LIGO Laboratory / LIGO Scientific Collaboration

LIGO-T080277-03-D *Advanced LIGO* 12/3/08

BS, CP, RM, ITM, and ETM Wedge Angle Tolerance

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Abstract

This technical note establishes the maximum and minimum wedge angles for the Advanced LIGO BS, CP, RM, ITM, and ETM in the folded and non-folded interferometers. The BS wedge angle is specified as 0.05 -0.00/+0.03 deg horizontal. A 5 deg clocking error of the BS wedge from the horizontal plane is acceptable. The CP wedge angle is specified as 0.04 - 0.03/+ 0.04 deg horizontal. The RM wedge angle is specified as 0.04 -0.03/+ 0.04 deg vertical, thick side up. The ITM and ETM wedge angles are specified as 0.07 -0.00/+0.03 deg vertical, thick side down.

1 Introduction

The horizontal wedge on the BS provides a horizontal separation of the ITM pick-off beam, which is generated by the prompt reflection of the recycling cavity beam incident on the AR surface of the BS from the direction of the ITM, from the main output beam.

The horizontal wedge angle of the Compensation Plate (CP) steers the recycling cavity main beam away from the center of the HAM chamber; however, it must be small enough so that the first order ghost beams from the CP will be captured by the PR3 and SR3 mirrors.

The vertical wedge angle of the ITM steers the recycling cavity main beam down toward the HAM optical table; however, it must be small enough so that the first order ghost beams from the ITM will be captured by the PR3 and SR3 mirrors.

The vertical wedge angle of the ETM separates the ETM HR and the ETM AR reflections for diagnostics of the ETM Hartmann system.

This technical note establishes the maximum and minimum wedge angle for the Advanced LIGO BS, CP, RM, ITM, and ETM mirrors in the folded and non-folded interferometers.

1.1 References

1. T080268-00, Optical Layout and Parameters for the Recycling Cavities

2 Analysis

2.1 Optical Layout

The centerlines of the main beam and the ITM pick-off beam at the BS for the non-folded IFO are shown in the ZEMAX model in Figure 1.

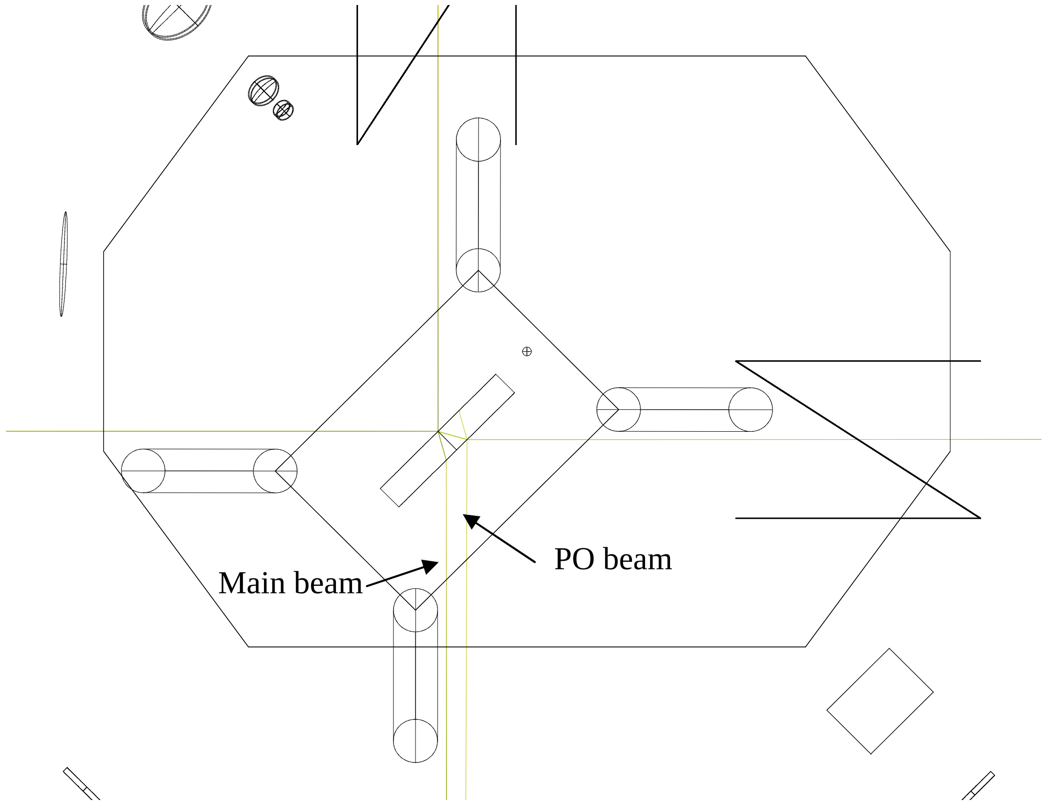

Figure 1: ITM PO Beam from AR Surface of BS

The pick-off beam and the main beam are both collected by the SR3 mirror, as shown in Figure 2.

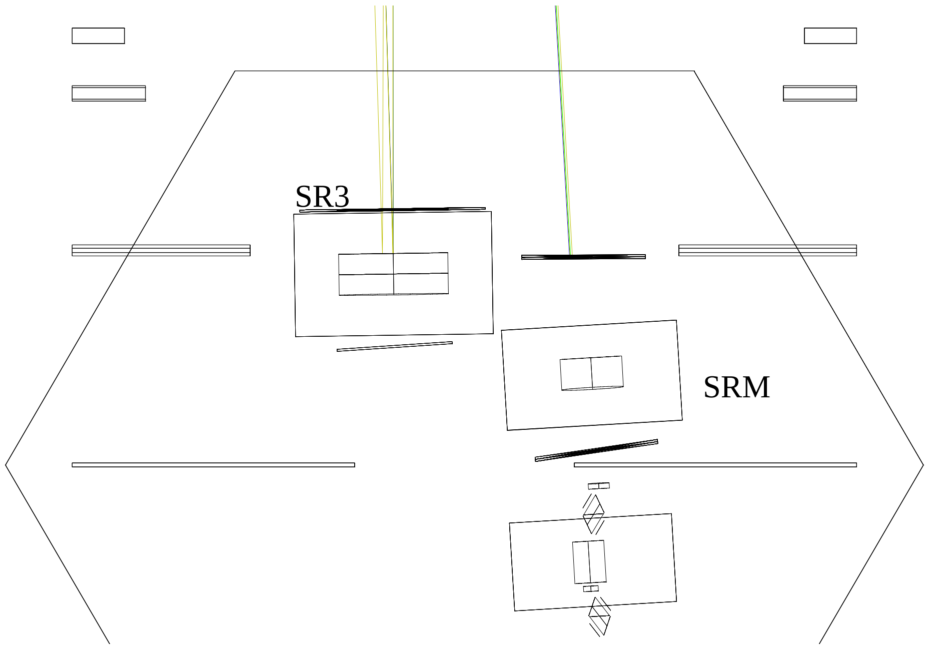

Figure 2: ITM PO Beam at the SR3 mirror

The pick-off beam separates from the main beam in the vicinity of the SR2 mirror, as shown in Figure 3.

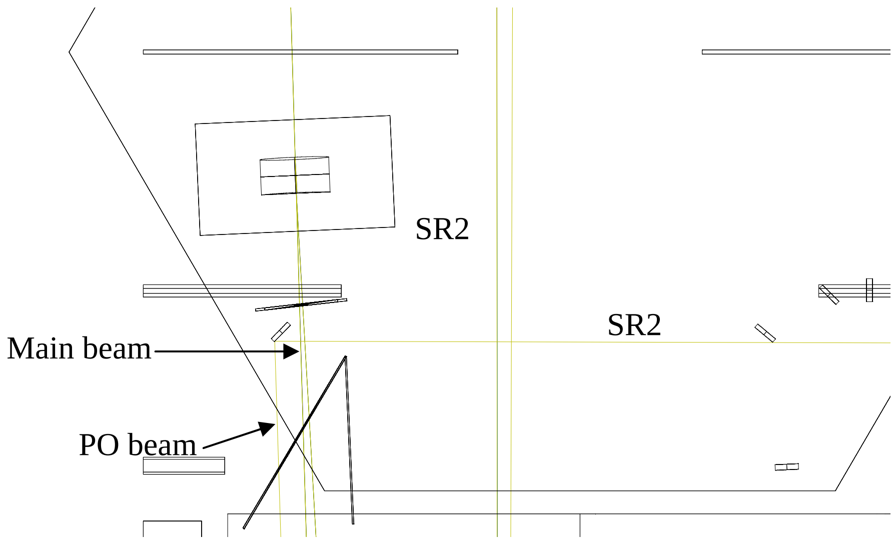

Figure 3: ITM PO Beam Separation from the Main Beam at SR2

2.2 BS Wedge Analysis

The Gaussian beam profile of the 56 mm radius ITM PO beam on the surface of the SR3 mirror is shown in Figure 4, with a 60 mm displacement from the center of SR3 in the horizontal plane.

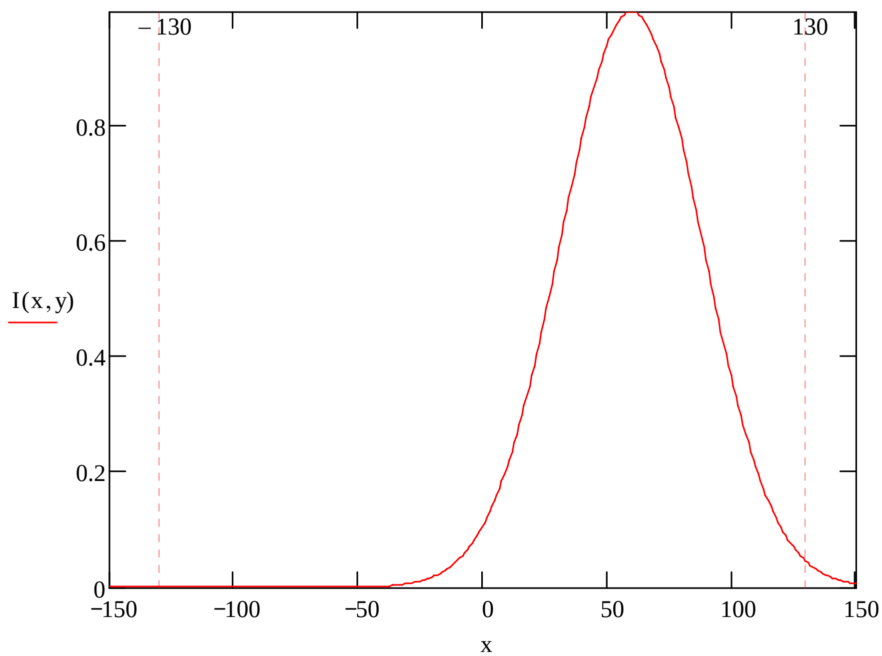

Figure 4: ITM PO Beam Profile at SR3

The fractional PO beam power captured within the 260 mm clear aperture diameter of the SR3 is given by the following expression, and is shown in Figure 5.

total relative power within the mirror aperture

$$PF(x_0) := \frac{2}{\frac{\pi}{2} \cdot w^2} \cdot \int_0^{R_m} \int_{-\sqrt{R_m^2 - y^2}}^{\sqrt{R_m^2 - y^2}} e^{-2 \cdot \frac{\left[(x - x_0)^2 + y^2\right]}{w^2}} \, dx \, dy$$

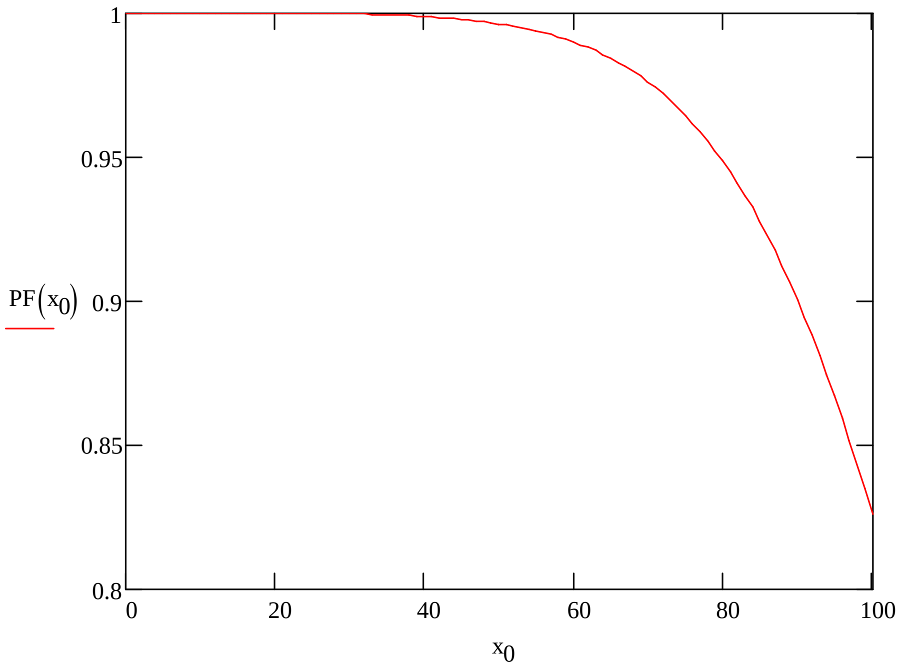

Figure 5: Relative Power of ITM PO Beam within SR3 Clear Aperture

The displacement, x_0, of the ITM PO beam on the SR3 mirror for various BS wedge angles was measured using ZEMAX and is shown in Figure 6. The red curve is for the non-folded IFO and the dotted blue curve is for the folded IFO.

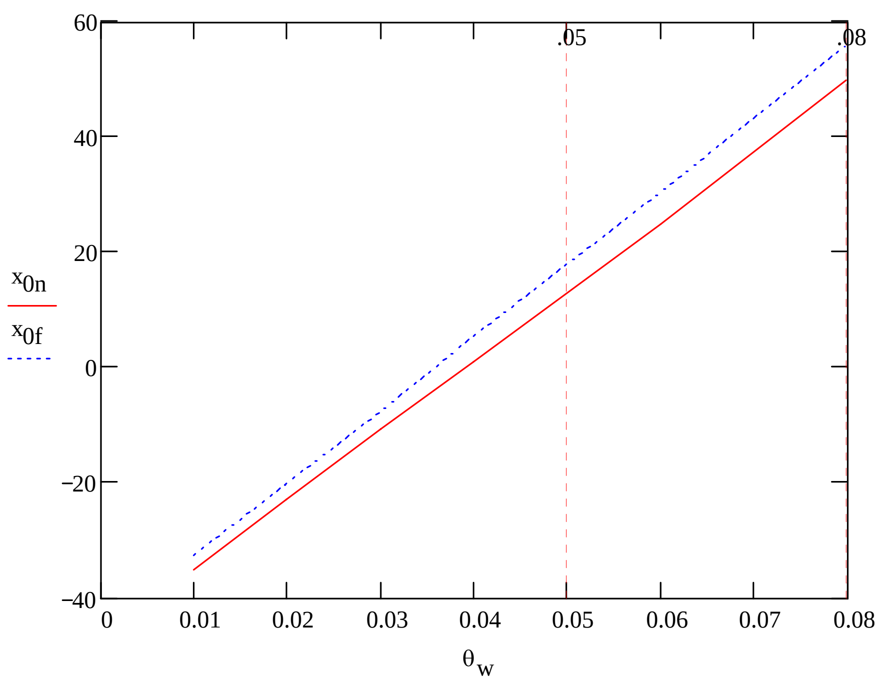

Figure 6: Displacement of ITM PO Beam on SR3

2.2.1 Minimum BS Wedge Angle

The minimum wedge angle will allow a separation of 25 mm between the main beam and the PO beam measured at the 1ppm radius. The Gaussian spot radius at the SR2 mirror is 5.7 mm for the non-folded IFO and 4.0 mm for the folded IFO, see T080268-00. The 1 ppm radius is 2.6 times larger than the spot radius. Therefore, the minimum separations between the beam centerlines are shown below for the non-folded and folded cases.

$$\Delta_{nmin} = 54.962$$

$$\Delta_{fmin} = 46.026$$

The separations of the ITM PO beam and the main IFO output beam centerlines in the vicinity of SR2 were measured using ZEMAX for various BS wedge angles and are shown in Figure 7. The minimum separation requires a minimum BS wedge angle of approximately 0.05 deg.

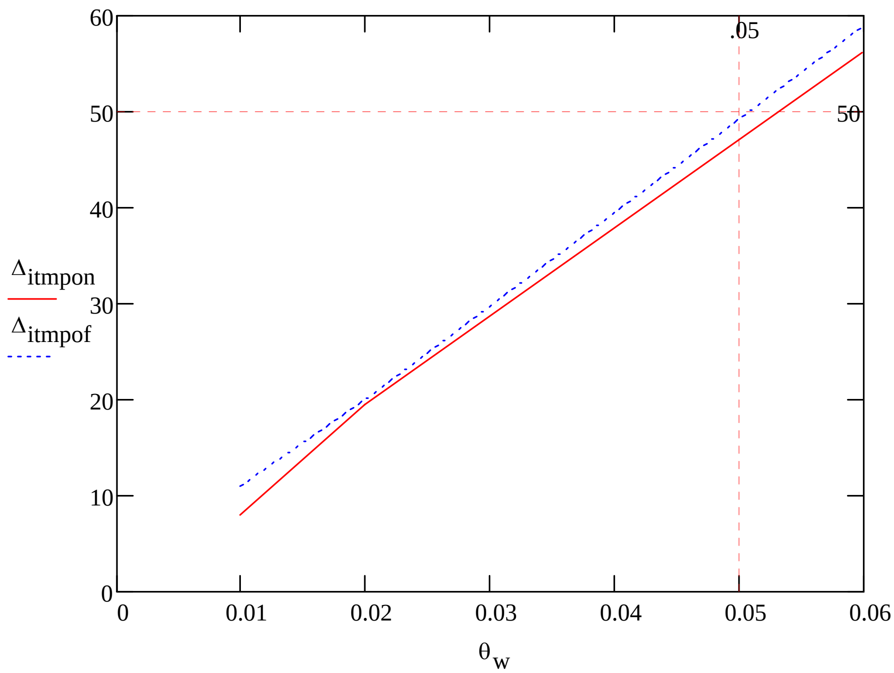

Figure 7: Separation of ITM PO Beam from Main Beam near SR2

2.2.2 Maximum BS Wedge Angle

The maximum BS wedge angle can be as large as 0.08 deg, which would result in a displacement of 60 mm and a loss of PO beam power of approximately 1%.

2.2.3 Clocking of the BS Wedge from the Horizontal Plane

If the BS is mounted with the wedge rotated from the horizontal plane, the height of the main beam and the PO beam will be higher or lower at the SR3, depending upon the sense of the clocking angle.

For the folded IFO, the fold mirrors can be used to restore the beam to the nominal height at the SR3, and the BS can be tipped in the vertical direction to overlap the transmitted and reflected recycling cavity beams at the SR3.

For the non-folded IFO, the height of the main beam and the PO beam can not be corrected, and the height of the SR3 suspension would have to be changed to accommodate the height error. As in the folded case, the BS can be tipped in the vertical direction to overlap the transmitted and reflected recycling cavity beams at the SR3.

The height error at the SR3 as a function of the clocking angle error of the BS wedge from the horizontal plane was measured using ZEMAX and is shown in Figure 8. From the figure we can see that a 5 deg clocking error of the BS wedge from the horizontal plane will cause a height error of < 1mm at the SR3 mirror.

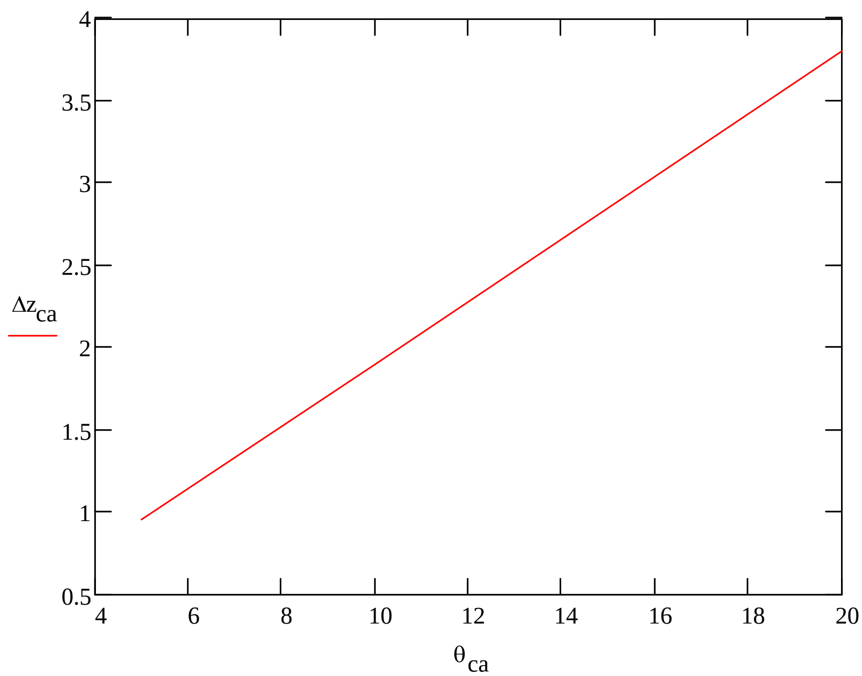

Figure 8: Height Error at SR3 Due to BS Wedge Clocking Angle Error

2.3 CP Wedge Angle Tolerance

The main recycling cavity beam hits the center of PR3, and the first internal ghost beam from the CP strikes PR3 at some distance toward the edge away from the center, as shown in Figure 9.

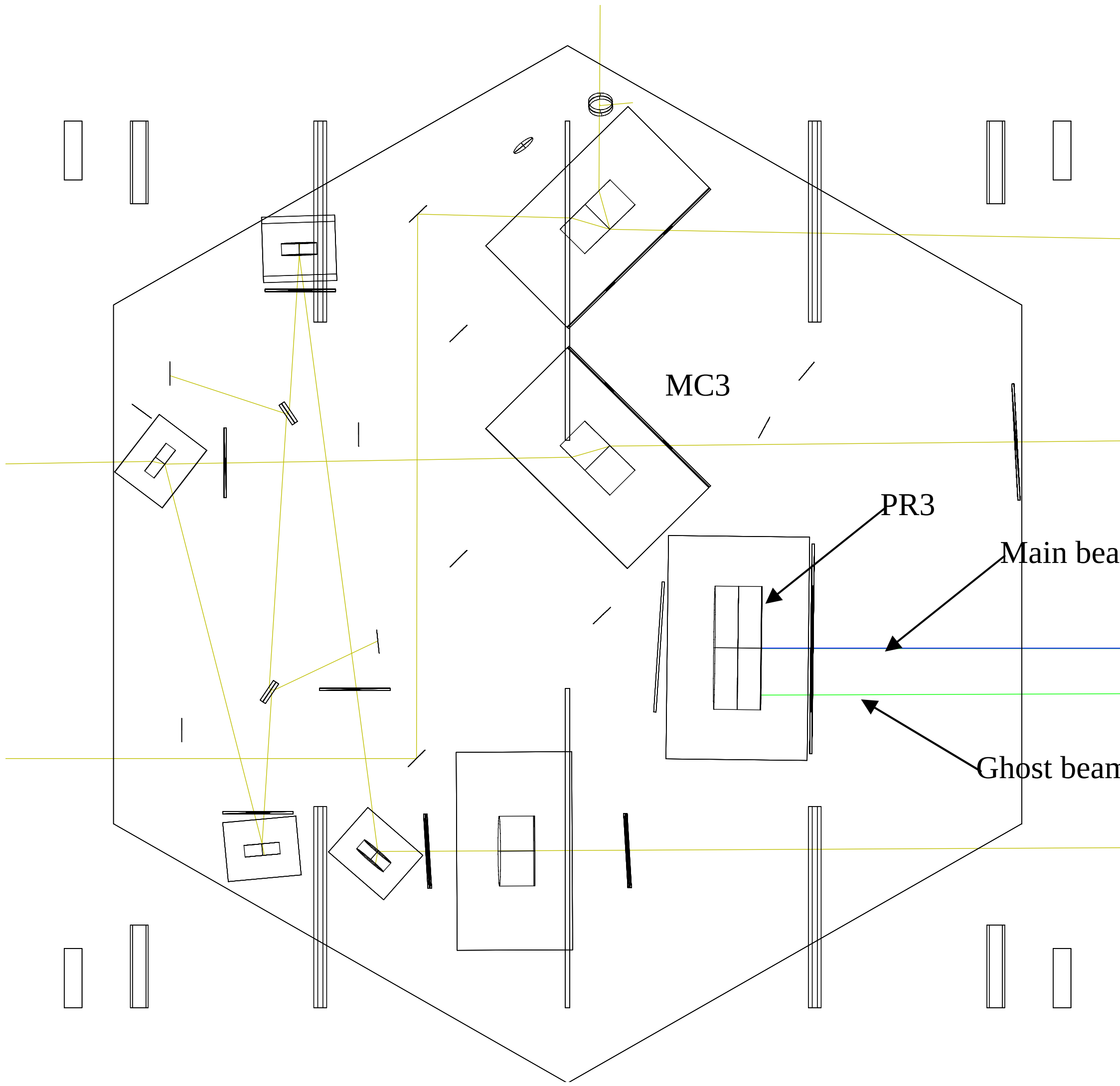

Figure 9: HAM2 Optics Table with PR3 Mirror

2.3.1 Minimum CP Wedge Angle

The minimum CP wedge angle is 0.00 deg, which allows clearance between the PR3 and MC3 suspensions.

2.3.2 Maximum CP Wedge Angle

The maximum CP wedge angle of 0.08 deg causes the CP ghost beam to deviate toward the edge from the center of the SR3 mirror by approximately 100 mm, which results in > 80% capture of the CP ghost beam power by SR3.

2.4 ITM Wedge Angle Tolerance

An elevation view of HAM5 chamber in the non-folded IFO is shown in Figure 10. The signal recycling cavity beam from the BS strikes the center of the SR3 mirror and then walks down as it reflects from the SR3 to the SR2 mirrors and back onto the center of the SRM. The lowest of the three beams shown in the figure is the first internal ghost beam from the ITM.

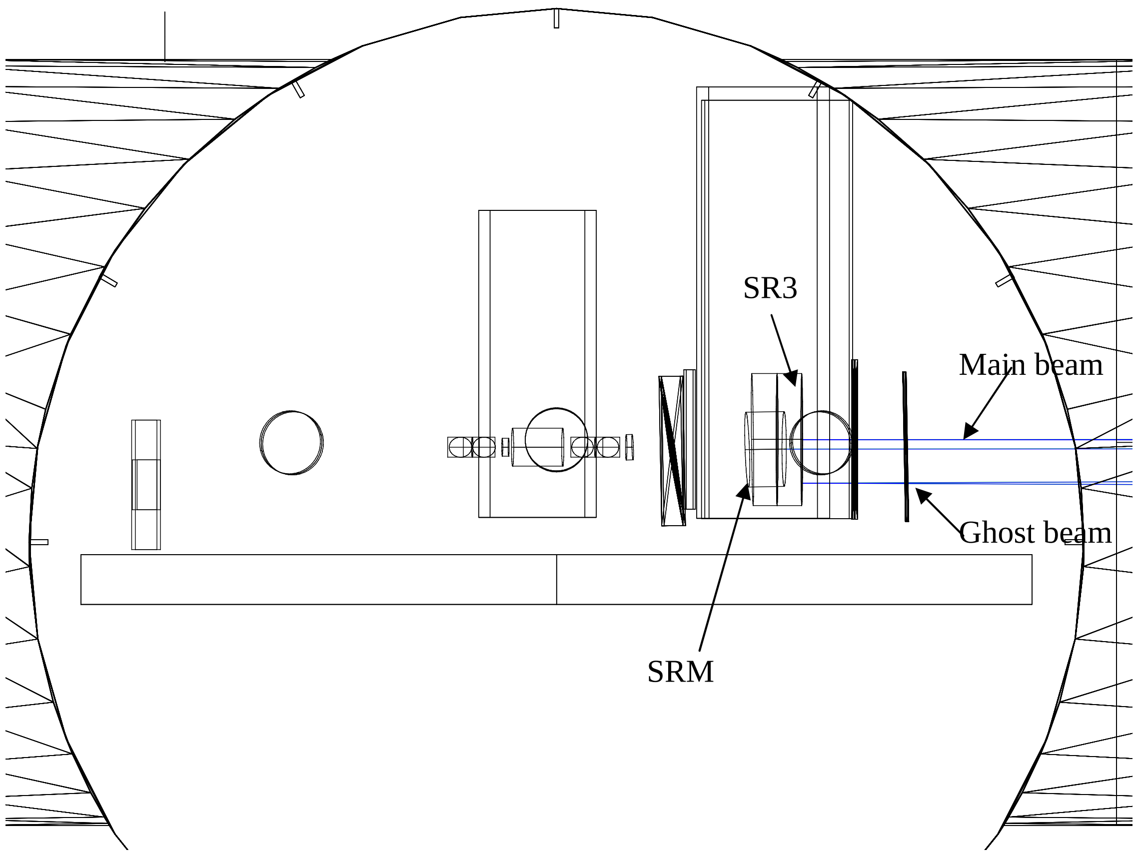

Figure 10: Elevation View of SR3 and SRM

2.4.1 Minimum ITM Wedge Angle

The minimum ITM vertical wedge angle occurs when the suspension structures for SR3 and SRM mirrors barely clear the top of the chamber, as shown in the figure. This corresponds to an ITM wedge angle of 0.07 deg.

2.4.2 Maximum ITM Wedge Angle

The maximum vertical wedge angle of 0.10 deg causes the ghost beam to deviate toward the edge from the center of the SR3 mirror by approximately 124 mm, which results in approximately 80% capture of the ghost beam power.

2.5 ETM Wedge Angle Tolerance

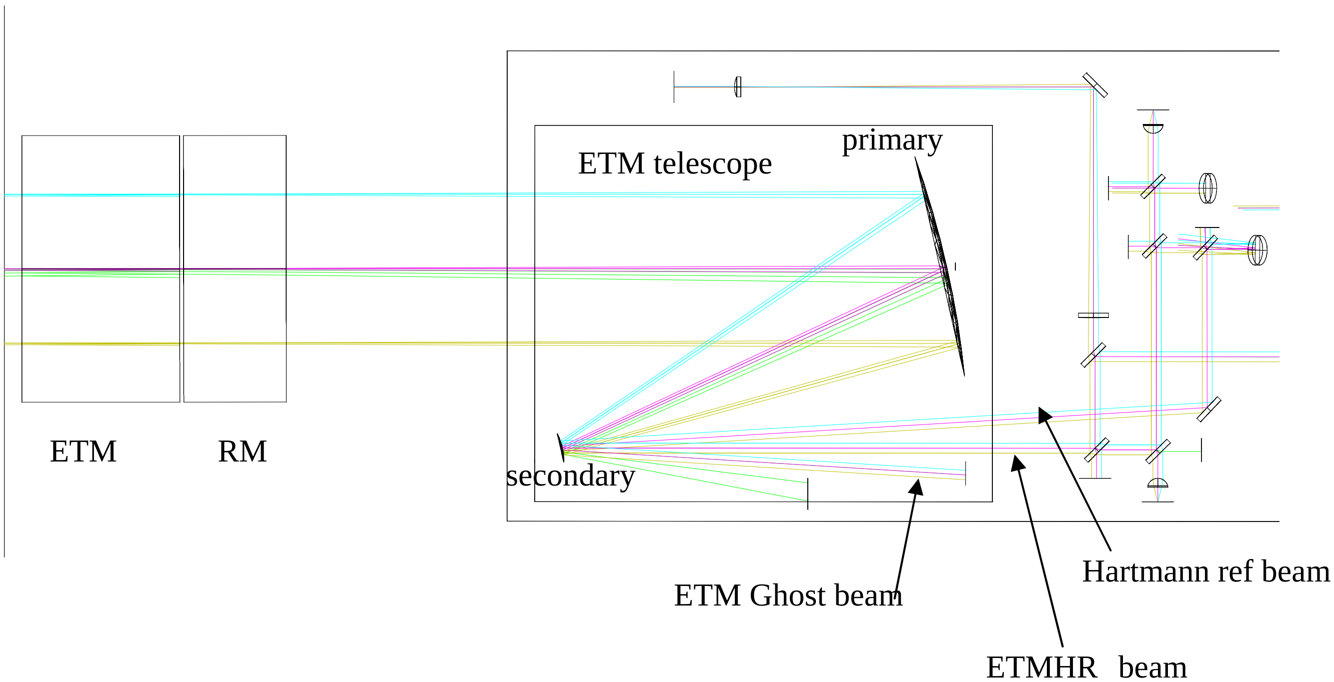

Figure 11: ETM Telescope

An elevation view of the ETM Telescope is shown in

Figure 11. The vertical wedge on the ETM has the thick side down, and the vertical wedge on the RM has the thick side up. The telescope is aligned so that the ETM transmitted beam from the left is coincident with the Hartmann and the End locking beams that enter the ETM Telescope from the right of this diagram by reflection from the small secondary mirror.

The ETM wedge angle determines the separation between the main beam (ETM HR reflection), the reflected beam from the ETM AR (Hartmann reference beam), and the first internal ghost beam reflected from the ETM HR and ETM AR surfaces. The Hartmann sensor system will measure the wavefront distortion of the main beam relative to the wavefront of the ETM AR reflection as a reference beam.

The tolerance and the orientation of the ETM vertical wedge angle will be the same as the ITM: orientation, thick side down; wedge angle, 0.07 -0.0 + 0.03 deg.

2.6 RM Wedge Angle Tolerance

The orientation and tolerance of the RM vertical wedge angle are: orientation, thick side up; wedge angle, 0.04 -0.03 + 0.04 deg.

3 Conclusion

3.1 BS Wedge Angle Tolerance

Based on the analysis above, the BS wedge angle is specified as 0.05 -0.00/+0.03 deg horizontal.

3.2 BS Clocking Angle Tolerance

A 5 deg clocking error of the BS wedge from the horizontal plane will cause a height error of < 1mm at the SR3 mirror. This is probably acceptable.

3.3 CP Wedge Angle Tolerance

The CP wedge angle is specified as 0.04 -0.03 + 0.04 deg horizontal.

3.4 RM Wedge Angle Tolerance

The RM wedge angle is specified as 0.04 -0.03 + 0.04 deg vertical, thick side up.

3.5 ITM and ETM Wedge Angle Tolerance

The ITM and ETM wedge angles are specified as 0.07 -0.00/+0.03 deg vertical, thick side down.