltages.
* From the fit of ρ_{dev1}/ρ'_{dev2} as a function of temperature $\kappa_{dev1,\,insulated} = m_{dark}\,/\alpha'_{dev1,dev2}$ is calculated.
* Additionally κ is corrected for the impact of the integrating spheres being insulated when the measurements were made to get $\kappa_{PS2,\,non-insulated}$.

Run python3 PS3PS2iter.py

* Generates PS2(3)_kappacorr.pdf with shifted kappa, PS3PS2Seciter.pdf and PS2(3)PS3(2)params.csv with columns dev, m_{dark}, V_{dark}, kappa. This is required to be done once to start off the temperature dependent correction of the power standards. It has already been done. Need not redo it. For PS3_PS2 we did not have any resp.ratio measurements hence we applied (PS3/WSS)/(WSS/PS2) to get PS3/PS2 resp.ratio measurements for the shifting.

Iteration to determine κ values for PS2 and PS3

Analysis steps listed in order performed. First iteration with no temperature compensation for device 2.

Ratio	κ (hop/K)	$\alpha^{'}$	$1/\alpha^{'}$
PS3/PS2	$\kappa_{PS3} = -2.05$	$\alpha^{'}_{PS3,PS2} = 1.317$	$1/\alpha^{'}_{PS3,PS2} = 0.759$
PS2/PS3	$\kappa_{PS2} = -2.82$	$\alpha^{'}_{PS2,PS3} = 0.758$	$1/\alpha^{'}_{PS2,PS3} = 1.319$
PS3/PS2	$\kappa_{PS3} = -2.03$	$\alpha^{'}_{PS3,PS2} = 1.317$	$1/\alpha^{'}_{PS1,PS3} = 0.759$
PS2/PS3	$\kappa_{PS2} = -2.82$	$\alpha^{'}_{PS2,PS3} = 0.759$	$1/\alpha^{'}_{PS2,PS3} = 1.319$

Generation of O4params.csv file

path to script: /ligo/svncommon/CalSVN/aligocalibration/trunk/Projects/PhotonCalibrator/scripts/O4/generate_params.py

* The script copies PS2PS3params.csv to O4params.csv

Run python3 generate_params.py

* Generates O4params.csv for PS2 and PS3 in PhotonCalibrator/measurements/LabData with columns dev, m_{dark}, V_{dark}, kappa.

Temperature-dependent responsivity ratio using PS3 as the reference standard

path to script: /ligo/svncommon/CalSVN/aligocalibration/trunk/Projects/PhotonCalibrator/scripts/O4/kappa.py

* The script copies O4params.csv which is saved under measurements/LabData and dev1_darkparams.csv into the measurement directory.
* The temperature dependent background is subtracted from the voltages for both dev1 and dev2.
* The temperature dependence of dev2 is corrected to 300.15 K.
* From the fit of $\rho_{dev1}/\rho^{'}_{dev2}$ as a function of temperature $\kappa_{dev1,\,insulated}$ is calculated.
* If there are existing t-directories, κ is corrected for the impact of the integrating spheres being insulated when the measurements were made to get $\kappa_{dev1,\,non-insulated}$. If there are no t-directories, we get $\kappa_{dev1,\,insulated}$.

Temperature-dependent responsivity ratio using PS3 as the reference standard - contd.

Copy the script into the temperature dependent background measurement directory

Run python3 kappa.py bkg_dir

* Generates dev1_kappa_woshift.pdf if there are no existing t-directories OR Generates dev1_kappa.pdf when there are existing t-directories to generate a slope shifted corrected kappa.
* Generates dev1_kappa.csv with columns Dev, kappa.

For cases when the temperature dependent background measurement is in a different parent directory (for e.g., the temperature dependent resp. ratio measurements are in directory PS1_PS3 whereas the temperature dependent background measurements are in the directory PS1_PS2), one would have to modify the script accordingly.

Summary of temperature-dependent responsivity ratio results

Ratio	κ (hop/K)	$\alpha^{'}$	$1/\alpha^{'}$
PS3/PS2	$\kappa_{PS3} = -2.03$	$\alpha^{'}_{PS3,PS2} = 1.315$	$1/\alpha^{'}_{PS3,PS2} = 0.7593$
PS2/PS3	$\kappa_{PS2} = -2.82$	$\alpha^{'}_{PS2,PS3} = 0.759$	$1/\alpha^{'}_{PS2,PS3} = 1.318$
PS1/PS3	$\kappa_{PS1} = -2.25$	$\alpha^{'}_{PS1,PS3} = 0.775$	$1/\alpha^{'}_{PS1,PS3} = 1.290$
PS1/PS3	$\kappa_{PS1} = -2.56$	$\alpha^{'}_{PS1,PS3} = 0.775$	$1/\alpha^{'}_{PS1,PS3} = 1.290$
WSS/PS2	$\kappa_{WSS} = +5.06$	$\alpha^{'}_{WSS,PS2} = 1.926$	$1/\alpha^{'}_{WSS,PS2} = 0.518$
VPS1/PS3	$\kappa_{VPS1} = -1.87$	$\alpha^{'}_{VPS1,PS3} = 0.466$	$1/\alpha^{'}_{VPS1,PS3} = 2.146$
VPS2/PS3	$\kappa_{VPS2} = -0.91$	$\alpha^{'}_{VPS2,PS3} = 0.463$	$1/\alpha^{'}_{VPS2,PS3} = 2.160$
PS7/PS3	$\kappa_{PS7} = -1.832$	$\alpha^{'}_{PS7,PS3} = 0.83903$	$1/\alpha^{'}_{PS7,PS3} = 1.19185$
PS4/PS3	$\kappa_{PS4} = -2.694$	$\alpha^{'}_{PS4,PS3} = 0.8355$	$1/\alpha^{'}_{PS4,PS3} = 1.1969$
PS5/PS3	$\kappa_{PS5} = -2.064$	$\alpha^{'}_{PS5,PS3} = 0.91069$	$1/\alpha^{'}_{PS5,PS3} = 1.0981$
PS6/PS3	$\kappa_{PS5} = -1.169$	$\alpha^{'}_{PS6,PS3} = 0.7896$	$1/\alpha^{'}_{PS6,PS3} = 1.2665$

Summary of temperature-dependent responsivity ratio results

Ratio	κ (hop/K)	α'	$1/\alpha'$
PS10/PS3	$\kappa_{PS10} = -1.41$	$\alpha'_{PS10,PS3} = 0.8630$	$1/\alpha'_{PS10,PS3} = 1.1587$
PS11/PS3	$\kappa_{PS11} = -1.85$	$\alpha'_{PS11,PS3} = 0.7852$	$1/\alpha'_{PS11,PS3} = 1.2736$

Entries in the **Ratio** column are hyperlinked to relevant plots.

Responsivity ratios: α'

Data directories

Path in SVN: /ligo/svncommon/CalSVN/aligocalibration/trunk/Projects/PhotonCalibrator/measurements/LabData/...

Ratio	Data directory
PS1/PS3	.../PS1_PS3/t2022-03-15T121600
PS1/PS3	.../PS1_PS3/t2022-04-21T085542
PS1/PS3	.../PS1_PS3/t2022-05-16T145409
PS1/PS3	.../PS1_PS3/t2022-05-17T100254
PS1/PS3	.../PS1_PS3/t2022-05-17T165815
PS1/WSS	.../PS2_WSS/t2022-04-07T091947
PS1/WSS	.../PS1_WSS/t2022-04-12T121905
PS1/WSS	.../PS1_WSS/t2022-04-14T085422

Table: Data directories for responsivity ratio measurements

Data directories contd.

Path in SVN: /ligo/svncommon/CalSVN/aligocalibration/trunk/Projects/PhotonCalibrator/measurements/LabData/...

Ratio	**Data directory**
PS2/PS3	.../PS2_PS3/t2022-04-21T114138
PS2/PS3	.../PS2_PS3/t2022-04-21T154443
PS2/PS3	.../PS2_PS3/t2022-05-16T175355
PS2/PS3	.../PS2_PS3/t2022-05-17T150804
PS2/WSS	.../PS2_WSS/t2022-04-07T131950
PS2/WSS	.../PS2_WSS/t2022-04-12T145800
PS3/WSS	.../PS3_WSS/t2022-02-17T095321
PS3/WSS	.../PS3_WSS/t2022-02-22T103612
PS3/WSS	.../PS3_WSS/t2022-04-21T140136
PS3/WSS	.../PS3_WSS/t2022-04-22T085750
PS3/WSS	.../PS3_WSS/t2022-04-22T100723

Table: Data directories for responsivity ratio measurements

Data directories contd.

Path in SVN: /ligo/svncommon/CalSVN/aligocalibration/trunk/Projects/PhotonCalibrator/measurements/LabData/...

Ratio	Data directory
VPS1/PS3	.../VPS1_PS3/t2022-05-25T163849
VPS1/PS3	.../VPS1_PS3/t2022-05-26T083116
VPS1/PS3	.../VPS1_PS3/t2022-05-26T105844
VPS1/PS3	.../VPS1_PS3/t2022-05-26T135022
VPS1/PS3	.../VPS1_PS3/t2022-06-01T170606
VPS2/PS3	.../VPS2_PS3/t2022-05-26T094400
VPS2/PS3	.../VPS2_PS3/t2022-05-26T121313
VPS2/PS3	.../VPS2_PS3/t2022-06-01T154804
VPS2/PS3	.../VPS2_PS3/t2022-06-02T090315
VPS2/PS3	.../VPS2_PS3/t2022-06-02T100443

Table: Data directories for responsivity ratio measurements

Data directories contd.

Path in SVN: /ligo/svncommon/CalSVN/aligocalibration/trunk/Projects/PhotonCalibrator/measurements/LabData/...

Ratio	**Data directory**
PS7/PS3	.../PS7_PS3/t2022-06-28T131323
PS7/PS3	.../PS7_PS3/t2022-06-28T161730
PS7/PS3	.../PS7_PS3/t2022-06-29T112626
PS7/PS3	.../PS7_PS3/t2022-06-29T172511
PS7/PS3	.../PS7_PS3/t2022-07-11T152414
PS4/PS3	.../PS4_PS3/t2022-05-24T090850
PS4/PS3	.../PS4_PS3/t2022-07-15T112550
PS4/PS3	.../PS4_PS3/t2022-07-15T145742
PS4/PS3	.../PS4_PS3/t2022-07-18T123727
PS4/PS3	.../PS4_PS3/t2022-07-20T090009

Table: Data directories for responsivity ratio measurements

Data directories contd.

Path in SVN: /ligo/svncommon/CalSVN/aligocalibration/trunk/Projects/PhotonCalibrator/measurements/LabData/...

Ratio	Data directory
PS5/PS3	.../PS5_PS3/t2022-06-28T143818
PS5/PS3	.../PS5_PS3/t2022-06-28T175755
PS5/PS3	.../PS5_PS3/t2022-06-29T093821
PS5/PS3	.../PS5_PS3/t2022-06-29T125536
PS5/PS3	.../PS5_PS3/t2022-07-12T181338
PS6/PS3	.../PS6_PS3/t2022-07-15T092504
PS6/PS3	.../PS6_PS3/t2022-07-15T132019
PS6/PS3	.../PS6_PS3/t2022-07-18T112056
PS6/PS3	.../PS6_PS3/t2022-07-19T132308
PS6/PS3	.../PS6_PS3/t2022-07-20T102502

Table: Data directories for responsivity ratio measurements

Data directories contd.

Path in SVN: /ligo/svncommon/CalSVN/aligocalibration/trunk/Projects/PhotonCalibrator/measurements/LabData/...

Ratio	**Data directory**
PS10/WSS	.../PS10_WSS/t2022-09-30T090219
PS10/WSS	.../PS10_WSS/t2022-09-30T111005
PS10/WSS	.../PS10_WSS/t2022-10-03T115432
PS10/WSS	.../PS10_WSS/t2022-10-03T141942
PS10/WSS	.../PS10_WSS/t2022-11-03T113413
PS11/PS3	.../PS11_PS3/t2022-08-12T084219
PS11/PS3	.../PS11_PS3/t2022-08-12T102040
PS11/PS3	.../PS11_PS3/t2022-11-04T103046
PS11/PS3	.../PS11_PS3/t2022-11-04T120807
PS11/PS3	.../PS11_PS3/t2022-11-07T094210

Table: Data directories for responsivity ratio measurements

Standard responsivity ratios - Running the alphaprime.py script

path to script: /ligo/svncommon/CalSVN/aligocalibration/trunk/Projects/PhotonCalibrator/scripts/O4/alphaprime.py

* The script copies O4params.csv and dev1_darkparams.csv into the measurement folder.
* DC background is subtracted from the voltages.
* IF there are multiple measurements of κ for dev1, the average is taken.

Copy the script into the standard resp. ratio measurement directory

Run python3 alphaprime.py bkg_dir

* Generates temperature corrected dev1dev2_avgvoltage_tcorr.pdf and dev1dev2_avgratios_tcorr.pdf
* Generates dev1dev2_alphaprime.csv with Dev, m_dark, V'_dark, kappa, alpha_prime, std_dev, std_err

For cases when the temperature dependent background measurement is in a different parent directory one must modify the script accordingly.

Summary of standard responsivity ratio measurement results

Ratio	Directory	α'	std. dev.
PS1/PS3	t2022-03-15T121600	$\alpha'_{PS1,PS3} = 0.7751$	3.9366e-4
PS1/PS3	t2022-04-21T085542	$\alpha'_{PS1,PS3} = 0.7751$	3.6472e-4
PS1/PS3/	t2022-05-16T145409	$\alpha'_{PS1,PS3} = 0.7749$	3.5956e-4
PS1/PS3	t2022-05-17T100254	$\alpha'_{PS1,PS3} = 0.7750$	3.3393e-4
PS1/PS3	t2022-05-17T165815	$\alpha'_{PS1,PS3} = 0.7747$	3.8513e-4
PS2/PS3	t2022-04-21T114138	$\alpha'_{PS2,PS3} = 0.7599$	3.7386e-4
PS2/PS3	t2022-04-21T154443	$\alpha'_{PS2,PS3} = 0.7598$	3.7386e-4
PS2/PS3	t2022-05-16T175355	$\alpha'_{PS2,PS3} = 0.7595$	3.8451e-4
PS2/PS3	t2022-02-22T103612	$\alpha'_{PS2,PS3} = 0.7596$	3.8490e-4

Entries in the **Ratio** column are hyperlinked to relevant plots.

Summary of standard responsivity ratio measurement results cont.

Ratio	Directory	α'	std. dev.
PS1/WSS	t2022-04-07T091947	$\alpha'_{PS1,WSS} = 0.5302$	1.9775e-4
PS1/WSS	t2022-04-12T121905	$\alpha'_{PS1,WSS} = 0.5304$	1.5904e-4
PS1/WSS	t2022-04-14T085422	$\alpha'_{PS1,WSS} = 0.5303$	1.8665e-4
PS2/WSS	t2022-04-07T131950	$\alpha'_{PS2,WSS} = 0.5198$	1.85232e-4
PS2/WSS	t2022-04-12T145800	$\alpha'_{PS2,WSS} = 0.5199$	2.0266e-4
PS3/WSS	t2022-02-17T095321	$\alpha'_{PS3,WSS} = 0.6841$	2.2986e-4
PS3/WSS	t2022-02-22T103612	$\alpha'_{PS3,WSS} = 0.6847$	2.2502e-4
PS3/WSS	t2022-04-21T140136	$\alpha'_{PS3,WSS} = 0.6836$	2.431e-4
PS3/WSS	t2022-04-22T085750	$\alpha'_{PS3,WSS} = 0.6842$	2.5781e-4
PS3/WSS	t2022-024-22T100723	$\alpha'_{PS3,WSS} = 0.6841$	2.2986e-4

Entries in the **Ratio** column are hyperlinked to relevant plots.

Summary of standard responsivity ratio measurement results cont.

Ratio	Directory	α'	std. dev.
VPS1/PS3	t2022-05-25T163849	$\alpha'_{VPS1,PS3} = 0.4663$	2.1858e-4
VPS1/PS3	t2022-05-26T083116	$\alpha'_{VPS1,PS3} = 0.4662$	1.9836e-4
VPS1/PS3	t2022-05-26T105844	$\alpha'_{VPS1,PS3} = 0.4662$	2.1218e-4
VPS1/PS3	t2022-05-26T135022	$\alpha'_{VPS1,PS3} = 0.4662$	1.9123e-4
VPS1/PS3	t2022-06-01T170606	$\alpha'_{VPS1,PS3} = 0.4664$	2.3414e-4
VPS2/PS3	t2022-05-26T094400	$\alpha'_{VPS2,PS3} = 0.4630$	2.1891e-4
VPS2/PS3	t2022-05-26T121313	$\alpha'_{VPS2,PS3} = 0.4629$	2.1030e-4
VPS2/PS3	t2022-06-01T154804	$\alpha'_{VPS2,PS3} = 0.4628$	2.0218e-4
VPS2/PS3	t2022-06-02T090315	$\alpha'_{VPS2,PS3} = 0.4627$	2.0021e-4
VPS2/PS3	t2022-06-02T100443	$\alpha'_{VPS2,PS3} = 0.4627$	2.0544e-4

Entries in the **Ratio** column are hyperlinked to relevant plots.

Summary of standard responsivity ratio measurement results cont.

Ratio	Directory	α'	std. dev.
PS7/PS3	t2022-06-28T131323	$\alpha'_{PS7,PS3} = 0.8393$	3.6255e-4
PS7/PS3	t2022-06-28T161730	$\alpha'_{PS7,PS3} = 0.8393$	3.1627e-4
PS7/PS3	t2022-06-29T112626	$\alpha'_{PS7,PS3} = 0.8391$	3.4660e-4
PS7/PS3	t2022-06-29T172511	$\alpha'_{PS7,PS3} = 0.8392$	3.9361e-4
PS7/PS3	t2022-07-11T152414	$\alpha'_{PS7,PS3} = 0.8394$	3.7181e-4
PS4/PS3	t2022-05-24T090850	$\alpha'_{PS4,PS3} = 0.8359$	3.6824e-4
PS4/PS3	t2022-07-15T112550	$\alpha'_{PS4,PS3} = 0.8356$	3.8396e-4
PS4/PS3	t2022-07-15T145742	$\alpha'_{PS4,PS3} = 0.8356$	3.9590e-4
PS4/PS3	t2022-07-18T123727	$\alpha'_{PS4,PS3} = 0.8359$	3.4268e-4
PS4/PS3	t2022-07-20T090009	$\alpha'_{PS4,PS3} = 0.8358$	3.1065e-4

Entries in the **Ratio** column are hyperlinked to relevant plots.

Summary of standard responsivity ratio measurement results cont.

Ratio	Directory	α'	std. dev.
PS5/PS3	t2022-06-28T143818	$\alpha'_{PS5,PS3} = 0.9109$	3.5310e-4
PS5/PS3	t2022-06-28T175755	$\alpha'_{PS5,PS3} = 0.9110$	4.0375e-4
PS5/PS3	t2022-06-29T093821	$\alpha'_{PS5,PS3} = 0.9107$	3.9821e-4
PS5/PS3	t2022-06-29T125536	$\alpha'_{PS5,PS3} = 0.9109$	3.9951e-4
PS5/PS3	t2022-07-12T181338	$\alpha'_{PS5,PS3} = 0.9112$	3.4732e-4
PS6/PS3	t2022-07-15T092504	$\alpha'_{PS6,PS3} = 0.7898$	3.1425e-4
PS6/PS3	t2022-07-15T132019	$\alpha'_{PS6,PS3} = 0.7897$	3.6272e-4
PS6/PS3	t2022-07-18T112056	$\alpha'_{PS6,PS3} = 0.7896$	3.7218e-4
PS6/PS3	t2022-07-19T132308	$\alpha'_{PS6,PS3} = 0.7897$	3.6585e-4
PS6/PS3	t2022-07-20T102502	$\alpha'_{PS6,PS3} = 0.7897$	3.7873e-4

Entries in the **Ratio** column are hyperlinked to relevant plots.

Summary of standard responsivity ratio measurement results cont.

Ratio	Directory	α'	std. dev.
PS10/WSS	t2022-09-30T090219	$\alpha'_{PS10,WSS} = 0.5911$	2.0536e-4
PS10/WSS	t2022-09-30T111005	$\alpha'_{PS10,WSS} = 0.5910$	1.9227e-4
PS10/WSS	t2022-10-03T115432	$\alpha'_{PS10,WSS} = 0.5910$	1.8429e-4
PS10/WSS	t2022-10-03T141942	$\alpha'_{PS10,WSS} = 0.5910$	2.0579e-4
PS10/WSS	t2022-11-03T113413	$\alpha'_{PS10,WSS} = 0.5905$	1.9544e-4
PS11/PS3	t2022-08-12T084219	$\alpha'_{PS11,PS3} = 0.7853$	3.1504e-4
PS11/PS3	t2022-08-12T102040	$\alpha'_{PS11,PS3} = 0.7854$	3.3372e-4
PS11/PS3	t2022-11-04T103046	$\alpha'_{PS11,PS3} = 0.7858$	3.2806e-4
PS11/PS3	t2022-11-04T120807	$\alpha'_{PS11,PS3} = 0.7857$	3.6282e-4
PS11/PS3	t2022-11-07T094210	$\alpha'_{PS11,PS3} = 0.7858$	3.2914e-4

Entries in the **Ratio** column are hyperlinked to relevant plots.

Running the alphatrends.py script

path to script: /ligo/svncommon/CalSVN/aligocalibration/trunk/Projects/PhotonCalibrator/scripts/O4/alphatrends.py

* The script goes into all the t-directories and extracts the alphaprime value and the rel.standard error from dev1dev2_alphaprime.csv file to plot the trend.

Copy the script into the standard resp. ratio measurement directory

Run python3 alphatrends.py

* Generates dev1dev2_alphatrends.pdf
* Generates dev1dev2_alpha.csv with columns dev, w_mean, w_rel_std and w_rel_serr

Summary of standard responsivity ratio measurement results

Ratio	**m**ean($\alpha^{'}$)	**s**td. dev. ($\alpha^{'}$)
PS1/PS3	$\alpha^{'}_{PS1,PS3} = 0.7750$	2.0435e-4
PS2/PS3	$\alpha^{'}_{PS2,PS3} = 0.7596$	2.4314e-4
PS1/WSS	$\alpha^{'}_{PS1,WSS} = 0.5303$	1.5207e-4
PS2/WSS	$\alpha^{'}_{PS2,WSS} = 0.5199$	1.3560e-4
PS3/WSS	$\alpha^{'}_{PS3,WSS} = 0.6844$	7.4606e-4
VPS1/PS3	$\alpha^{'}_{VPS1,PS3} = 0.4662$	1.3556e-4
VPS2/PS3	$\alpha^{'}_{VPS2,PS3} = 0.4628$	2.8526e-4
PS7/PS3	$\alpha^{'}_{PS7,PS3} = 0.8392$	1.2469e-4
PS4/PS3	$\alpha^{'}_{PS4,PS3} = 0.8358$	1.5648e-4
PS5/PS3	$\alpha^{'}_{PS5,PS3} = 0.9110$	2.1372e-4

Entries in the **Ratio** column are hyperlinked to relevant plots.

Summary of standard responsivity ratio measurement results

Ratio	**m**ean($\alpha^{'}$)	**s**td. dev. ($\alpha^{'}$)
PS6/PS3	$\alpha^{'}_{PS6,PS3} = 0.7897$	3.7873e-4
PS10/WSS	$\alpha^{'}_{PS10,WSS} = 0.5909$	4.2266e-4
PS11/PS3	$\alpha^{'}_{PS11,PS3} = 0.7856$	3.004e-4

Entries in the **Ratio** column are hyperlinked to relevant plots.

Generation of the O4 parameters file

Generate O4params.csv file

path to script: /ligo/svncommon/CalSVN/aligocalibration/trunk/Projects/PhotonCalibrator/scripts/O4/generate_params.py

* The script copies PS2PS3params.csv from PS3PS2iter folder to O4params.csv which is saved under measurements/LabData.
* It goes into the i-directories and the t-directories for the specified device and extracts all the relevant parameters.

Modify the script everytime to specify which device parameters you wish to append to the parameters file.

Run `python3 generate_params.py`

* Generates O4params.csv for PS2, PS3 and other devices in PhotonCalibrator/measurements/LabData with columns dev, m_{dark}, V_{dark}, kappa.

Responsivity trends

$\rho'_{dev1} = \alpha'_{dev1,PS3} \times \alpha'_{PS3,WSS} \times \rho'_{WSS}$

path to script: /ligo/svncommon/CalSVN/aligocalibration/trunk/Projects/PhotonCalibrator/scripts/O4/PS_resp.py

Copy script to PhotonCalibrator/measurements/LabData/rhoprime/

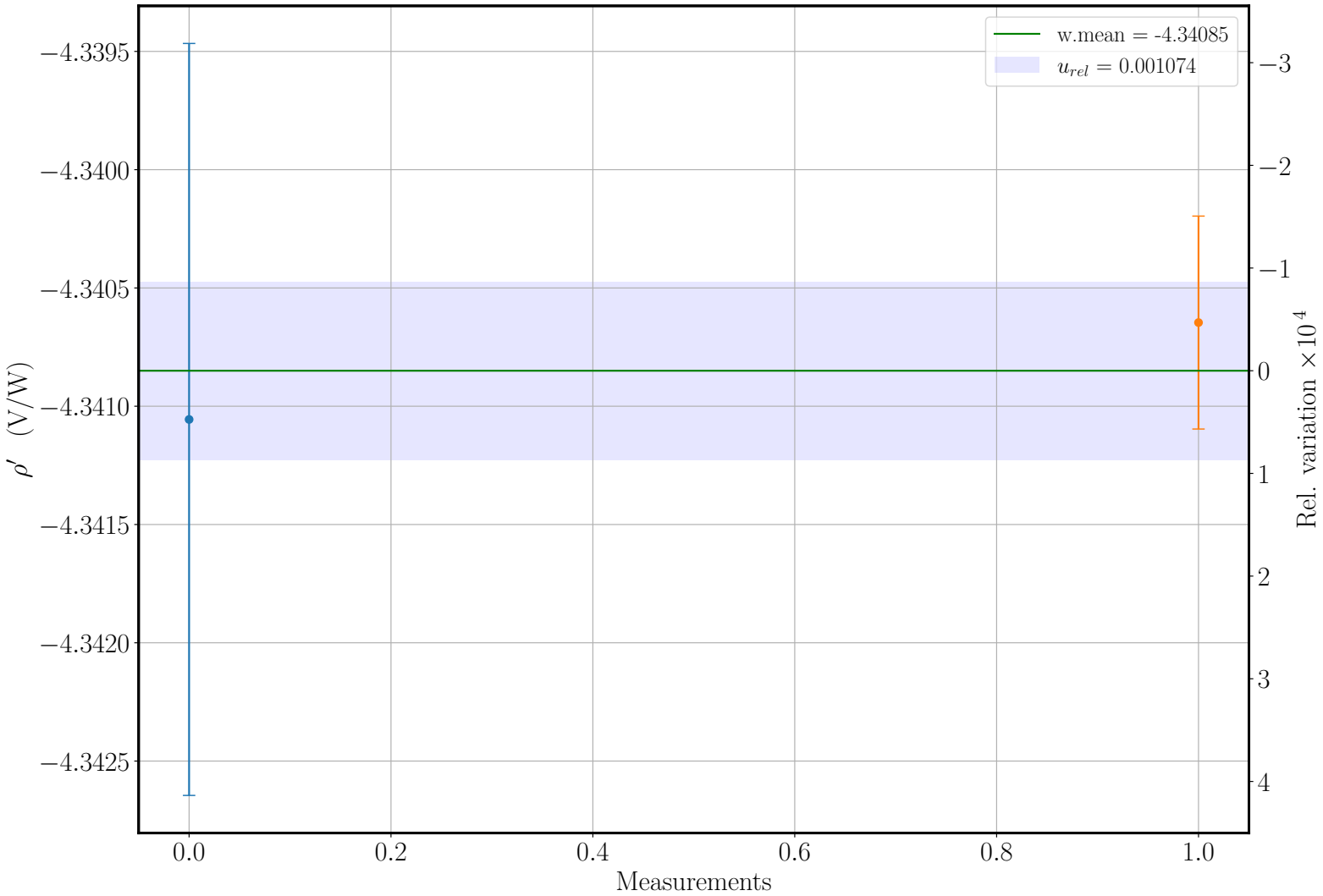
Run python3 PS_resp.py dev1

* Generates rhoPrimedev1.pdf with the responsivity trend

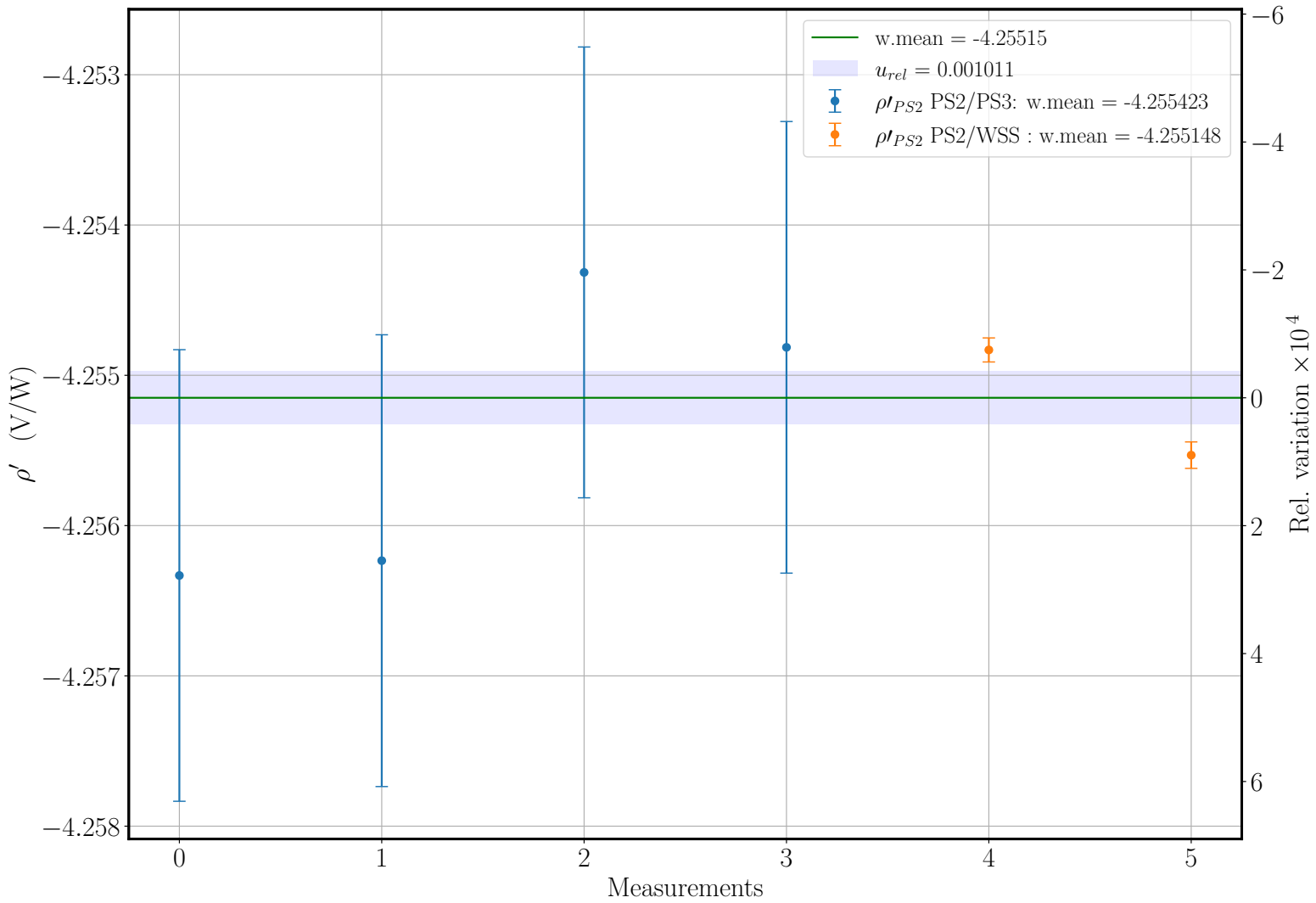
The script to generate responsivity trends for PS1 and PS2 has been modified and saved as PS1PS2_resp.py since we have PS1(2)/WSS and PS1(2)/PS3 measurements. The modified script calculates ρ' from ρ'_{PS3} as well as from ρ'_{WSS} and concatenates the two trends

The script to generate responsivity trends for PS3 has also been modified and saved as PS3_resp.py since we have PS3/WSS measurements. In this case, $\rho'_{dev1} = \alpha'_{PS3,WSS} \times \rho'_{WSS}$

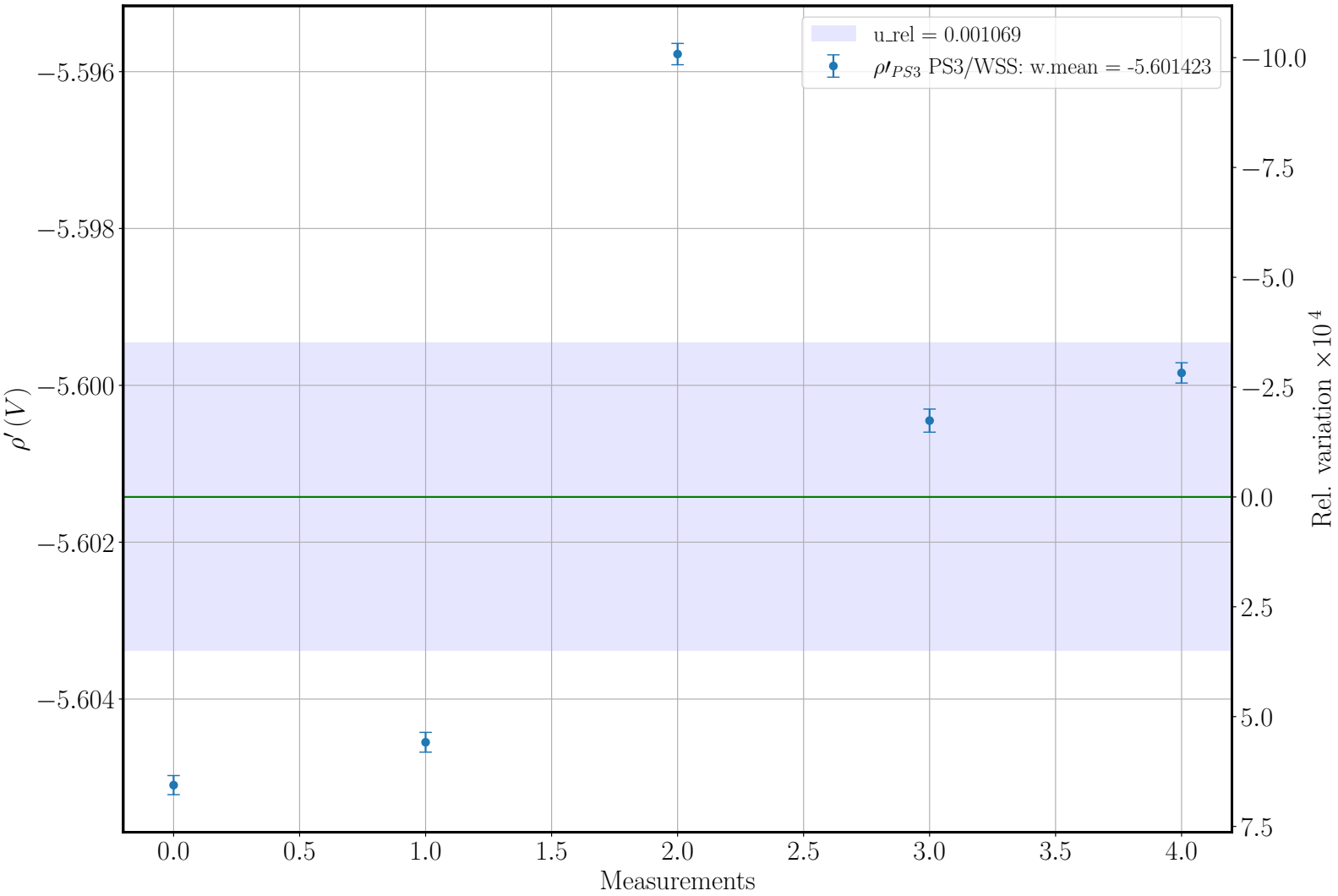
Responsivity trends - PS1



Responsivity trends - PS2

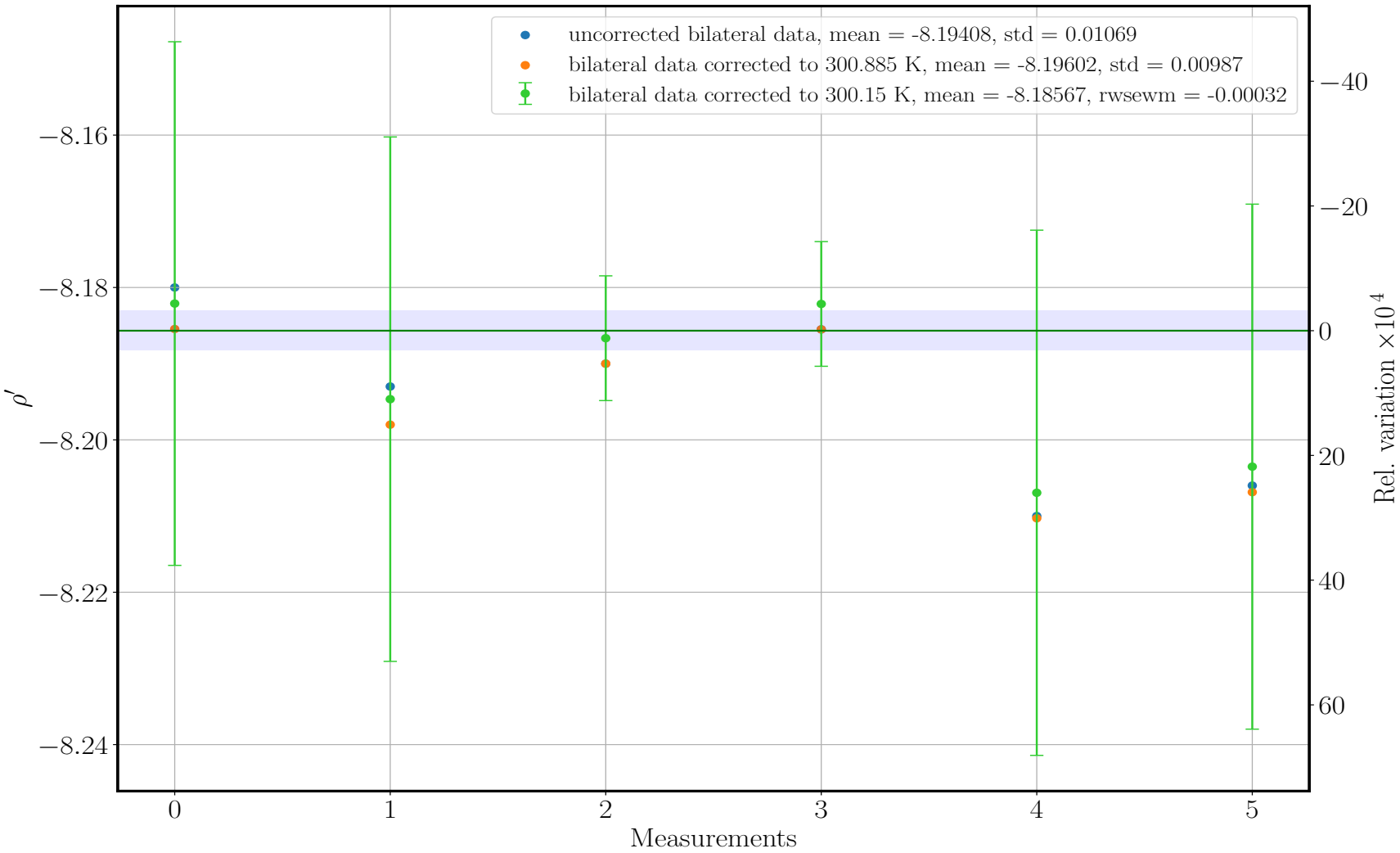


Responsivity trends - PS3

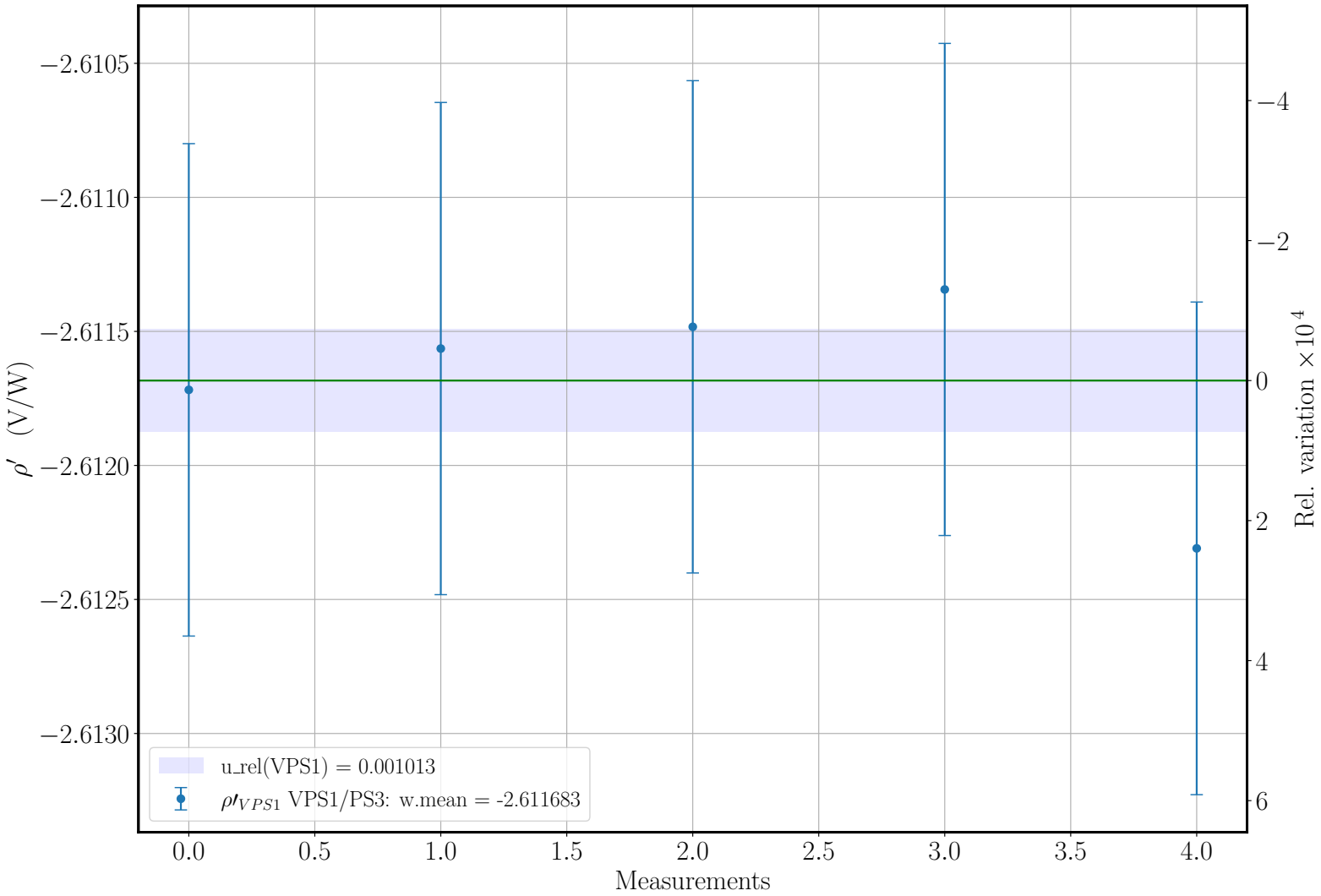


ρ'_{wss} from 2020 NIST/PTB bilateral comparison

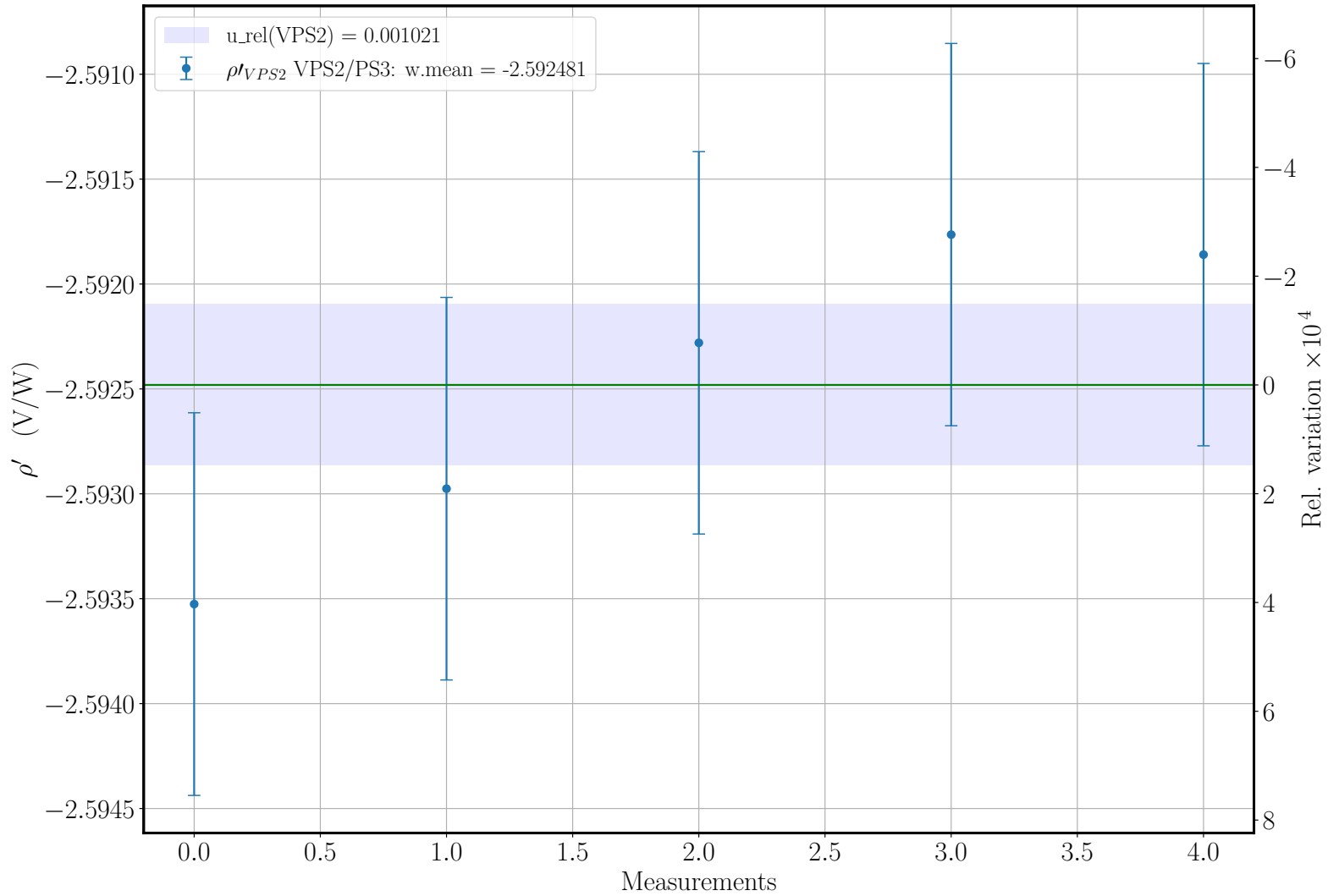
This plot is not generated from the PS_resp.py.



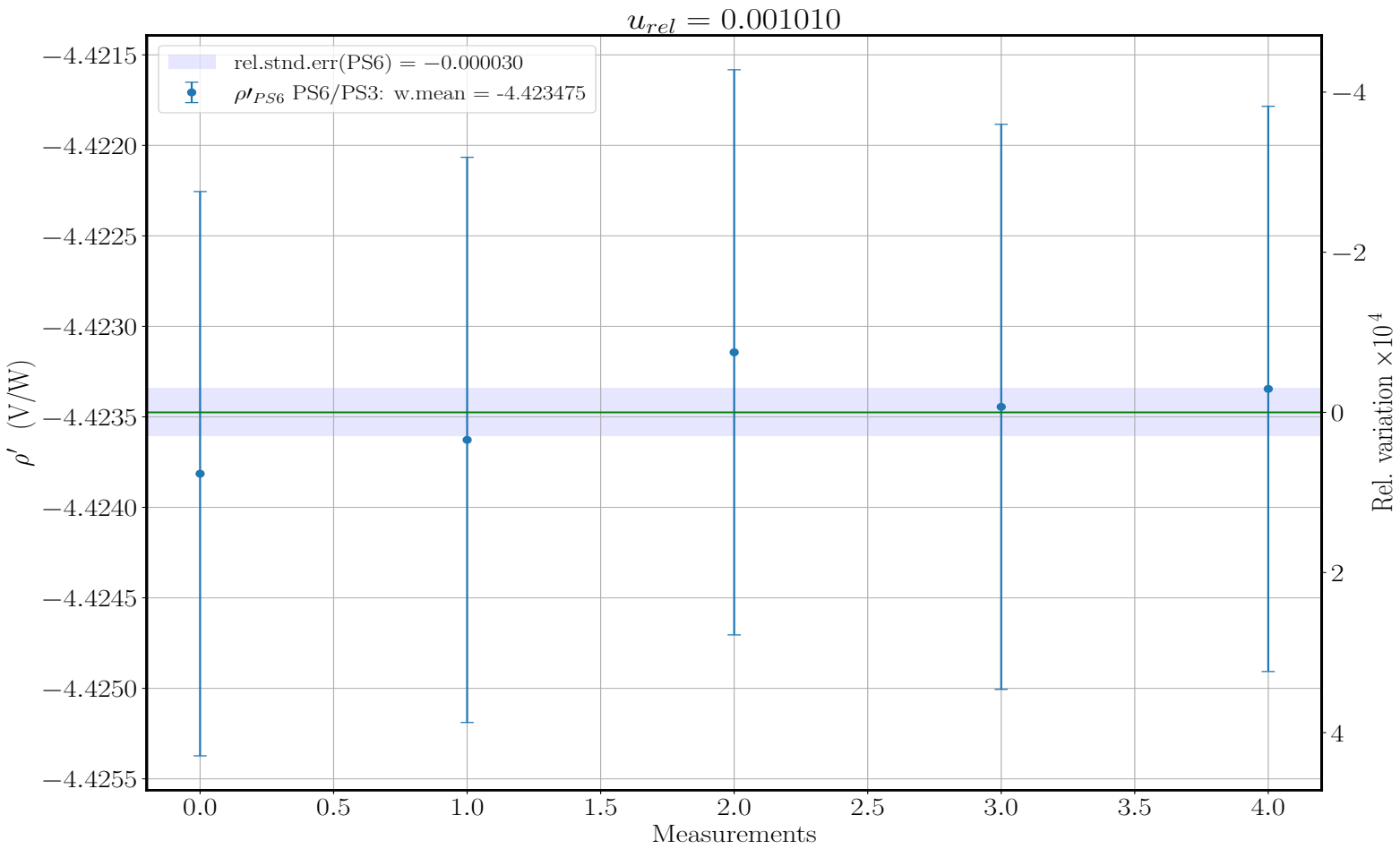
Responsivity trends - VPS1



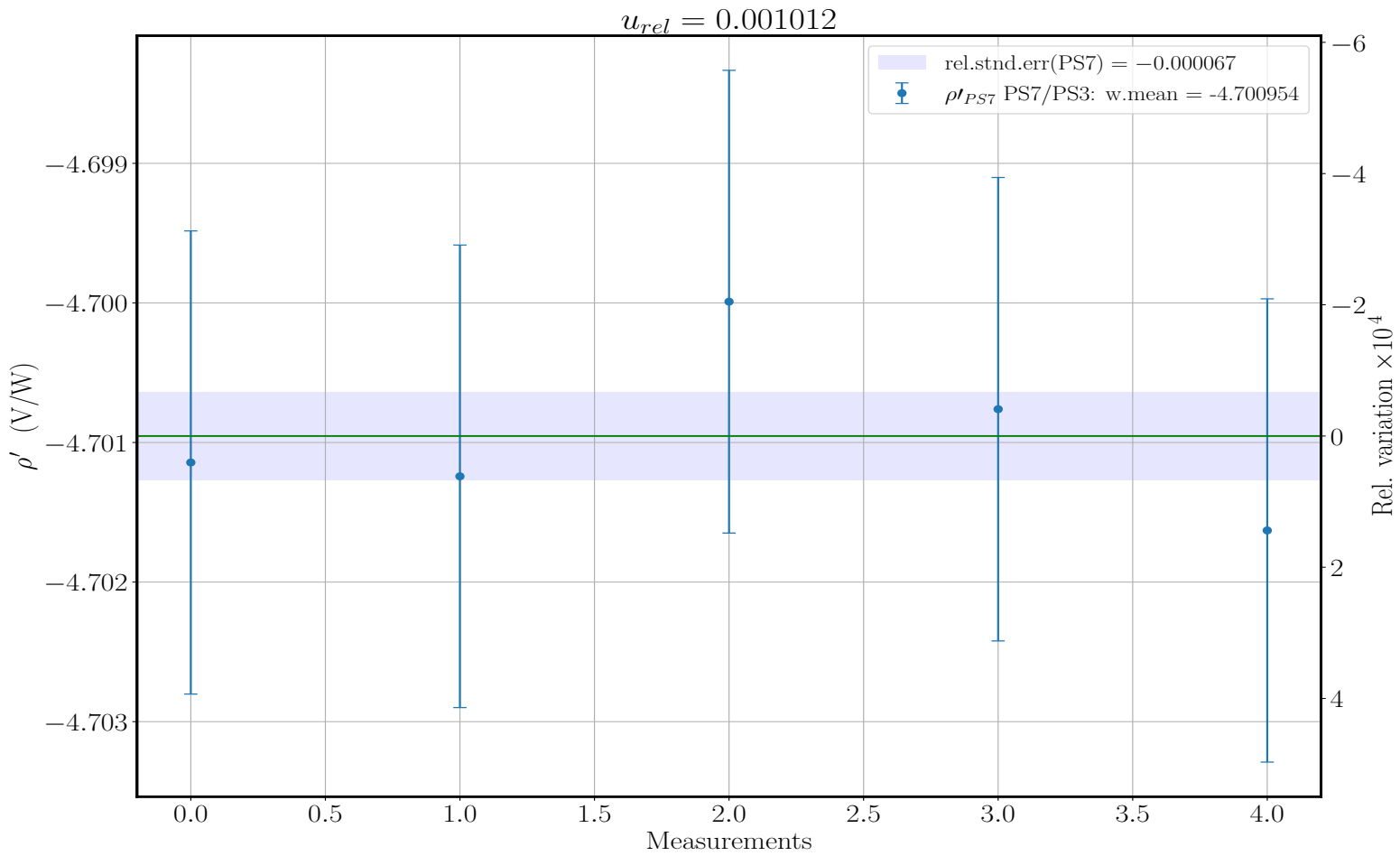
Responsivity trends - VPS2



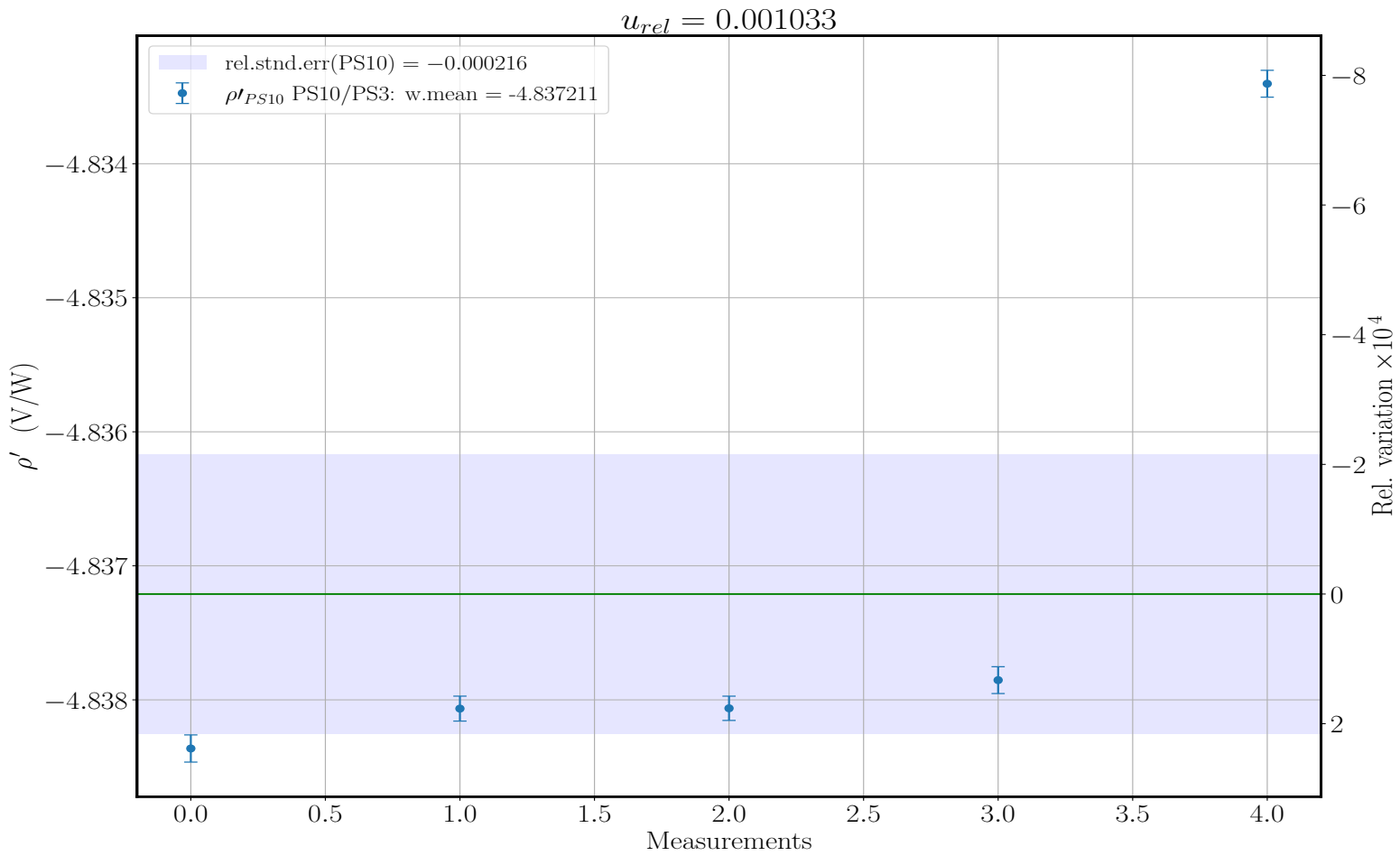
Responsivity trends - PS6



Responsivity trends - PS7



Responsivity trends - PS10



Responsivity trends - PS11