LIGO Laboratory / LIGO Scientific Collaboration

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L1 Optical Lever Commissioning and Testing

T1400393 – V5

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Distribution of this document:
Advanced LIGO Project

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of the LIGO Laboratory

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Scope and Introduction

This document covers the methods and results of each L1 aLIGO optical levers testing and commissioning phase. All measurements to date are done with HEPI floating and ISI damping for whenever applicable, if HEPI is not yet commissioned, then it will be locked prior to the beginning of the measurement. Additionally, all available suspension damping loops will be engaged wherever applicable. These results will serve the purpose of verifying that each optical lever is passing specs outlined in E1200719-v1 as well as letting the end user know the characteristics of each lever such as the linear range and structural resonances. If an optical lever does not meet spec, changes may be made to the physical system (mechanical, electronics, software, etc) in order to comply with requirements. Those changes to the system will require changes to this document (new graphs or data).

Required attributes that will deem an optical lever commissioned and passed testing phase:

- Calibration of the optical levers into micro radians.
- Beam profiles in vertical and horizontal directions at the QPD. The beam scan used for taking this data will be a THORLABS BP209-VIS.
- Calibrated spectra comparing the Optical Lever signals to OSEMS or ISI position sensors.
- Longitudinal to angular coupling coefficients (calculated via T1300130):
    - dɵ'/dx (yaw) = ds' (yaw) / (2 L) = (1 / L) sin(ɵ) cos(φ)
    - dφ'/dx (pitch) = ds' (pitch) / (2 L) = (1 / L) sin(ɵ) sin(φ)
- Long-term drift testing results.
- Dark current noise floor measurement.

Since the HAM optical levers do not have a translation stage with a micrometer, we need to find a separate method to measure the linear response curve.

The process for HAM and BS OpLev calibration will have two varieties:

The first way we can take the calibration data from another optical lever and scale the geometry, beam power, and beam width so that it matches HAM2. The geometry scaling can be derived from the Zeemax layouts and the lever arm is directly proportional to the sensitivity of the optical lever. The beam power for the optical levers can be found by looking at a time average of the sum of counts. The beam widths can be found by looking at the beam profile at the QPD. Both the power and the widths are linearly related to the sensitivity so they can be scaled simply as well. A potential source of error would associated with the performance of the QPDs on an individual basis, these will be tested to look at the variance of power and sensitivity in order to create and error via this method.

A second way to map the linear response curve is to drive the ISI and correlate the optical lever pitch and yaw signals to the position sensors (RX, RY, and RZ). This requires a set actuation at a few different amplitudes to prove linearity in the actuators as well as a coherence function to show that we see good correlation. For HAM2, the RY sensors will correspond to the pitch OptLev signals and the RZ sensors will correspond to the yaw OptLev signals.

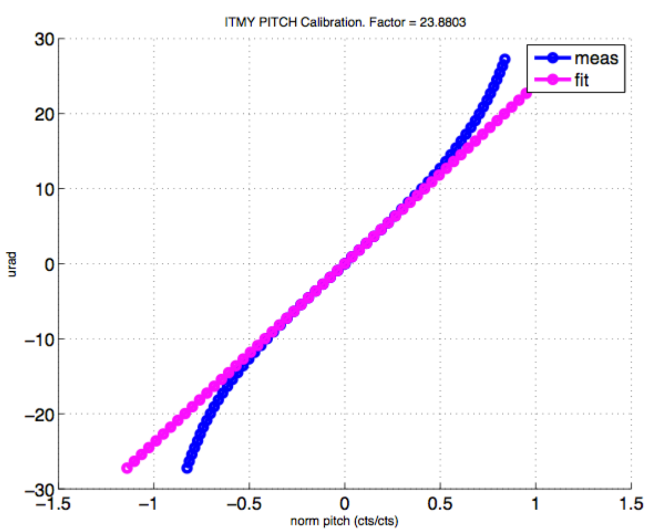
Summary:

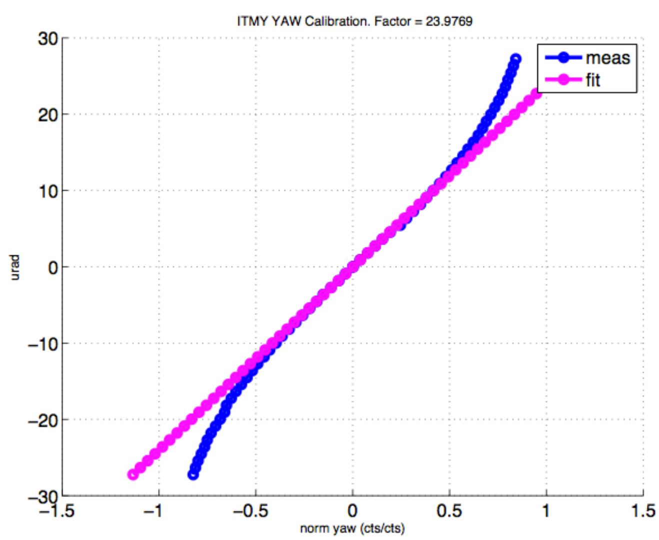
	Target	Laser SN	Profiled	Calibrated	Issues
L1	HAM2	-	No	No	Requires non-glitching laser.
L1	HAM3	136	No	No	Requires non-glitching laser.
L1	HAM4	-	No	No	Requires non-glitching laser.
L1	HAM5	-	No	No	Requires non-glitching laser.
L1	BS	186	No	No	Requires non-glitching laser.
L1	ITMX	192	Yes	Yes	Beam size is larger than required and will be adjusted.
L1	ITMY	190	Yes	Yes	Beam size is slightly larger than required. Adjustment possibly needed.
L1	ETMX	125	No	Yes	Beam scan reveals prominent rings. Telescope adjustment needed. Requires non-glitching laser.
L1	ETMY	139	Yes	No	Calibration values are ~100, a problem is suspected. Requires non-glitching laser.
L1	PR3	143	Yes	Yes	Requires non-glitching laser.
L1	SR3	187	No	Yes	Requires non-glitching laser.

1 ITMY

	Gaussian_Width (mm)	**Calibration (Counts/urad)**	**Low- Frequency Resonances (Hz)**	**Long-to-ang coupling coefficient (urad/m)**	**Peak-to-peak drift (uradians/10 minutes)**
Pitch	4.22	23.88		0.56	
Yaw	4.18	23.98		0.30	

1.1 Calibration Parameters





The slope of the linear region of the graph for pitch and yaw:

Pitch: 23.88 [uradians/counts]

Yaw: 23.98 [uradians/counts]

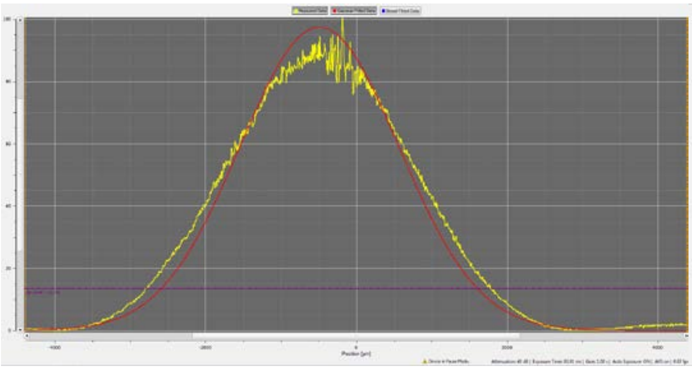
The geometric calculation for these parameters uses a Zeemax calculation for the path lengths of the lever arms from **E1200836--v1**. A DC method was used to obtain the y-axis data; we first translate the QPD a fixed amount as measured with a micrometer and use the geometry of the setup to correlate an angular deviation to the pitch or yaw signals.

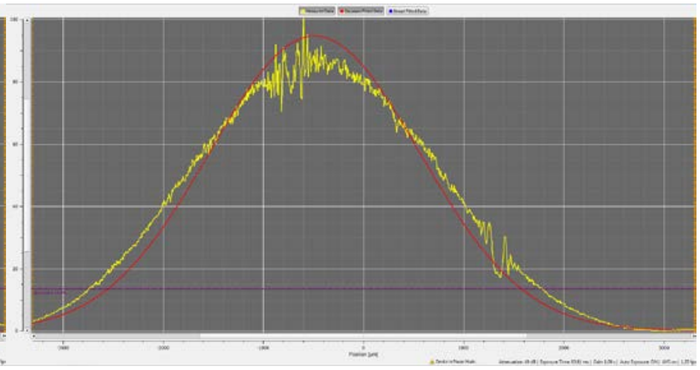
These results are inputted into the SUS gain filters:

L1-SUS-ITMY_L3_OPLEV_PIT_GAIN

L1-SUS-ITMY_L3_OPLEV_YAW_GAIN

1.2 Beam Profile





	Gaussian Width (mm)	Gaussianity (%)
X-Axis (left side)	4.22	95.3
Y-Axis (right side)	4.18	94.3

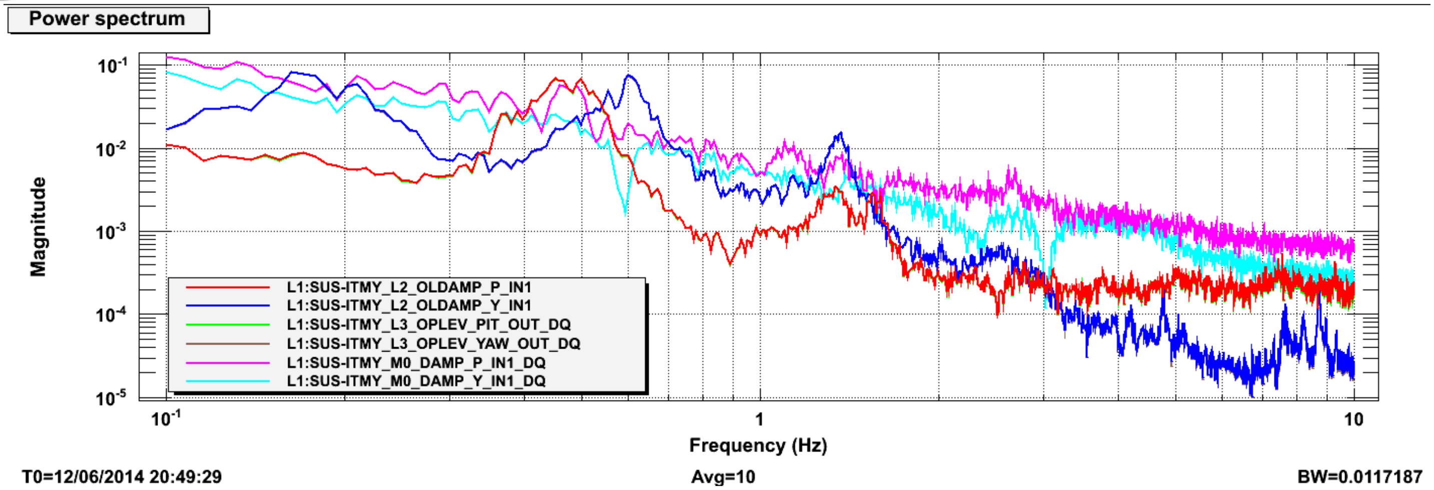
1.3 Longitudinal to Angular Coupling

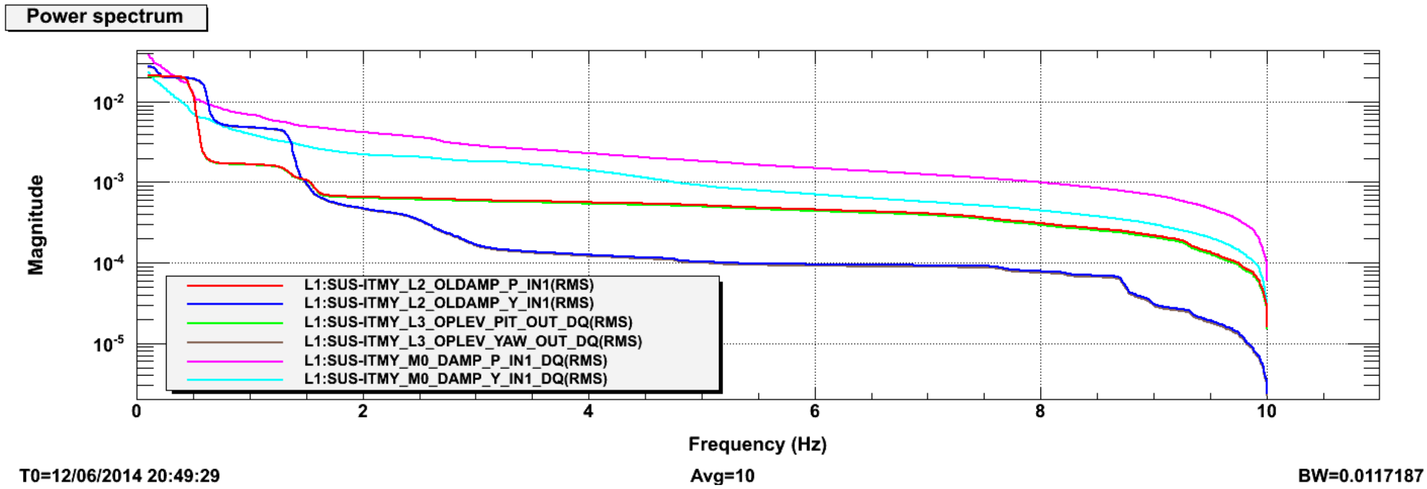
- L = 66.1207 m
- ɵ = 1.22 degrees
- φ = 59.62 degrees

dɵ'/dx = 0.56 urad/m

dφ'/dx = 0.3 urad/m

1.4 Calibrated Spectra





1.5 Calibrated Long Term Drift

1.6 QPD Sensor Dark Noise

2 ETMY

	Gaussian Width (mm)	Calibration (Counts/urad)	Low- Frequency Resonances (Hz)	Long-to-ang coupling coefficient (urad/m)	Peak-to-peak drift (uradians/10 minutes)
Pitch	2.44			20.91	
Yaw	2.36			11.9	

2.1 Calibration Parameters

The slope of the linear region of the graph for pitch and yaw:

Pitch: [uradians/counts]

Yaw: [uradians/counts]

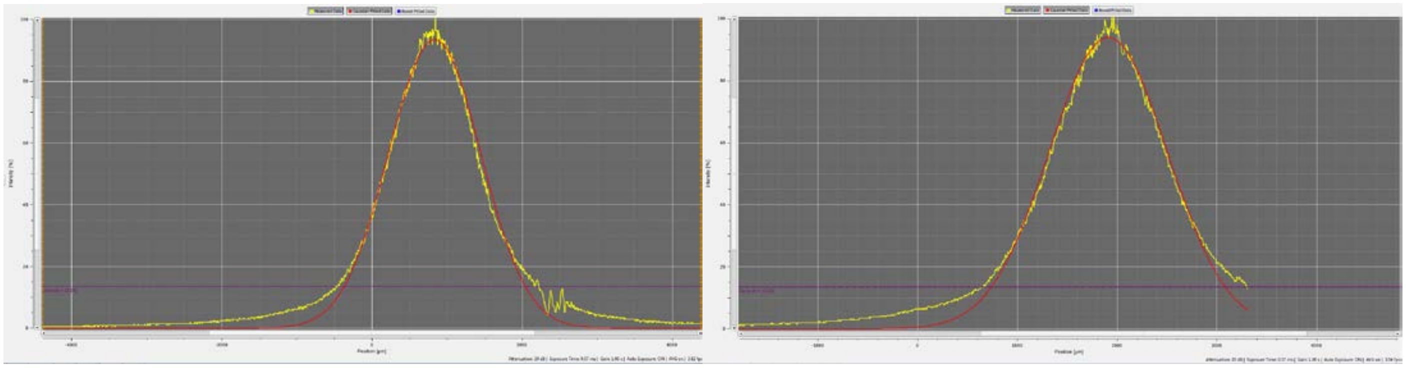
The geometric calculation for these parameters uses a Zeemax calculation for the path lengths of the lever arms from **E1200836--v1**. A DC method was used to obtain the y-axis data; we first translate the QPD a fixed amount as measured with a micrometer and use the geometry of the setup to correlate an angular deviation to the pitch or yaw signals.

These results are inputted into the SUS gain filters:

L1-SUS-ETMY_L3_OPLEV_PIT_GAIN

L1-SUS-ETMY_L3_OPLEV_YAW_GAIN

2.2 Beam Profile



	Gaussian Width (mm)	Gaussianity (%)
X-Axis (left side)	2.44	90.9
Y-Axis (right side)	2.36	91.6

2.3 Longitudinal to angular coupling

- L = 11.16 m
- ɵ = 7.65 degrees
- φ = 60.25 degrees

dɵ'/dx = 20.91 urad/m

dφ'/dx = 11.90 urad/m

2.4 Calibrated Spectra

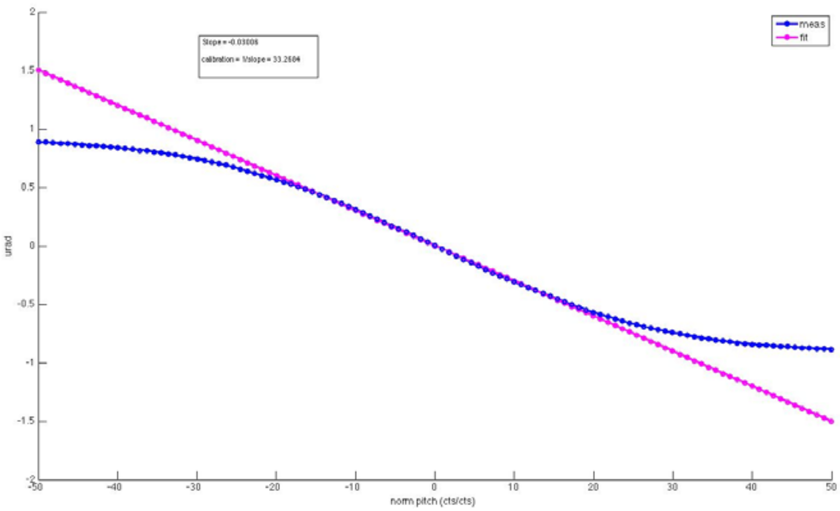
2.5 Calibrated Long Term Drift

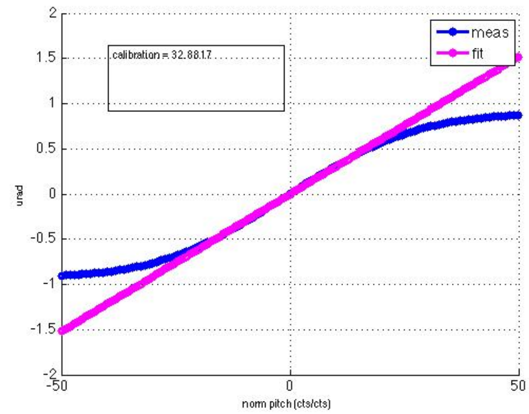
2.6 QPD Sensor Dark Noise

3 ITMX

	Gaussian_Width (mm)	Calibration (Counts/urad)	Low- Frequency Resonances (Hz)	Long-to-ang coupling coefficient (urad/m)	Peak-to-peak drift (uradians/10 minutes)
Pitch	5.33	33.27		0.56	
Yaw	5.37	32.88		0.30	

3.1 Calibration Parameters





The slope of the linear region of the graph for pitch and yaw:

Pitch: 33.27 [uradians/counts]

Yaw: 32.88 [uradians/counts]

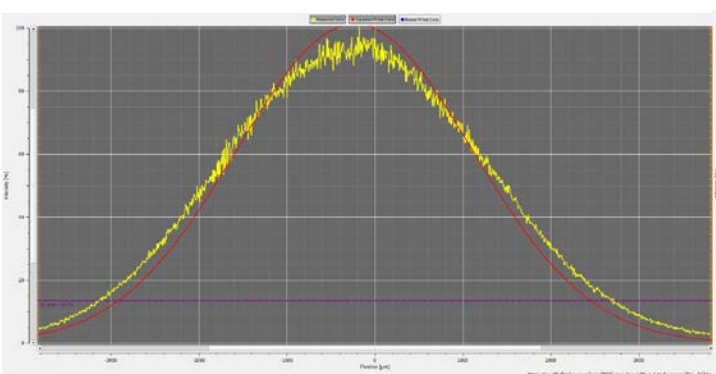
The geometric calculation for these parameters uses a Zeemax calculation for the path lengths of the lever arms from **E1200836--v1**. A DC method was used to obtain the y-axis data; we first translate the QPD a fixed amount as measured with a micrometer and use the geometry of the setup to correlate an angular deviation to the pitch or yaw signals.

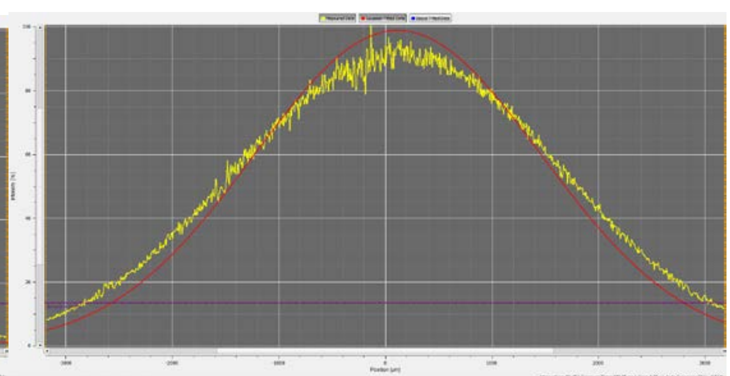
These results are inputted into the SUS gain filters:

L1-SUS-ITMX_L3_OPLEV_PIT_GAIN

L1-SUS-ITMX_L3_OPLEV_YAW_GAIN

3.2 Beam Profile





	Gaussian Width (mm)	Gaussianity (%)
X-Axis (left side)	5.33	93.5
Y-Axis (right side)	5.37	93.1

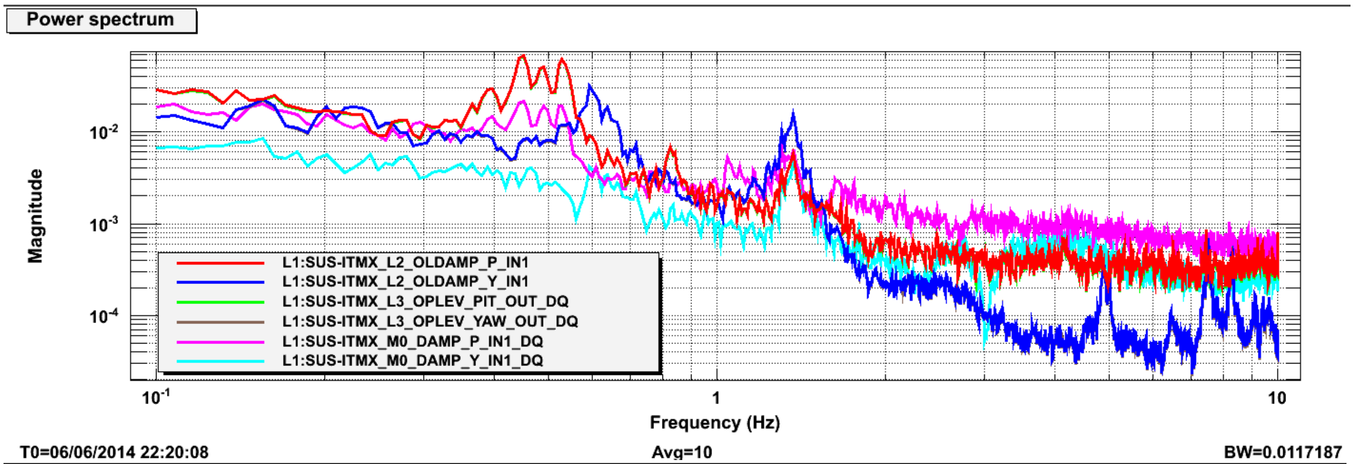
3.3 Longitudinal to Angular Coupling

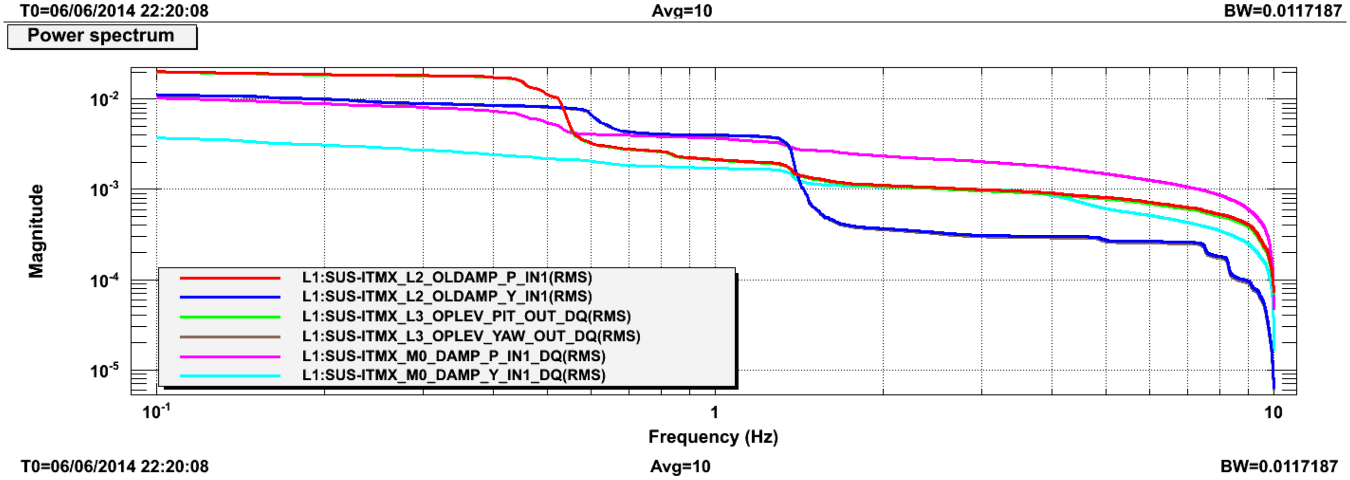
- L = 66.1147 m
- ɵ = 1.22 degrees
- φ = 59.62 degrees

dɵ'/dx = 0.56 urad/m

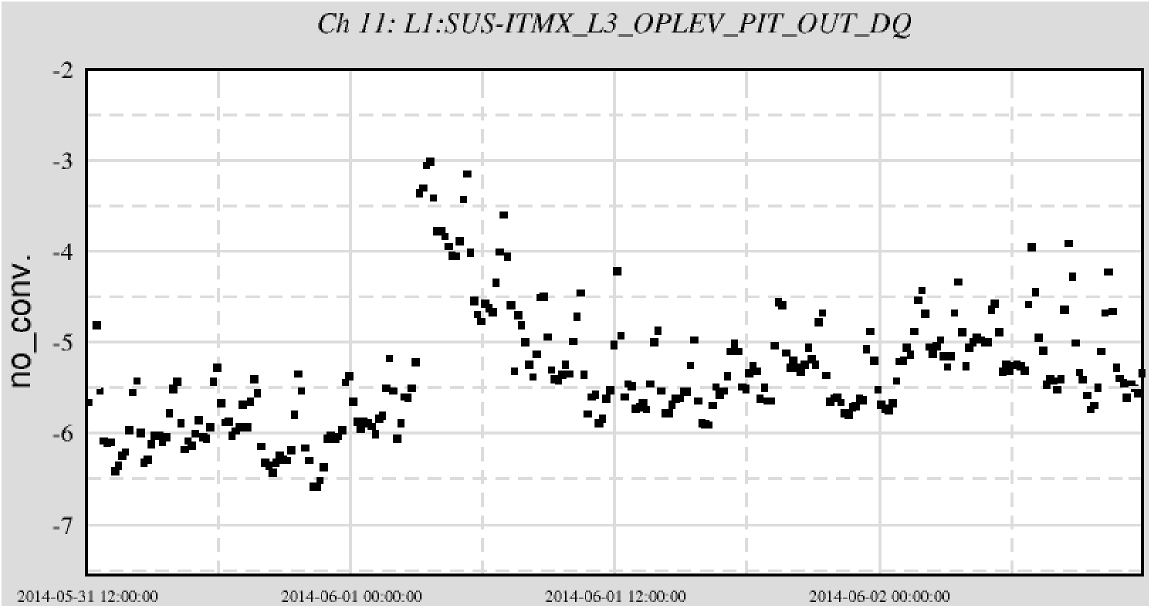
dφ'/dx = 0.3 urad/m

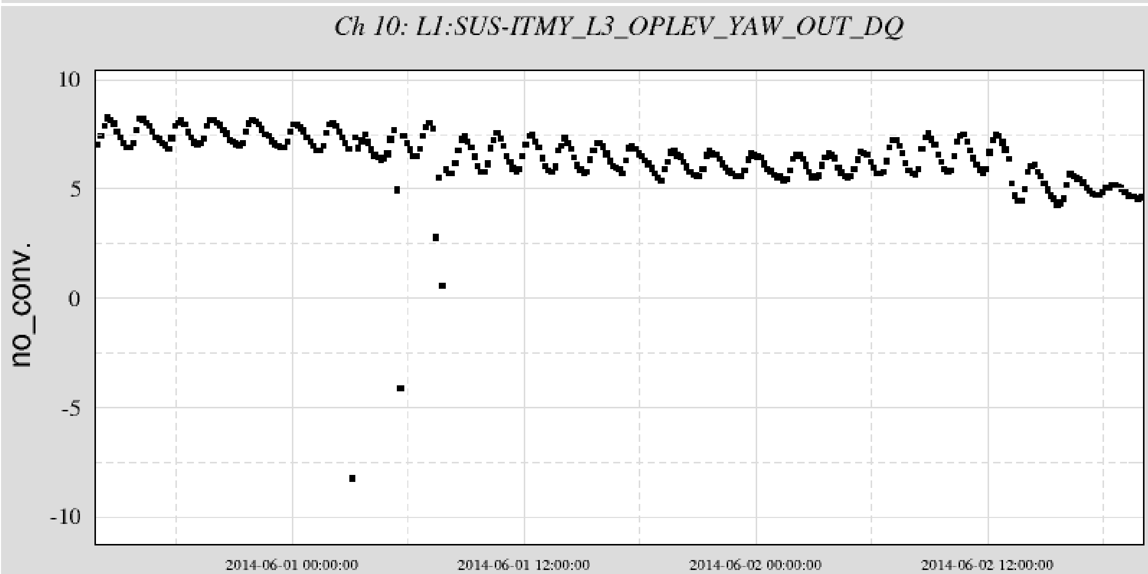
3.4 Calibrated Spectra





3.5 Calibrated Long Term Drift



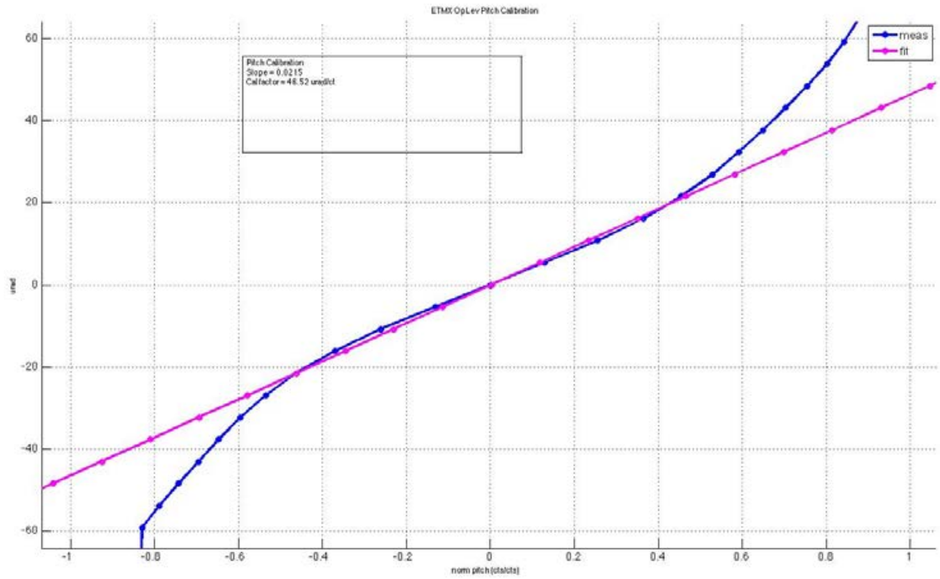


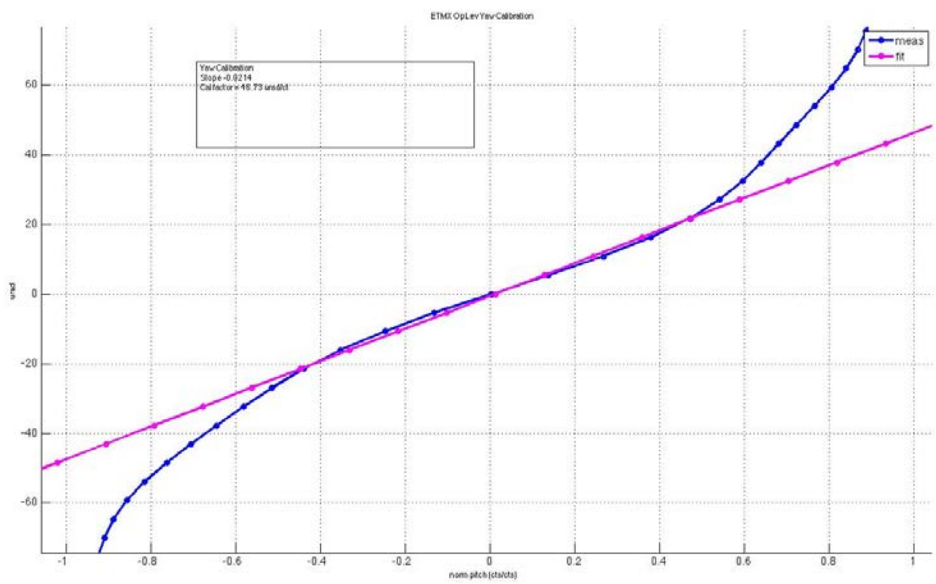
3.6 QPD Sensor Dark Noise

4 ETMX

	Gaussian Width (mm)	Calibration (Counts/urad)	Low- Frequency Resonances (Hz)	Long-to-ang coupling coefficient (urad/m)	Peak-to-peak drift (uradians/10 minutes)
Pitch		46.51		20.89	
Yaw		46.73		11.9	

4.1 Calibration Parameters





The slope of the linear region of the graph for pitch and yaw:

Pitch: 46.51 [uradians/counts]

Yaw: 46.73 [uradians/counts]

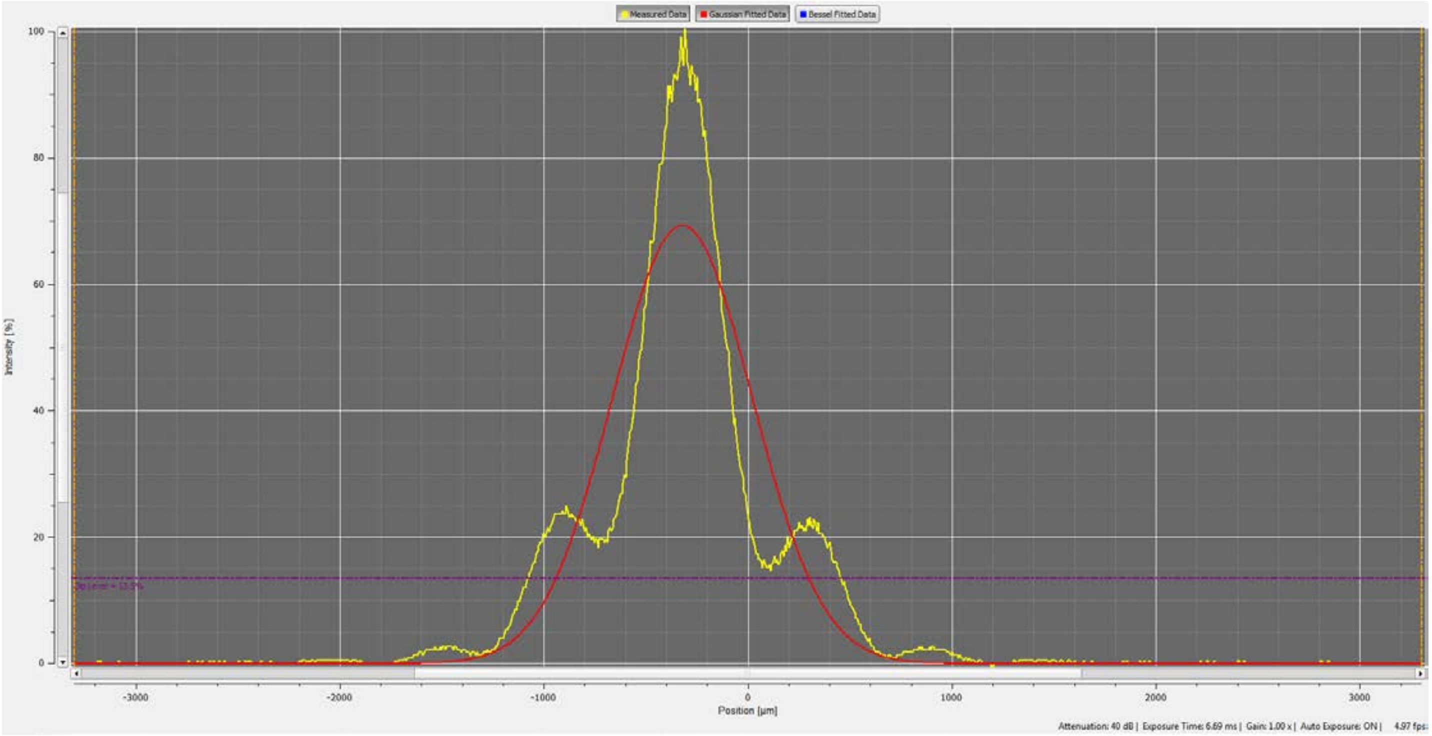
The geometric calculation for these parameters uses a Zeemax calculation for the path lengths of the lever arms from **E1200836--v1**. A DC method was used to obtain the y-axis data; we first translate the QPD a fixed amount as measured with a micrometer and use the geometry of the setup to correlate an angular deviation to the pitch or yaw signals.

These results are inputted into the SUS gain filters:

L1-SUS-ETMX_L3_OPLEV_PIT_GAIN

L1-SUS-ETMX_L3_OPLEV_YAW_GAIN

4.2 Beam Profile



	Gaussian Width (mm)	Gaussianity (%)
X-Axis (left side)		
Y-Axis (right side)		

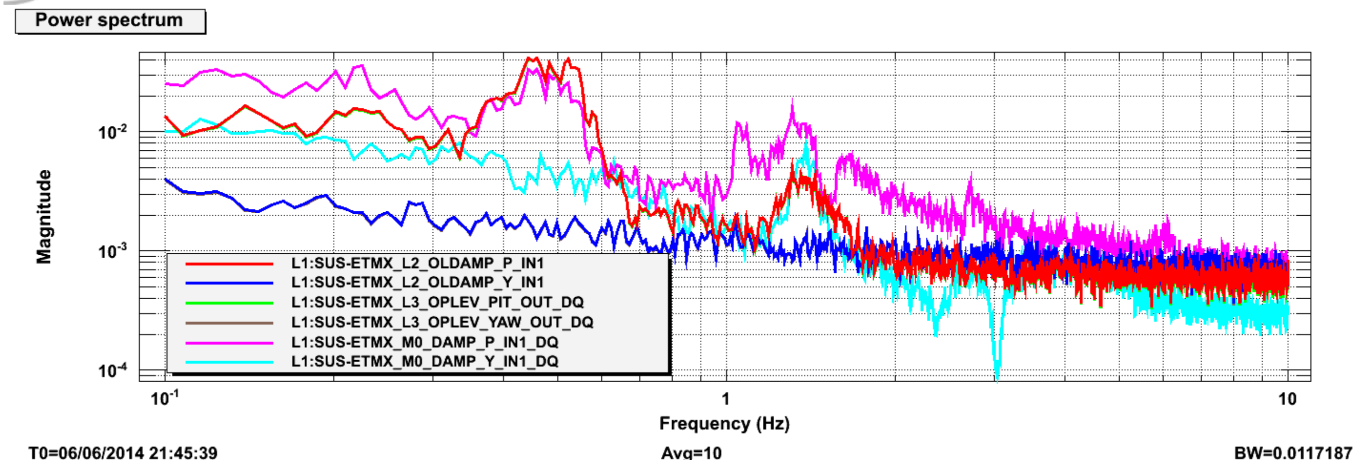
4.3 Longitudinal to angular coupling

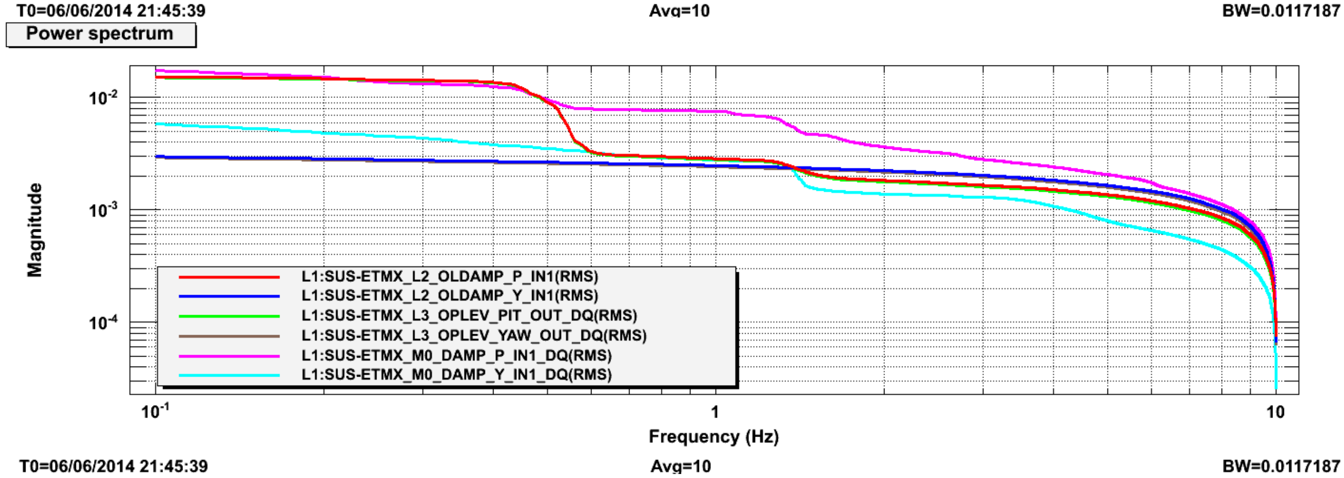
- L = 11.162 m
- θ = 7.65 degrees
- φ = 60.25 degrees

$d\theta'/dx$ = 20.89 urad/m

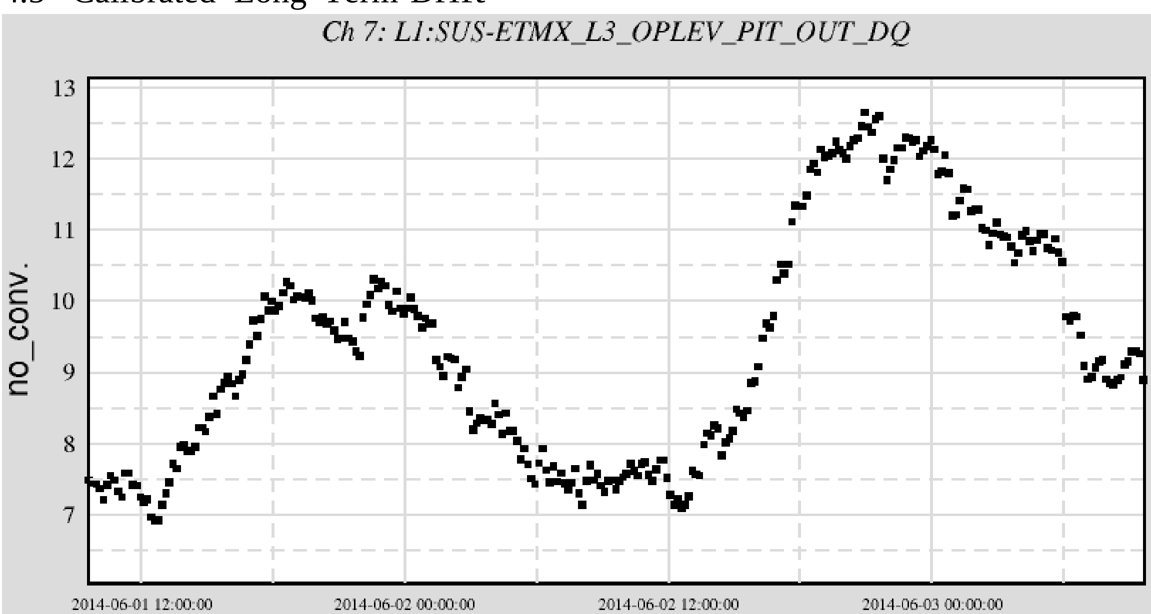
$d\varphi'/dx$ = 11.90 urad/m

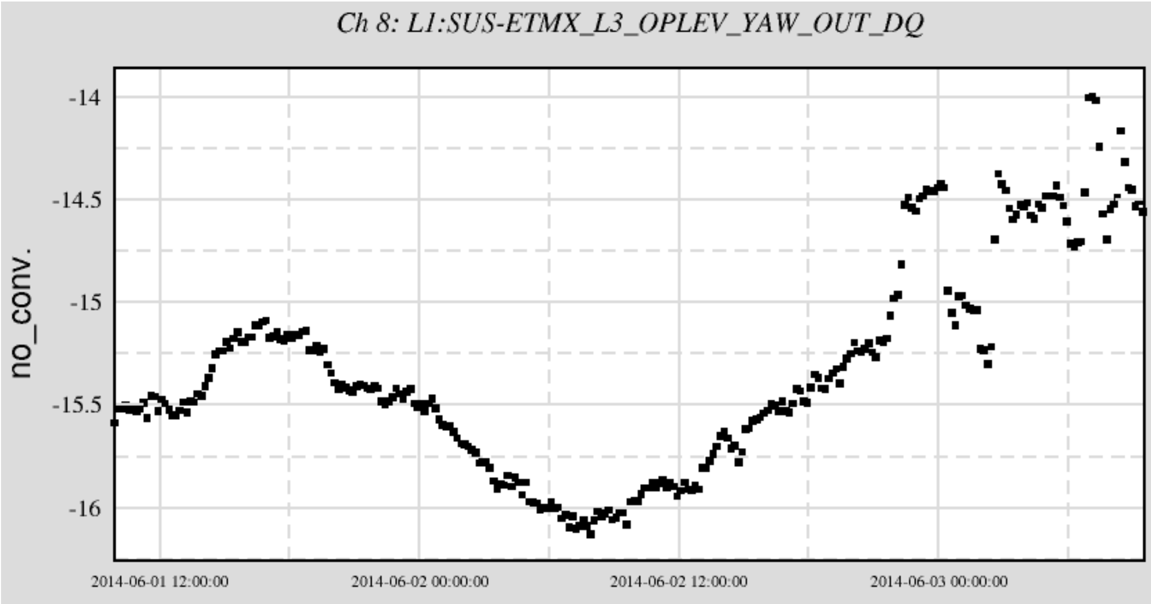
4.4 Calibrated Spectra





4.5 Calibrated Long Term Drift





4.6 QPD Sensor Dark Noise

5 Beam Splitter

	Gaussian Width (mm)	Calibration (Counts/urad)	Low- Frequency Resonances (Hz)	Long-to-ang coupling coefficient (urad/m)	Peak-to-peak drift (uradians/10 minutes)
Pitch				0.00	
Yaw				26.3	

5.1 Calibration Parameters

The slope of the linear region of the graph for pitch and yaw:

Pitch: [uradians/counts]

Yaw: [uradians/counts]

The geometric calculation for these parameters uses a Zeemax calculation for the path lengths of the lever arms from **E1200836--v1**.

These results are inputted into the SUS gain filters:

L1-SUS-BS_L3_OPLEV_PIT_GAIN

L1-SUS-BS_L3_OPLEV_YAW_GAIN

5.2 Beam Profile

	Gaussian Width (mm)	Gaussianity (%)

X-Axis (left side)		
Y-Axis (right side)		

5.3 Longitudinal to angular coupling

- L = 4.021 m
- ɵ = 3.03 degrees
- φ = 0 degrees

dɵ'/dx = 0.00 urad/m

dφ'/dx = 26.3 urad/m

5.4 Calibrated Spectra

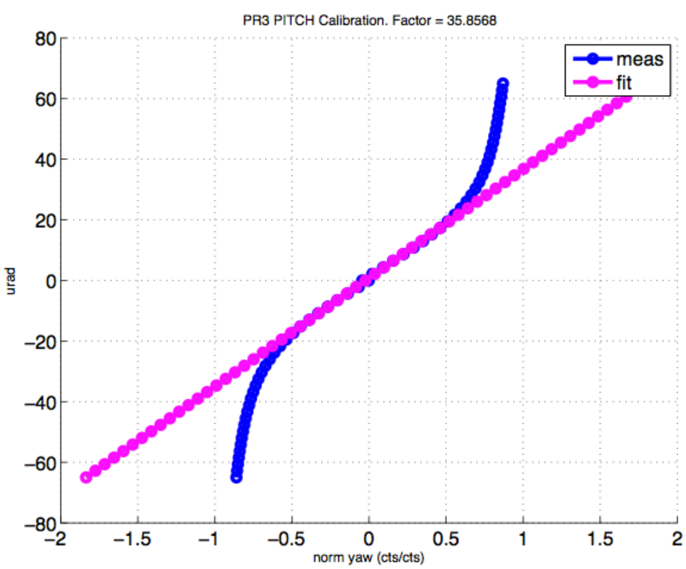
5.5 Calibrated Long Term Drift

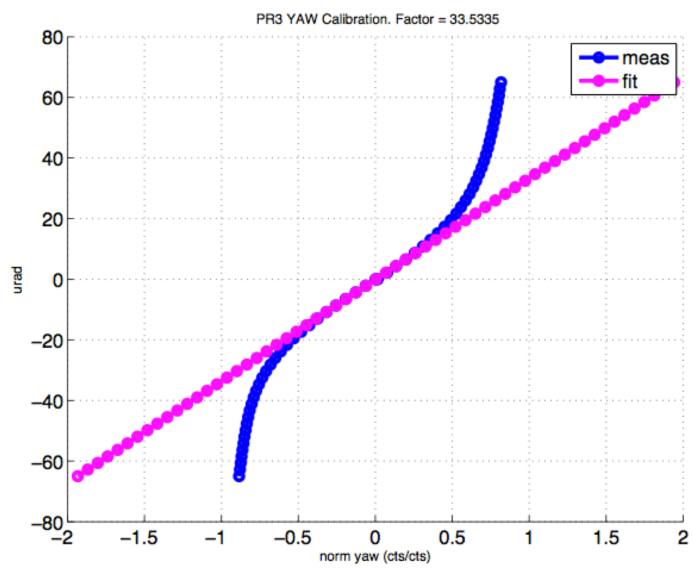
5.6 QPD Sensor Dark Noise

6 PR3

	Gaussian_Width (mm)	**Calibration (Counts/urad)**	**Low- Frequency Resonances (Hz)**	**Long-to-ang coupling coefficient (urad/m)**	**Peak-to-peak drift (uradians/10 minutes)**
Pitch	3.09	35.86		4.59	
Yaw	3.18	33.54		0.00	

6.1 Calibration Parameters





The slope of the linear region of the graph for pitch and yaw:

Pitch: 35.86 [uradians/counts]

Yaw: 33.54 [uradians/counts]

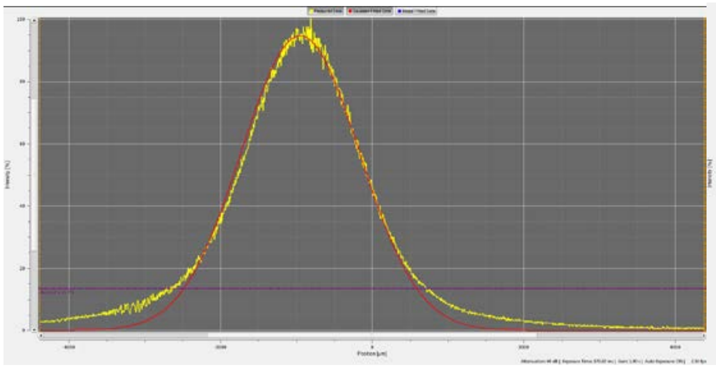
The geometric calculation for these parameters uses a Zeemax calculation for the path lengths of the lever arms from **E1200836--v1**. A DC method was used to obtain the y-axis data; we first translate the QPD a fixed amount as measured with a micrometer and use the geometry of the setup to correlate an angular deviation to the pitch or yaw signals.

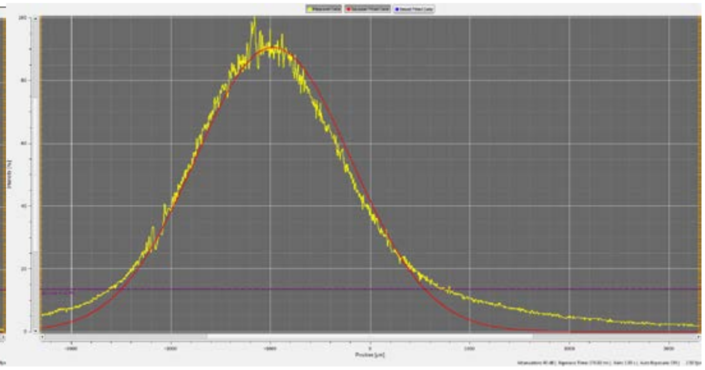
These results are inputted into the SUS gain filters:

L1-SUS-PR3_L3_OPLEV_PIT_GAIN

L1-SUS-PR3_L3_OPLEV_YAW_GAIN

6.2 Beam Profile





	Gaussian Width (mm)	Gaussianity (%)
X-Axis (left side)	3.09	90.27
Y-Axis (right side)	3.18	88.16

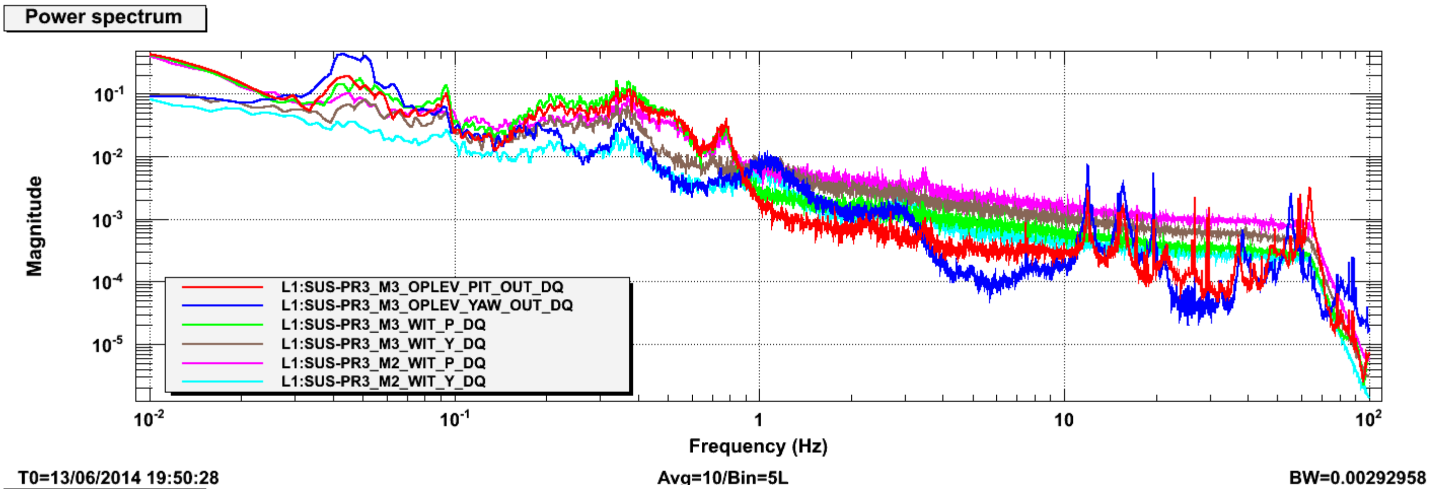
6.3 Longitudinal to Angular Coupling

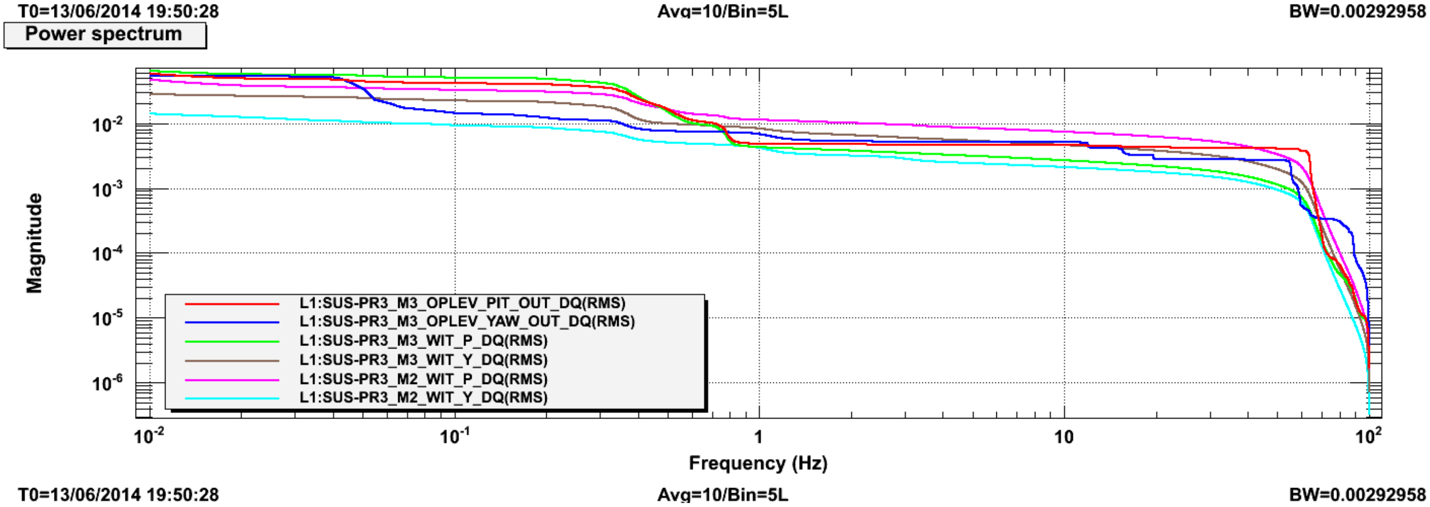
- L = 27.726 m
- ɵ = 3.64 degrees
- φ = 89.99 degrees

dɵ'/dx = 4.59 urad/m

dφ'/dx = 0.00 urad/m

6.4 Calibrated Spectra





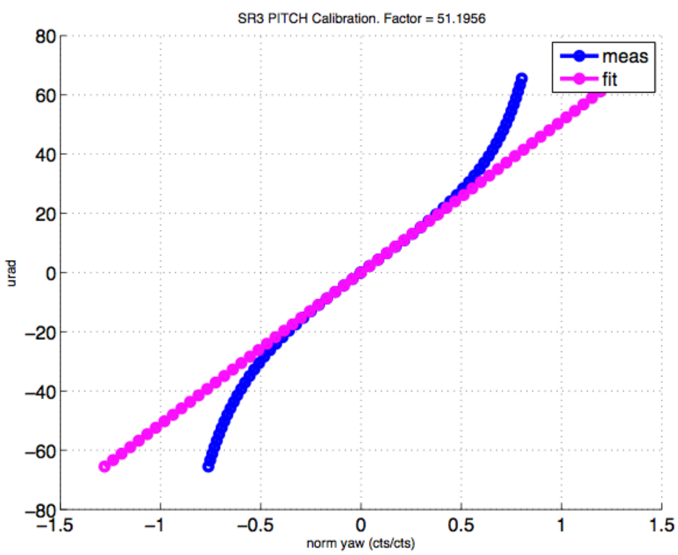
6.5 Calibrated Long Term Drift

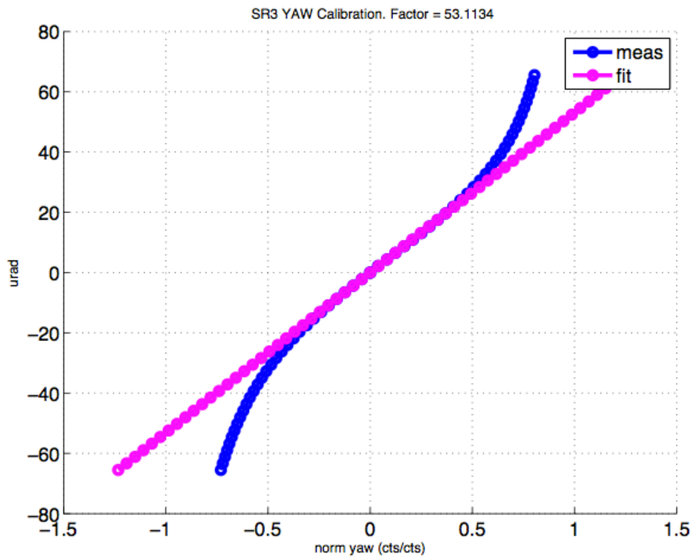
6.6 QPD Sensor Dark Noise

7 SR3

	Gaussian Width (mm)	**Calibration (Counts/urad)**	**Low- Frequency Resonances (Hz)**	**Long-to-ang coupling coefficient (urad/m)**	**Peak-to-peak drift (uradians/10 minutes)**
Pitch		51.20		2.48	
Yaw		53.11		0.00	

7.1 Calibration Parameters





The slope of the linear region of the graph for pitch and yaw:

Pitch: 51.20 [uradians/counts]

Yaw: 53.11 [uradians/counts]

The geometric calculation for these parameters uses a Zeemax calculation for the path lengths of the lever arms from **E1200836--v1**. A DC method was used to obtain the y-axis data; we first translate the QPD a fixed amount as measured with a micrometer and use the geometry of the setup to correlate an angular deviation to the pitch or yaw signals.

These results are inputted into the SUS gain filters:

L1-SUS-SR3_L3_OPLEV_PIT_GAIN

L1-SUS-SR3_L3_OPLEV_YAW_GAIN

7.2 Beam Profile

	Gaussian Width (mm)	Gaussianity (%)
X-Axis (left side)		
Y-Axis (right side)		

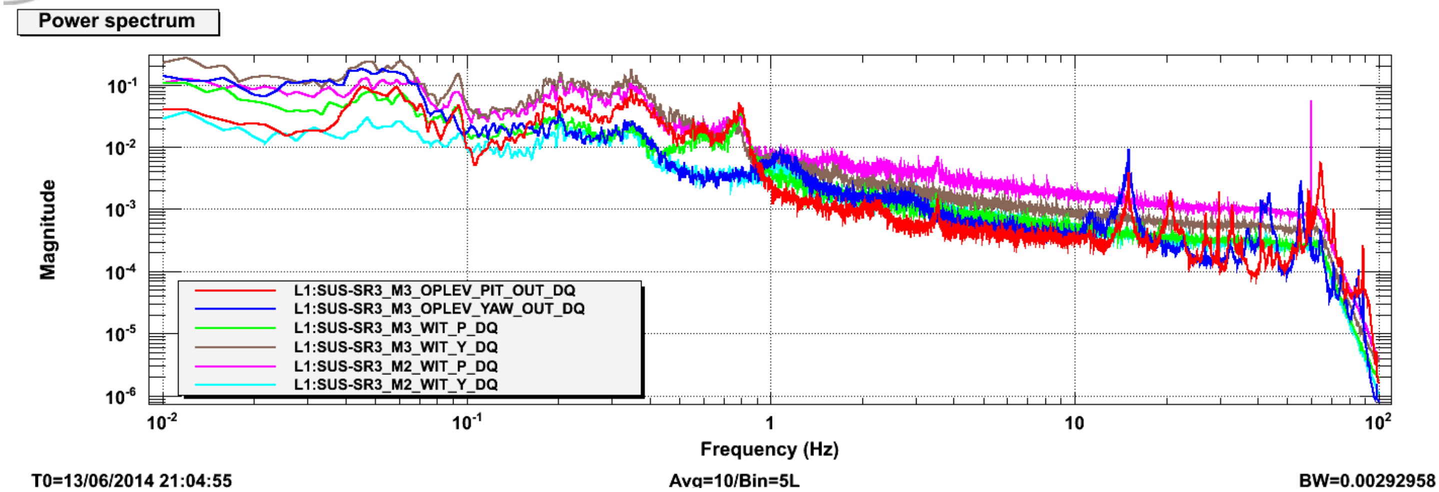
7.3 Longitudinal to angular coupling

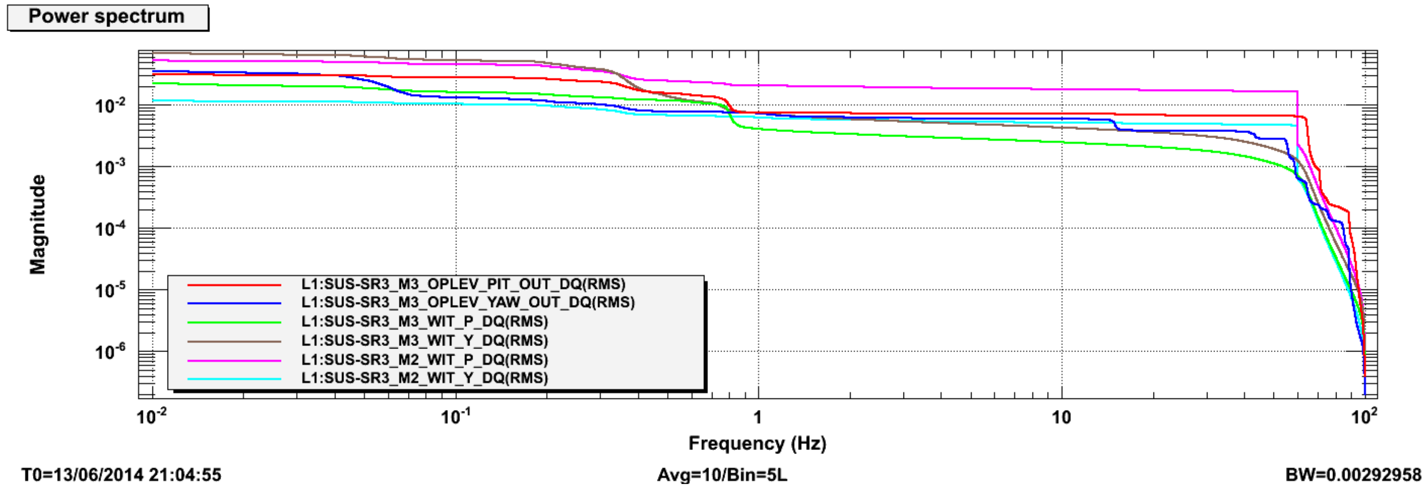
- L = 27.50 m
- θ = 1.95 degrees
- φ = 89.94 degrees

$d\theta'/dx$ = 2.48 urad/m

$d\varphi'/dx$ = 0.00 urad/m

7.4 Calibrated Spectra





7.5 Calibrated Long Term Drift

7.6 QPD Sensor Dark Noise

8 HAM2

	Gaussian_Width (mm)	**Calibration (Counts/urad)**	**Low- Frequency Resonances (Hz)**	**Long-to-ang coupling coefficient (urad/m)**	**Peak-to-peak drift (uradians/10 minutes)**
Pitch				0.02	
Yaw				0.20	

8.1 Calibration Parameters

The slope of the linear region of the graph for pitch and yaw:

Pitch: [uradians/counts]

Yaw: [uradians/counts]

The geometric calculation for these parameters uses a Zeemax calculation for the path lengths of the lever arms from **E1200836--v1**.

These results are inputted into the SUS gain filters:

L1-ISI-HAM2_L3_OPLEV_PIT_GAIN

L1-ISI-HAM2_L3_OPLEV_YAW_GAIN

8.2 Beam Profile

	Gaussian Width (mm)	Gaussianity (%)
X-Axis (left side)		
Y-Axis (right side)		

8.3 Longitudinal to Angular Coupling

- L = 26.643 m
- ө = 0.19 degrees
- φ = 3.58 degrees

dө'/dx = 0.02 urad/m

dφ'/dx = 0.20 urad/m

8.4 Calibrated Spectra

8.5 Calibrated Long Term Drift

8.6 QPD Sensor Dark Noise

9 HAM3

	Gaussian Width (mm)	**Calibration (Counts/urad)**	**Low- Frequency Resonances (Hz)**	**Long-to-ang coupling coefficient (urad/m)**	**Peak-to-peak drift (uradians/10 minutes)**
Pitch				0.02	
Yaw				0.30	

9.1 Calibration Parameters

The slope of the linear region of the graph for pitch and yaw:

Pitch: [uradians/counts]

Yaw: [uradians/counts]

The geometric calculation for these parameters uses a Zeemax calculation for the path lengths of the lever arms from **E1200836--v1**.

These results are inputted into the SUS gain filters:

L1-ISI-HAM3_L3_OPLEV_PIT_GAIN

L1-ISI-HAM3_L3_OPLEV_YAW_GAIN

9.2 Beam Profile

	Gaussian Width (mm)	Gaussianity (%)
X-Axis (left side)		
Y-Axis (right side)		

9.3 Longitudinal to angular coupling

- L = 26.580 m
- ɵ = 0.22 degrees
- φ = 3.01 degrees

dɵ'/dx = 0.02 urad/m

dφ'/dx = 0.30 urad/m

9.4 Calibrated Spectra

9.5 Calibrated Long Term Drift

9.6 QPD Sensor Dark Noise

10 HAM4

	Gaussian_Width (mm)	**Calibration (Counts/urad)**	**Low- Frequency Resonances (Hz)**	**Long-to-ang coupling coefficient (urad/m)**	**Peak-to-peak drift (uradians/10 minutes)**
Pitch				0.01	
Yaw				0.30	

10.1 Calibration Parameters

The slope of the linear region of the graph for pitch and yaw:

Pitch: [uradians/counts]

Yaw: [uradians/counts]

The geometric calculation for these parameters uses a Zeemax calculation for the path lengths of the lever arms from **E1200836--v1**.

These results are inputted into the SUS gain filters:

L1-ISI-HAM4_L3_OPLEV_PIT_GAIN

L1-ISI-HAM4_L3_OPLEV_YAW_GAIN

10.2 Beam Profile

	Gaussian Width (mm)	Gaussianity (%)
X-Axis (left side)		
Y-Axis (right side)		

10.3 Longitudinal to Angular Coupling

- L = 26.559 m
- ɵ = 0.2 degrees
- φ = 3 degrees

dɵ'/dx = 0.01 urad/m

dφ'/dx = 0.30 urad/m

10.4 Calibrated Spectra

10.5 Calibrated Long Term Drift

10.6 QPD Sensor Dark Noise

11 HAM5

	Gaussian Width (mm)	**Calibration (Counts/urad)**	**Low- Frequency Resonances (Hz)**	**Long-to-ang coupling coefficient (urad/m)**	**Peak-to-peak drift (uradians/10 minutes)**

Pitch				0.01	
Yaw				0.20	

11.1 Calibration Parameters

The slope of the linear region of the graph for pitch and yaw:

Pitch: [uradians/counts]

Yaw: [uradians/counts]

The geometric calculation for these parameters uses a Zeemax calculation for the path lengths of the lever arms from **E1200836--v1**.

These results are inputted into the SUS gain filters:

L1-ISI-HAM5_L3_OPLEV_PIT_GAIN

L1-ISI-HAM5_L3_OPLEV_YAW_GAIN

11.2 Beam Profile

	Gaussian Width (mm)	Gaussianity (%)
X-Axis (left side)		
Y-Axis (right side)		

11.3 Longitudinal to angular coupling

- L = 26.760 m
- ɵ = 0.18 degrees
- φ = 2.97 degrees

dɵ'/dx = 0.01 urad/m

dφ'/dx = 0.20 urad/m

11.4 Calibrated Spectra

11.5 Calibrated Long Term Drift

11.6 QPD Sensor Dark Noise