LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

*LIGO Laboratory / LIGO Scientific Collaboration*

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# Direct signature of the large angle scattering by the spiral pattern in LMA coating

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# 1 Introduction

The baffle PD on the ITMX in L1 is used to measures the power distribution outside of the test mass. PD2 and PD3 show increase of power when they come close to the region where the spiral pattern in the LMA coating would produce larger angle scattering.

# 2 Setup

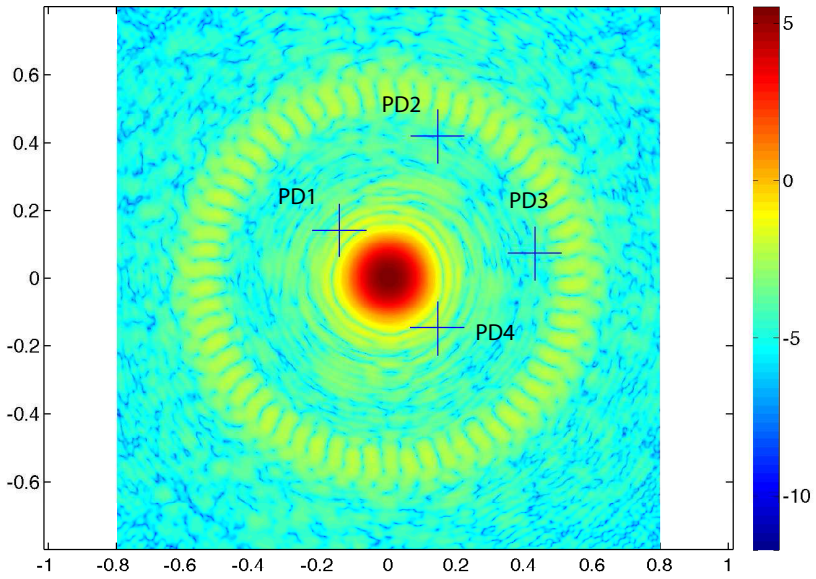


**Figure 1 Baffle Photo Diodes and power around ITMX**

Figure 1 shows the (log of) power distribution around ITMX and the locations of the four PDs on the arm tube baffle. The geometry of baffles are shown in Fig.2.

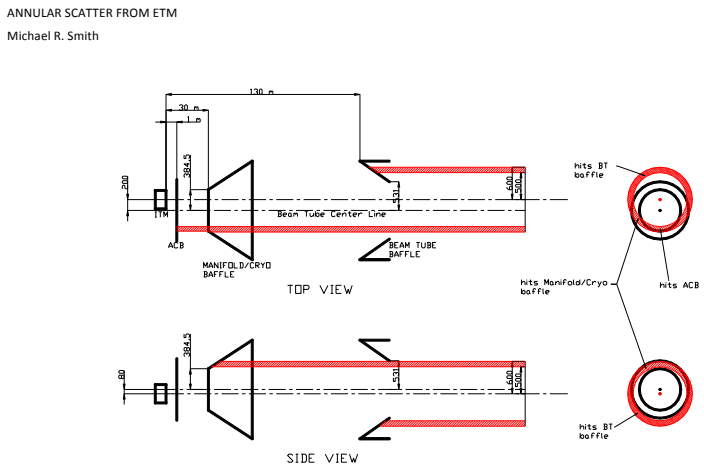


**Figure 2 Baffle geometries and annular scatter by ETM**

The cross marks in Fig.1 show the range when PDs are moved by 8cm in four directions. The locations of those PDs and distances from the center of the beam are shown in the following table. The distance of the inner PDs, PD1 and PD4, from the center of the beam changes from 15cm to 27cm, while the distance of the outer PDs, PD2 and PD3, changes from 36cm to 52cm. The ring of power caused by the scattering off the spiral pattern on ETM is located around 50cm to 60cm from the center of the beam.

| | Location (mm) | r(0,0) | r(-80,0) | r(80,0) | r(0,-80) | r(0,80) |
|---|---|---|---|---|---|---|
| PD1 | (-144,140) | 200.8 | 264.2 | 153.9 | 156 | 262.9 |
| PD2 | (144,419) | 443.1 | 423.9 | 475.1 | 368.3 | 519.4 |
| PD3 | (430,71.4) | 435.9 | 357.2 | 515.0 | 430.1 | 455.9 |
| PD4 | (144,-148) | 206.5 | 161.3 | 268.5 | 269.7 | 159.3 |

**Table 1 PD locations :** r(dx,dy) is the distance from the beam center to displaced PD location

The power distribution around ITM is scanned by using these PDs on the ATB. Details of measuring baffle PD power is discussed in P1400197 by H. Rew and J. Betzwieser. Instead of moving the PDs, the beam on ITM is moved. The L1 X arm ITM was tilted to move the beam center on ITM to be off centered, while that on ETM to be kept centered. The detail of this technique is discussed in P1400198 by Leo Tsukada, D. Martynov and V. Frolov.

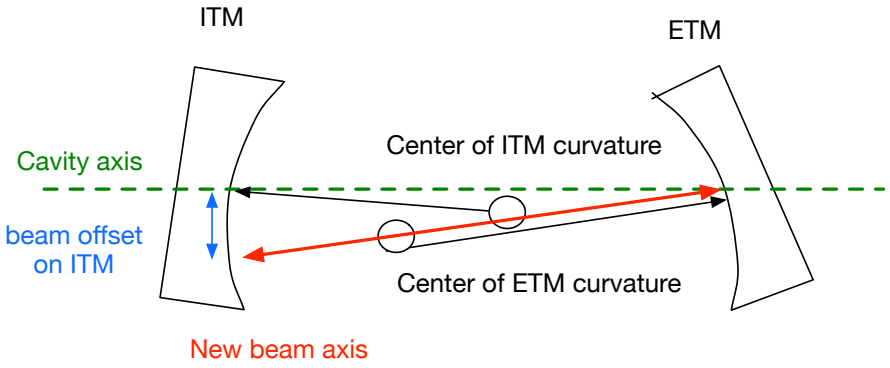


**Figure 3 Arm mirror setup**

The round trip loss increase is mostly dominated by the clipping loss on ITM due to the beam off centering. The increase of the round trip loss with 8cm off centering is around 800ppm, and the expected drop of the cavity power is 10%. Through out this analysis, the change of the power is neglected and the power is assumed to be 33W.

# 3 Data

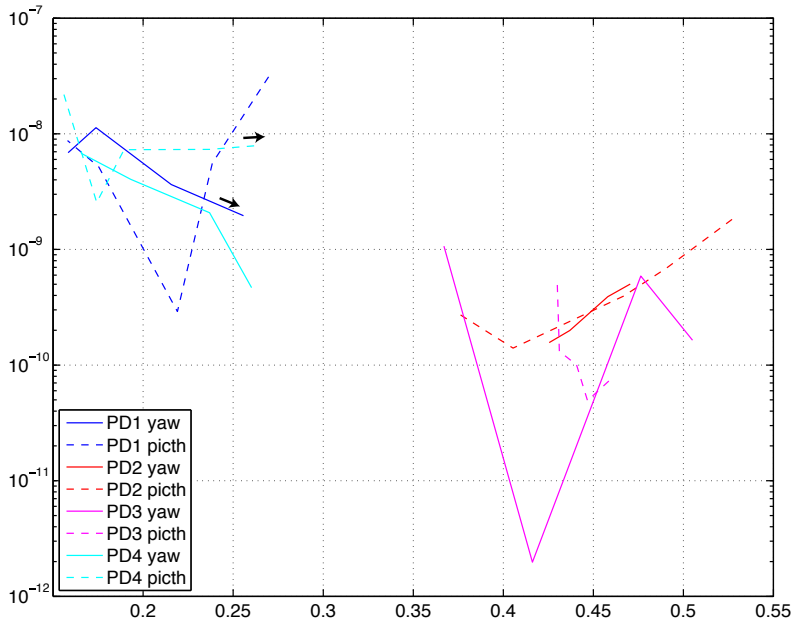


**Figure 4 Power on PDs vs distance between the PD and beam center in m**

Fig.4 shows the power detected by the four baffle PDs on ATB. The measurements are done at 4 yaw orientations corresponding to -7cm, -4.1cm, +2cm and +7cm offset of the beam center in the horizontal direction and at 5 pitch orientations corresponding to -8.8cm, -5cm, -2.5cm, +4cm and +7.5cm in the vertical direction. In the figure, for all lines except PD1 yaw and PD4 pitch, left end of the line corresponds to the largest positive offset, and the right end to the largest negative offset. For the PD1 yaw and PD4 pitch, marked by arrows in the figure, right end corresponds to the largest positive offset.

# 4 Comparison with model

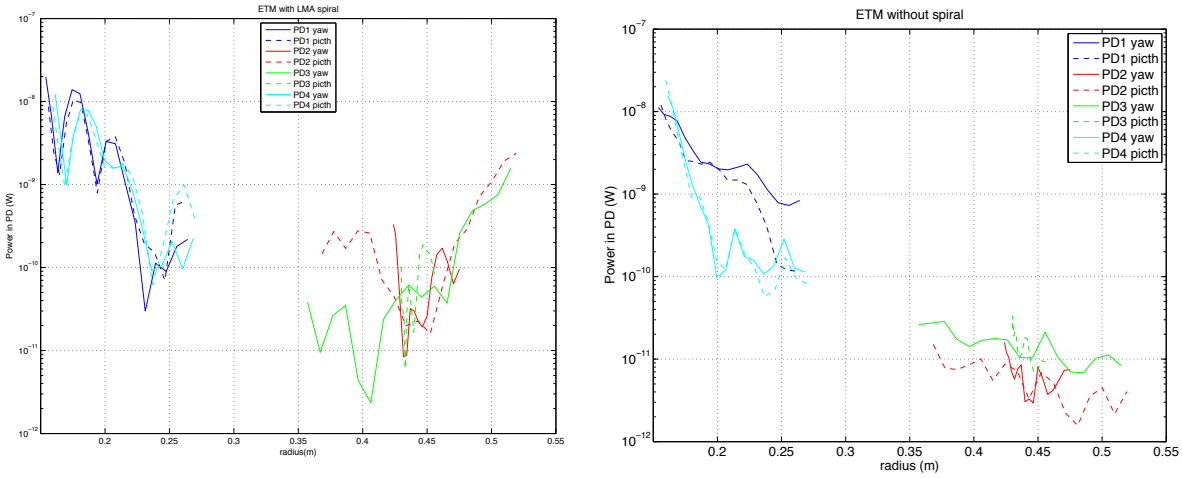


**Figure 5 Model prediction using ETM phasemap**

Fig.5 left is the model calculation based on the measured ETM phasemap with the spiral pattern. Fig.5 right is calculated with the same phasemap, but after subtracting Zernike(n,m) terms with n+m>17. This removes clear spiral pattern.

In Fig.5 right, model calculation without spiral on ETM, it is seen that the power drops down as a function of the radius and the PD2 and PD3 power is 2 order of magnitude smaller than the PD1 and PD4 power.

In Fig.5 left, model calculation with spiral, the power of PD2 and PD3 go up starting at 45cm, and the average power of PD1, PD4 and that of PD2, PD3 are much closer than the case seen in Fig.5 right. Also, the power of PD1,PD4 shows much complex structure in Fig.5 left than Fig.5 right, i.e., the spiral pattern makes the Gaussian power tail more complex.

## 5 Discussion about the data

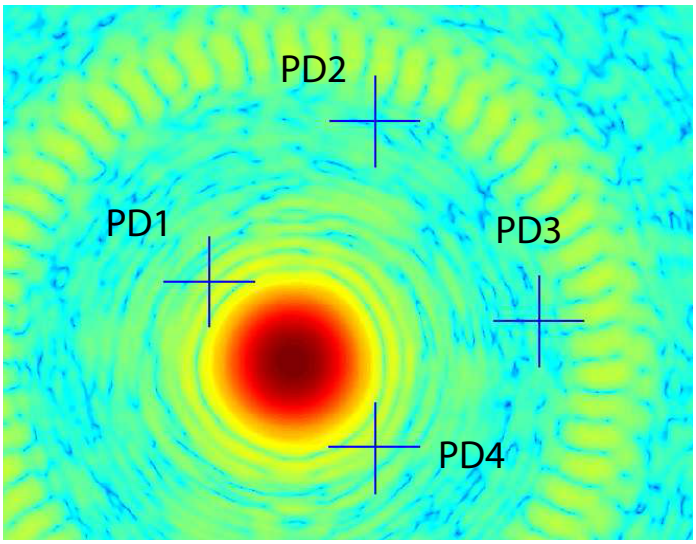


**Figure 6 Zoomed in image around the baffle PDs**

Fig.6 is the zoomed in image of Fig.1. Due to the spiral structure on ETM, the power distribution is not a simple Gaussian. Nearby of the main Gaussian tail at 15-20cm, there are several rings. PD1 and PD4 scan power across these rings. The power ring at 50-60cm has 62 slits along the circle, and PD2 and PD3 scan goes these structures.

The identification of the position of the beam center has an uncertainty of several mm, may be a few mm, and yaw and pitch scan will have a offset in the orthogonal direction. During the measurement of the powers on PDs, the beam position fluctuated. The size of the fluctuation on ETM was measured to be 1~2mm. The size of the PD is 100mm$^2$, and this beam position fluctuation may not have large effect. Roughly speaking, the measured power is an energy with the inaccuracy of the location of several mm in both directions.

As of now, the largest known systematic error will be the calibration of the baffle PD, 20-30% (may be). Unknown is the stability of the beam in the arm, and time fluctuation of the measured PD power was observed. The current measurement will be semi-quantitative with accuracy of factor 2.

What is observed from this result is that, in each group, PD1 and PD4 between 15cm to 27cm, and PD2 and PD3 in 36cm to 53cm, powers do not decrease as a function of the distance from the beam center, and the power at the largest radius, 50-55cm, is around the same size as the values at 25cm.