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AOS SLC
Signal Recycling Cavity Baffles
Final Design

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1 INTRODUCTION

1.1 Scope

This document provides the final designs for the Signal Recycling Cavity Baffle for aLIGO.

1.2 Final Design Review Checklist

1.2.1 Final requirements – any changes or refinements from PDR?

- The updated requirements for the Signal Recycling Cavity Baffles are listed in T070061 Stray Light Control Design Requirements.
- The Hartmann Viewport Beam Dumps were eliminated; see section 4.1.9.9.

1.2.1.1 Direct Requirements

Phase noise due to scattered light fields injected into the interferometer is treated as a technical noise source. Therefore, the total scattered light phase noise, expressed in equivalent displacement noise, must be < $1/10^{th}$ of the quadrature sum of the suspension thermal noise and the test mass thermal noise (referred to as the SRD), as given in Figure 1 of M060056-06, Advanced LIGO Reference Design.

1.2.1.2 Hartmann Baffle Requirements—NEW

Baffles shall be placed to mitigate the scattered displacement noise caused by scatter from Hartmann optics in the Hartmann sensing train for the ITM mirrors; the total scattered light displacement noise, must be < $1/10^{th}$ of the quadrature sum of the suspension thermal noise and the test mass thermal noise (referred to as the SRD), as given in Figure 1 of M060056-06, Advanced LIGO Reference Design.

1.2.1.3 Ghost Beam Baffle Requirements

Baffles shall be placed to mitigate the scattered light displacement noise caused by scatter from the ghost beams generated by the wedged optics, ITM, FM, BS, SR3, SR2, and SRM; the total scattered light displacement noise, must be < $1/10^{th}$ of the quadrature sum of the suspension thermal noise and the test mass thermal noise (referred to as the SRD), as given in Figure 1 of M060056-06, Advanced LIGO Reference Design.

1.2.1.4 Clear Aperture Requirements

All Scraper Baffles shall not vignette the recycling cavity beam > 100 ppm power loss;

1.2.2 Resolutions of action items from SLC PDR

Refer to: LIGO-L0900119-v1

1.2.2.1 Lower BRDF Material for Baffles

We suggest the team consider a lower-BRDF material for the more critical baffles,
and in particular suggest looking at the electro-static frit black-enameled steel as an option
that would give better optical performance.

Ans: *The lowest BRDF material that is practical at the moment is oxidized polished stainless steel.*

1.2.3 Final Parts Lists and Drawing Package

TBD

1.2.4 Final specifications

E1100842 Specification for Mirror Finished (Super #8) Stainless Steel to be used in the LIGO Ultra-High Vacuum System

E0900364-v8 Metal components intended for use in the Adv LIGO Vacuum System

1.2.5 Final interface control documents

TBD The mechanical and optical interfaces of the Signal Recycling Cavity Baffles are described in E110XXX-v1AOS SLC Signal Recycling Cavity Baffles Interface Control Doc.

1.2.6 Relevant RODA changes and actions completed

NO Rodas!

1.2.7 Signed Hazard Analysis

E1100984 SLC Signal Recycling Cavity Baffle Install Hazard Analysis

1.2.8 Final Failure Modes and Effects Analysis

Not Required

1.2.9 Risk Registry items discussed

None for this subsystem

1.2.10 Design analysis and engineering test data

See Section 3, Descriptions of Signal Recycling Cavity Baffles and Section 4, Scattered Light Displacement Noise

1.2.11 Software detailed design

Not applicable

1.2.12 Final approach to safety and use issues

No operational safety issues

1.2.13 Production Plans for Acquisition of Parts, Components, Materials Needed For Fabrication

E1101001-v1_AOS SLC Signal Recycling Cavity Baffles production plan

1.2.14 Installation Plans and Procedures

This will be deferred until after FDR

1.2.15 Final hardware test plans

See E1101023 Signal Recycling Cavity Baffles Fabrication, Installation, and Test Plan

1.2.16 Final software test plans

Not applicable.

1.2.17 Cost compatibility with cost book

See E1101001-v1_AOS SLC Signal Recycling Cavity Baffles production plan

1.2.18 Fabrication, installation and test schedule

See E1101023 Signal Recycling Cavity Baffles Fabrication, Installation, and Test Plan

1.2.19 Lessons Learned Documented, Circulated

1.2.20 Porcelainizing

The baffles will be constructed of oxidized polished stainless steel to avoid shedding of the porcelain surface.

1.2.21 Problems and concerns

There are presently no problems or concerns with the recycling cavity baffles.

1.3 Applicable Documents

T070303 Arm Cavity Finesse for aLIGO

T070247 aLIGO ISC Conceptual Design

E0900364-v8 LIGO Metal in Vacuum

E1101023 Signal Recycling Cavity Baffles Fabrication, Installation, and Test Plan

T060073-00 Transfer Functions of Injected Noise

T070061-v2 Stray light Control Design Requirements

T0900269-v2 Stray Light Control (SLC) Preliminary Design

T1100056-v2 Arm Cavity Baffle Edge Scatter

E1100984_SLC Signal Recycling Cavity Baffle Install Hazard Analysis

E1101001-v1_AOS SLC Signal Recycling Cavity Baffles production plan

TBD E110XXX-v1AOS SLC Signal Recycling Cavity Baffles Interface Control Doc.

2 SIGNAL RECYCLING CAVITY BAFFLES

2.1 FUNCTION

2.1.1 SR3 HR BAFFLE

The SR3 HR Baffle catches, on its recycling cavity side, some of the ghost beams from the ITM, CP, and BS; the stray light that is not absorbed is reflected toward the mode cleaner tube baffle near HAM5 and HAM11.

2.1.2 SR3 AR BAFFLE

The SR3 AR Baffle catches and absorbs the signal recycling cavity power that leaks through the SR3AR surface.

2.1.3 SR2 SCRAPER BAFFLE

The SR2 Scraper Baffle catches most of the ghost beams from ITM, CP, and BS. It also catches, on the side facing the SR2 mirror, some of the SR2 HR ghost beams.

2.1.4 HAM SCRAPER BAFFLE

The HAM Scraper Baffle behind the SR2 AR side catches some of the SR2 AR ghost beams, and the reverse-path main IFO beam reflected by SRM that transmits through the SR2 AR surface.

2.1.5 HARTMANN Beam Dump

The Hartmann Beam Dumps catch the 1064nm light that transmits through the first two dichroic steering mirrors in the Hartmann beam paths.

2.1.6 SRM HR BAFFLE

The SRM HR Baffle catches the reflected beam from the OFI TGG crystal

2.2 ZEMAX LAYOUT

2.2.1 H1 & L1 IFO ZEMAX LAYOUT

The H1 and L1 IFO ZEMAX layout of HAM4 is shown in Figure 1.

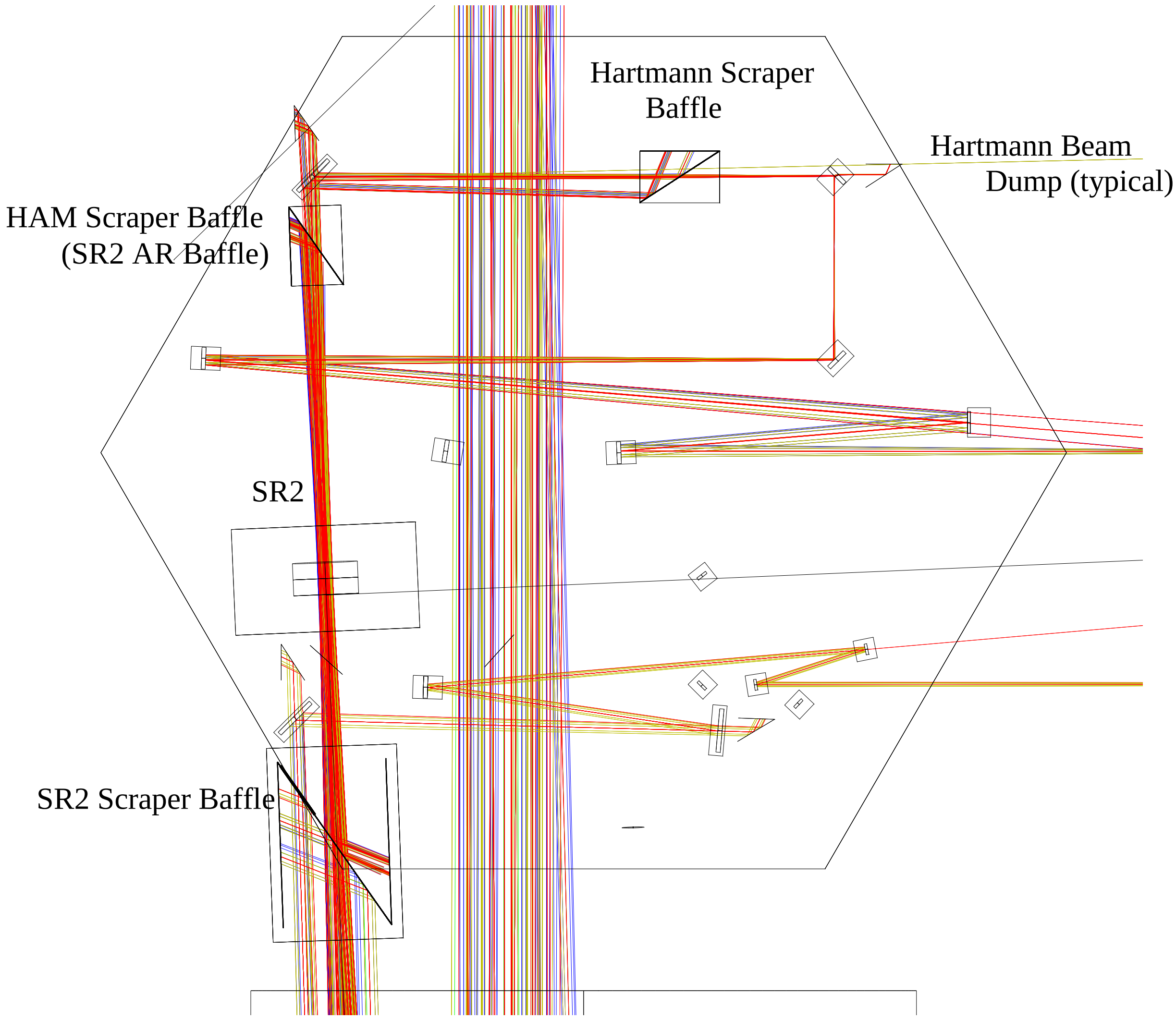

Figure 1: H1 & L1 HAM4: SR2 Scraper Baffle, SR2 AR Baffle, Hartmann Scraper Baffle, Hartmann Beam Dump

The H1 and L1 IFO ZEMAX layout of HAM5 is shown in Figure 2.

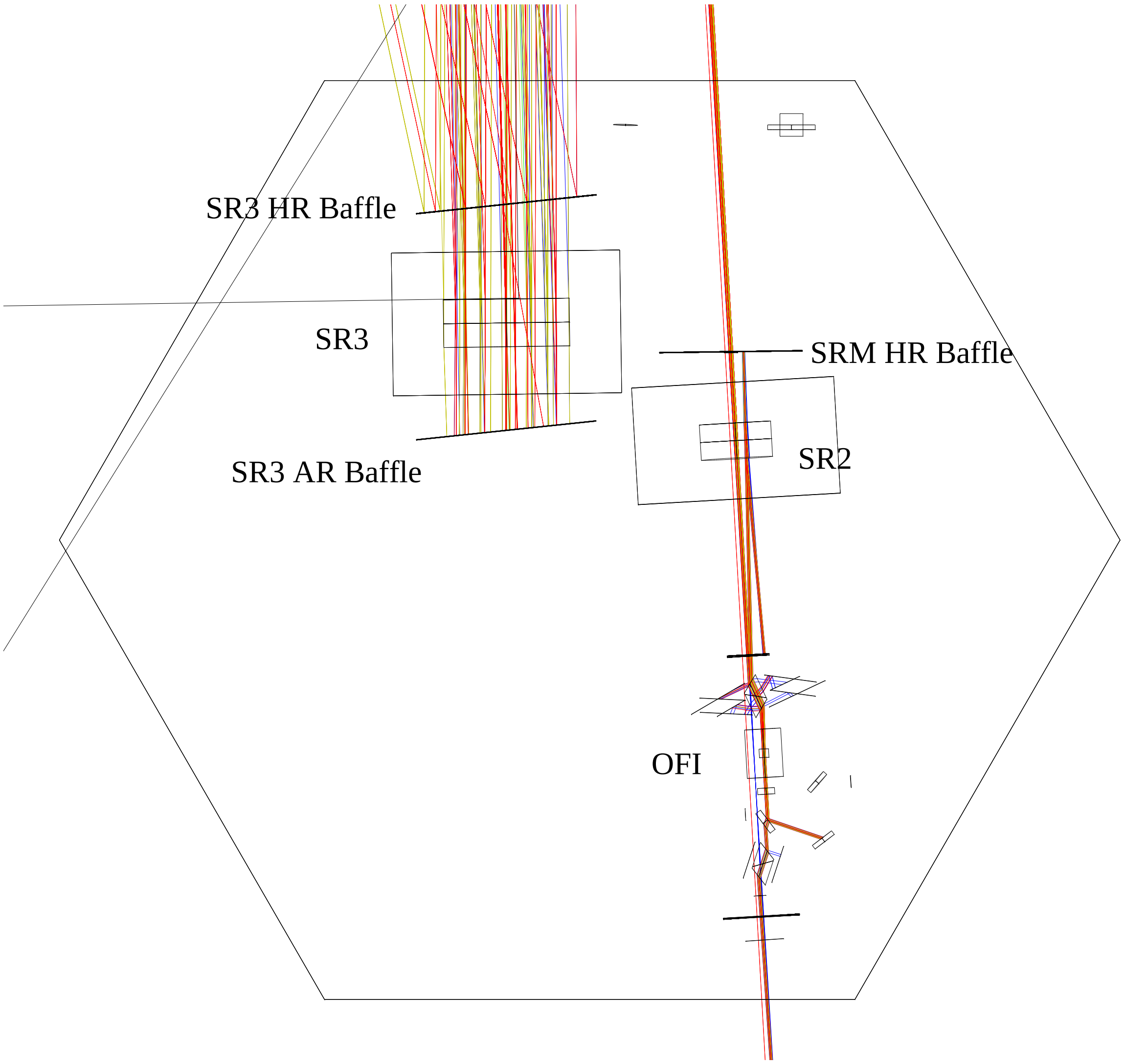

Figure 2: H1& L1 HAM5: SR3 HR Baffle, SR3 AR Baffle, SRM HR Baffle

2.2.2 H2 IFO ZEMAX LAYOUT

The H2 IFO ZEMAX layout of HAM10 is shown in Figure 3.

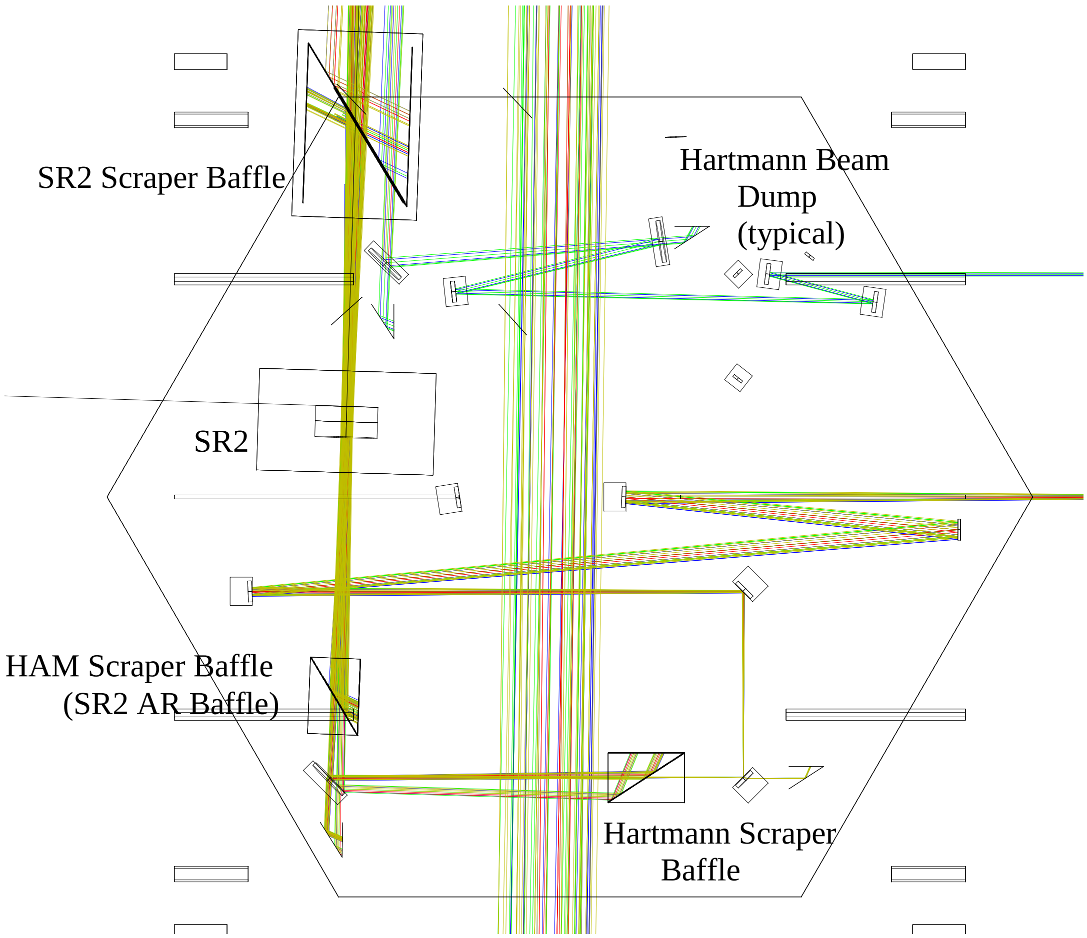

Figure 3: H2 HAM10: SR2 Scraper Baffle, SR2 AR Baffle, Hartmann Scraper Baffle, Hartmann Beam Dump

The H2 IFO ZEMAX layout of HAM11 is shown in Figure 4.

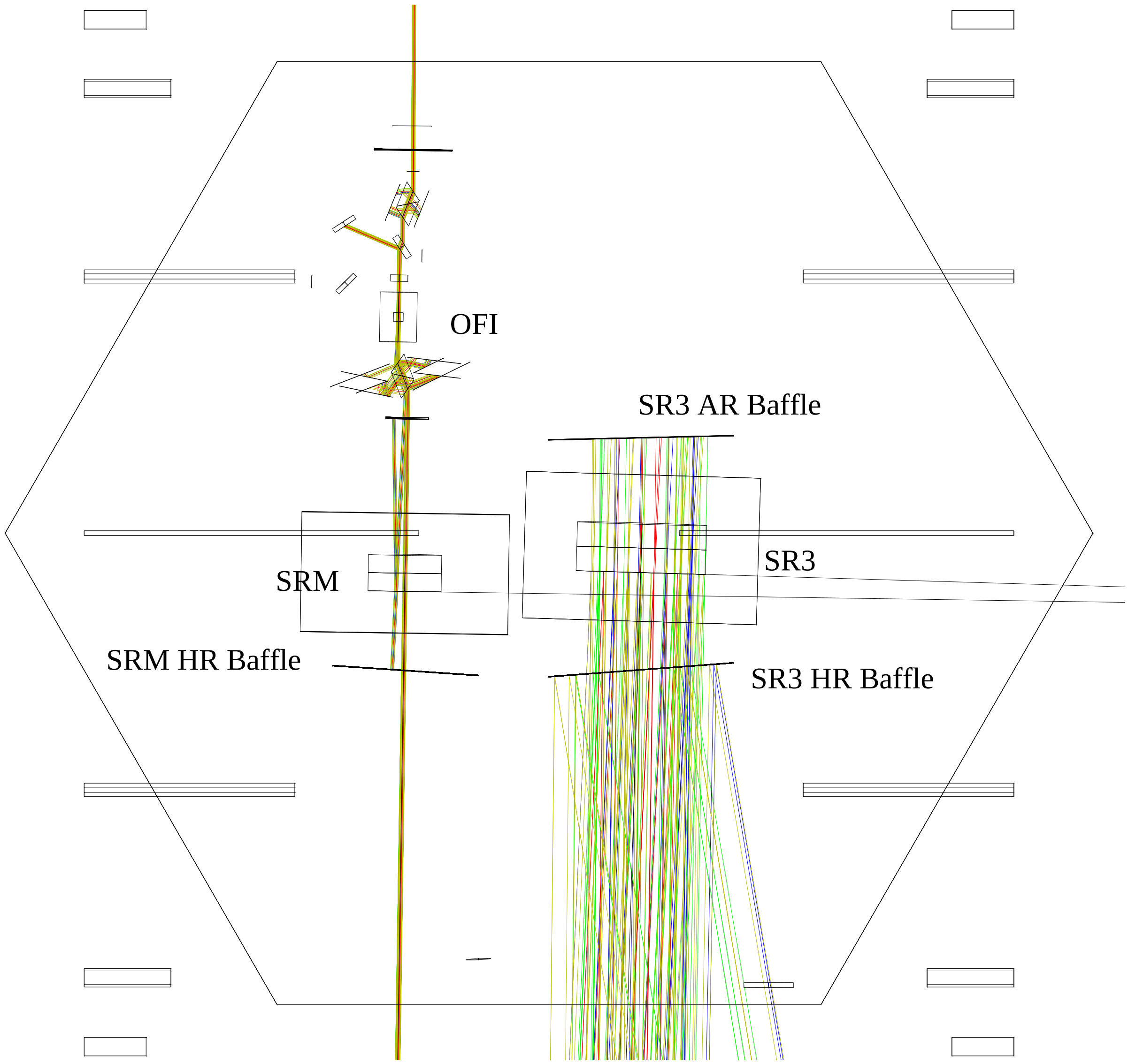

Figure 4: H2 HAM11: SR3 HR Baffle, SR3 AR Baffle, SRM HR Baffle

2.3 BEAM SIZES

2.3.1 H1/L1 BEAM SIZES IN SIGNAL RECYCLING CAVITY

2.3.1.1 H1/L1 ZEMAX PHYSICAL OPTICS PROPAGATION MODEL

The beam sizes in the signal recycling cavity were calculated using the ZEMAX physical optics program; a Gaussian beam with a 12mm waist located a distance 1835000m away from the ITM HR surface (approximately at the middle of the arm) was propagated down the signal recycling cavity optical train. The ZEMAX layout is shown in Figure 5.

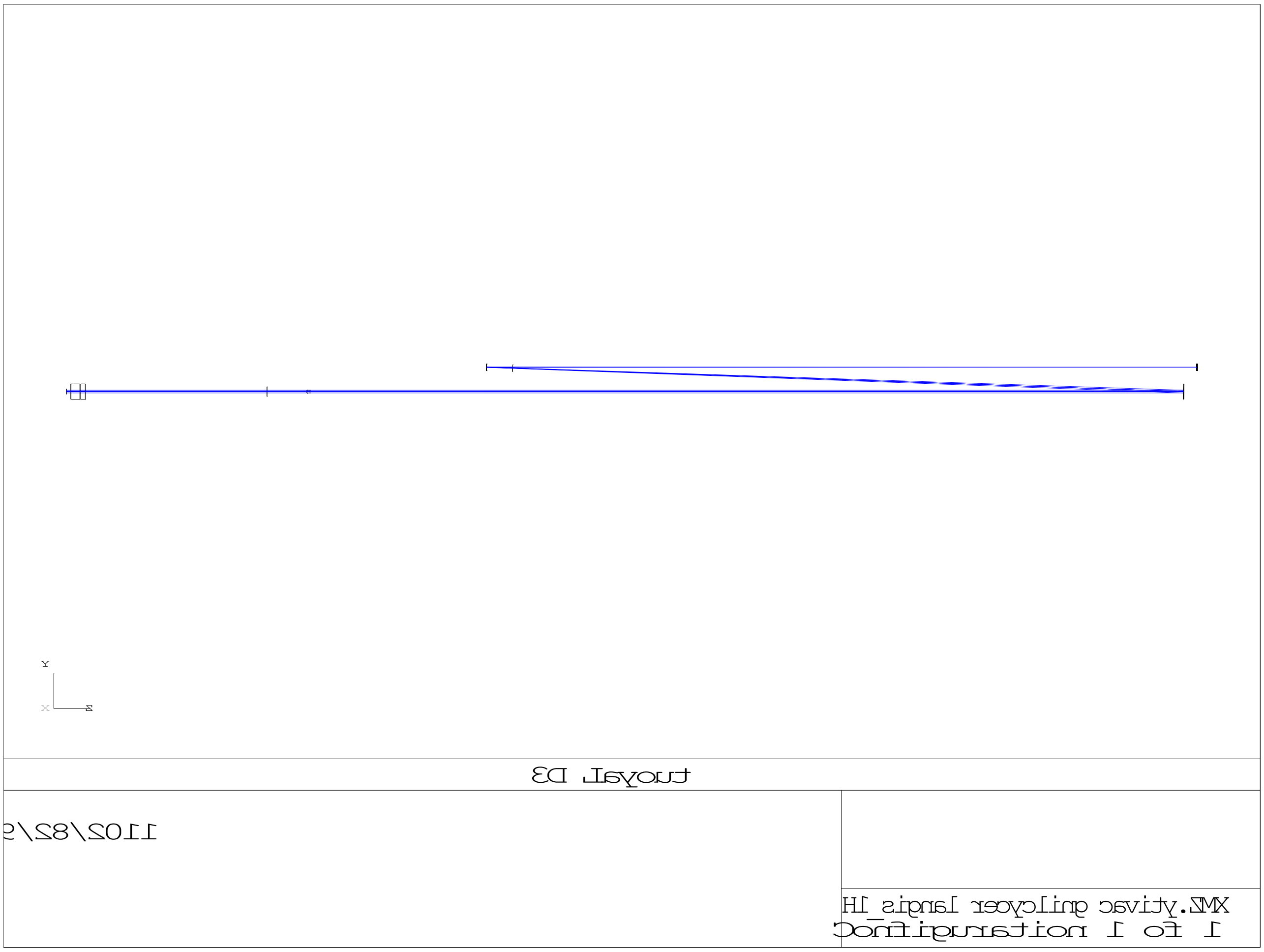

Figure 5: 3D Layout, H1/L1 Physical Optics Propagation

The x (vertical) and y (horizontal) beam profiles at various surfaces within the signal recycling cavity optical train are shown in the following figures.

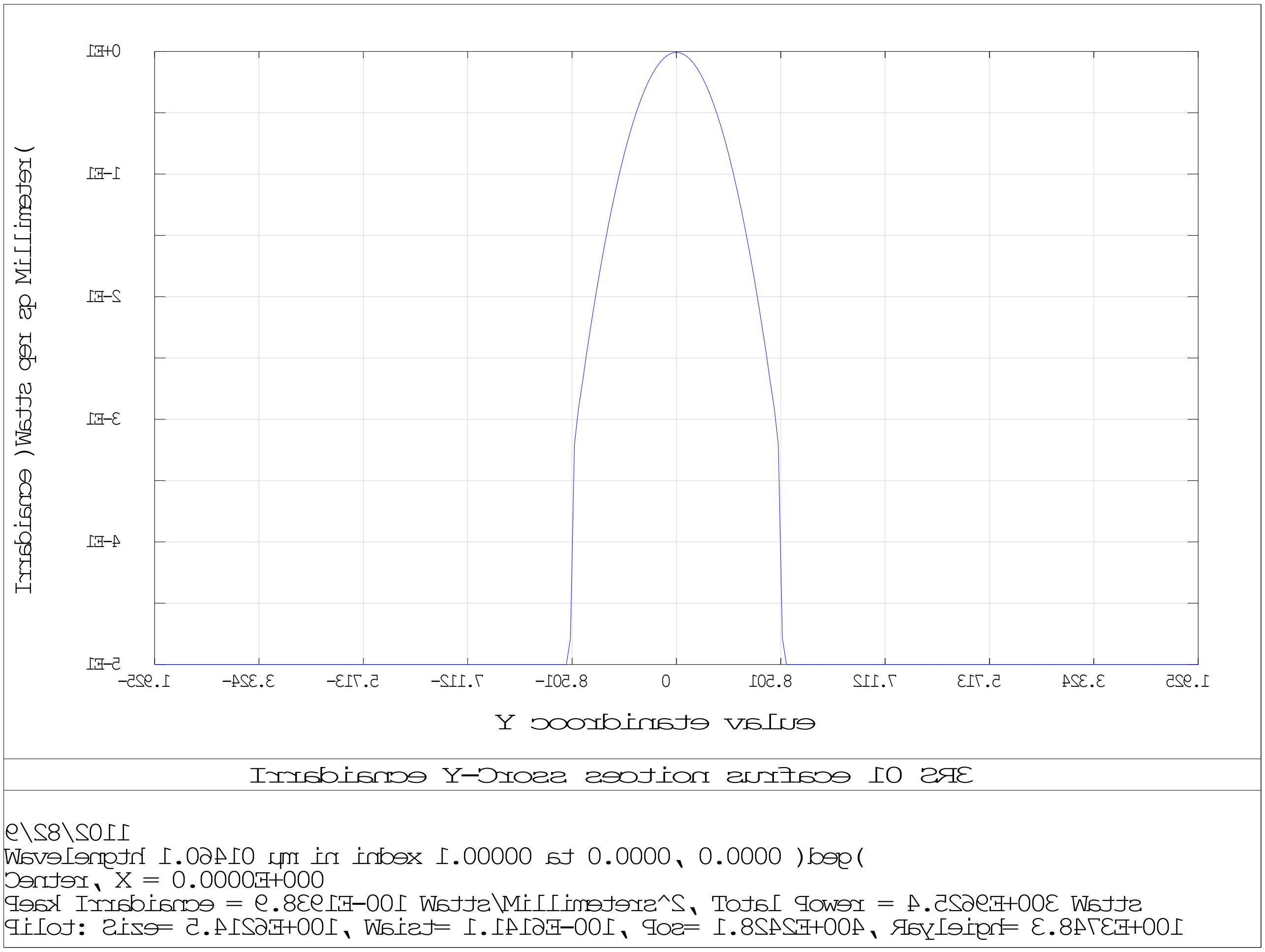

Figure 6: H1/L1 SR3, Horizontal Beam Profile

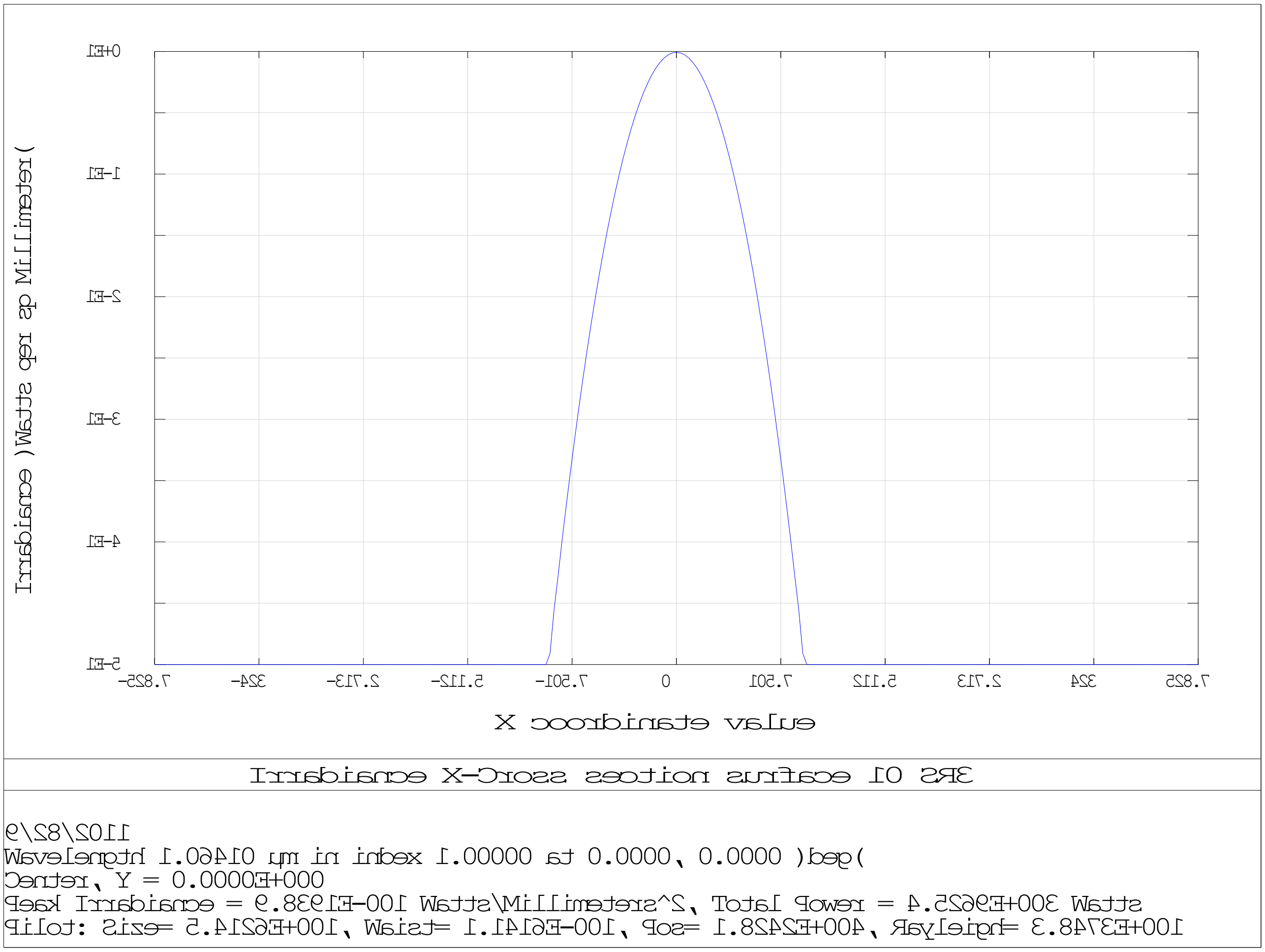

Figure 7: H1/L1 SR3, Vertical Beam Profile

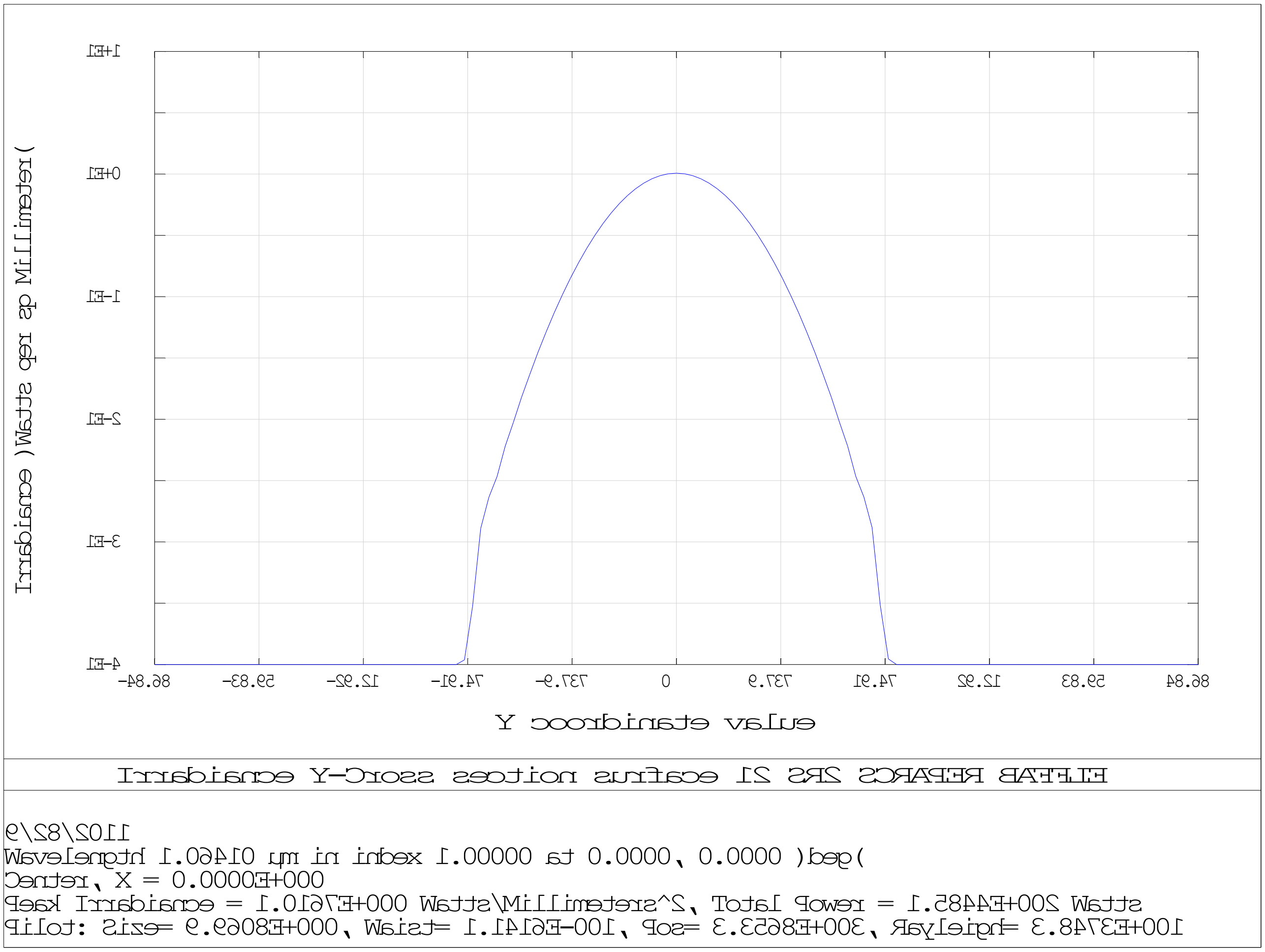

Figure 8: : H1/L1 SR2 Scraper Baffle, Horizontal Beam Profile

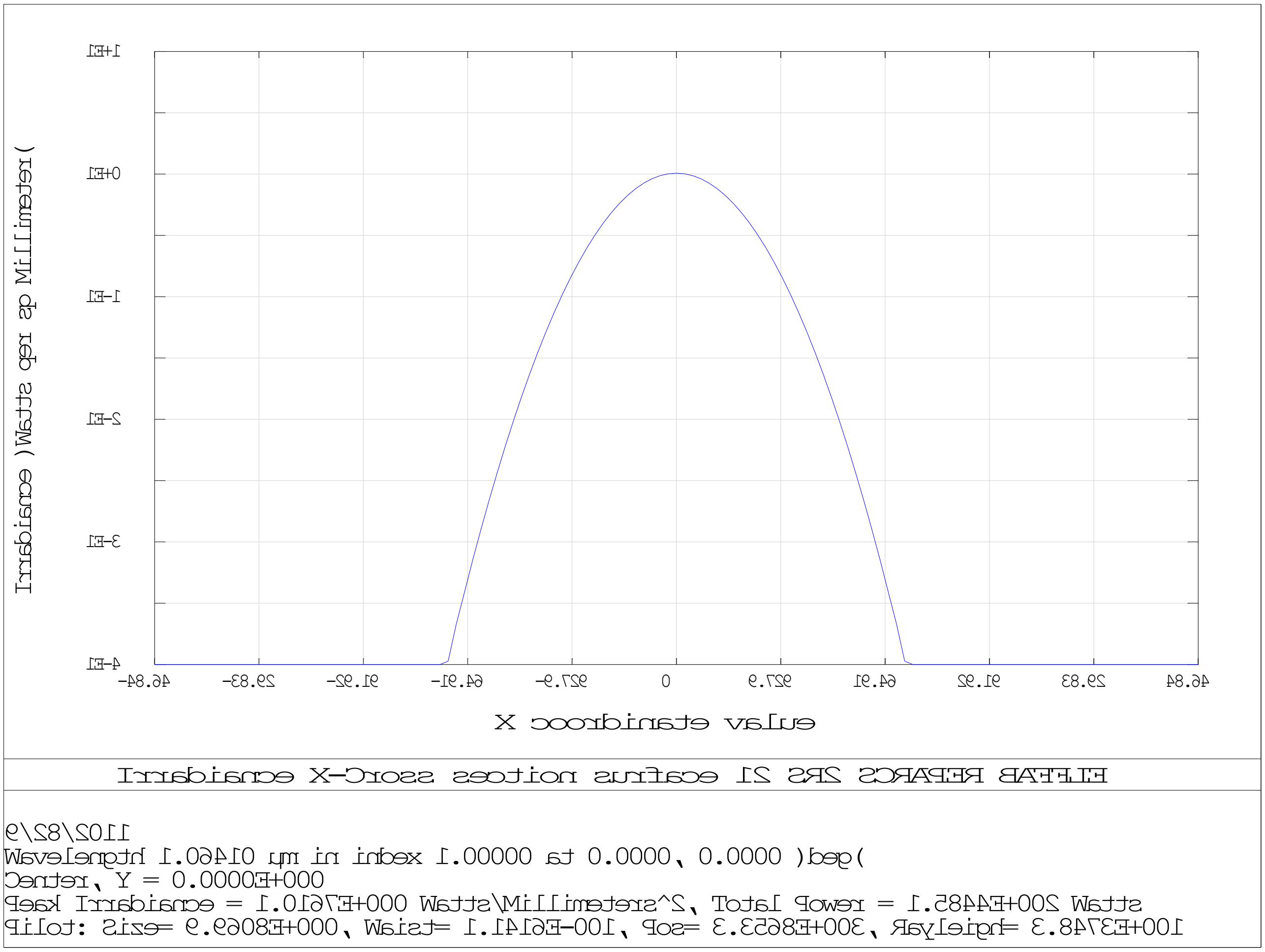

Figure 9: H1/L1 SR2 Scraper Baffle, Vertical Beam Profile

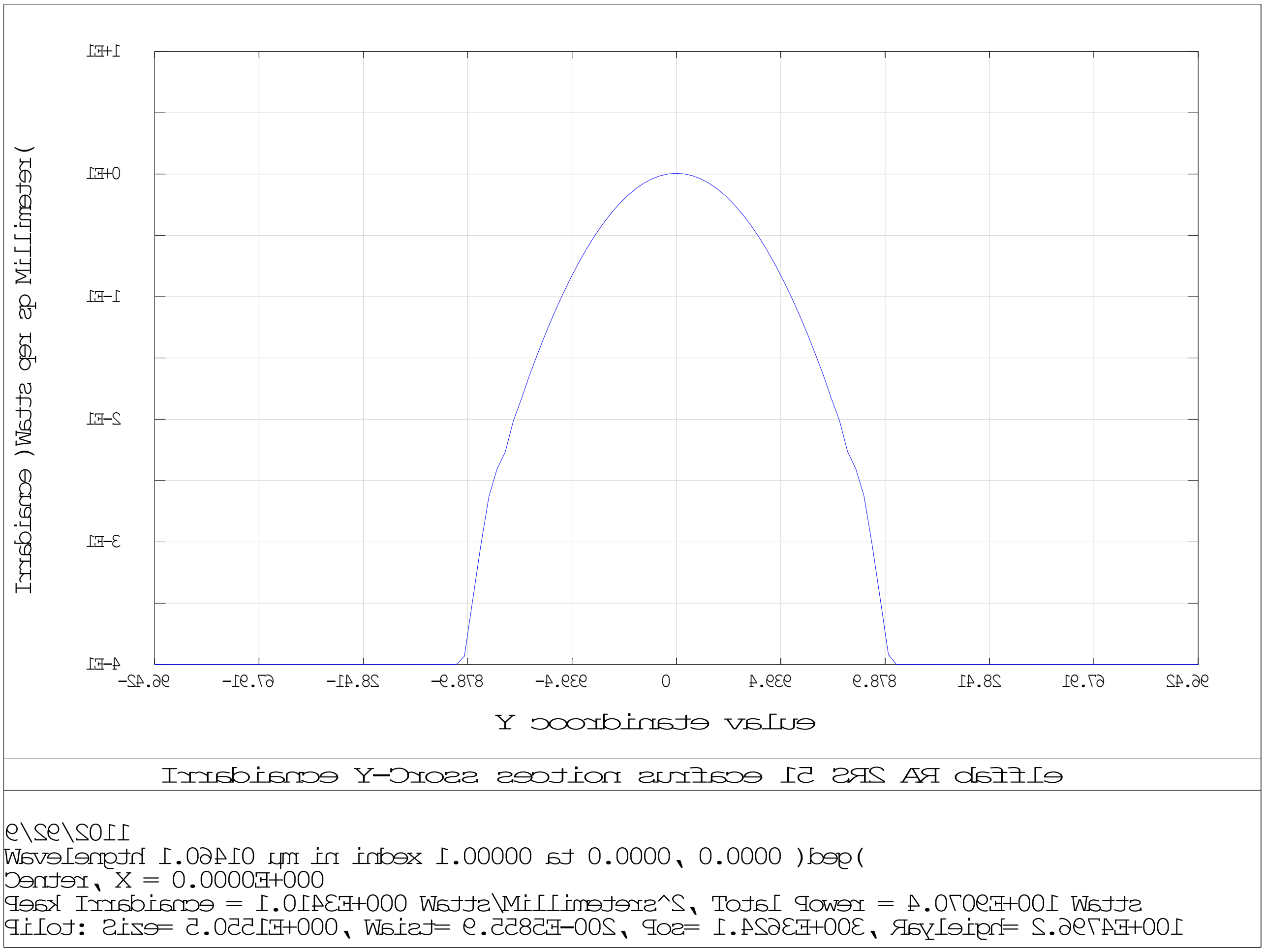

Figure 10: H1/L1 HAM Scraper Baffle (SR2 AR Baffle), Horizontal Beam Profile

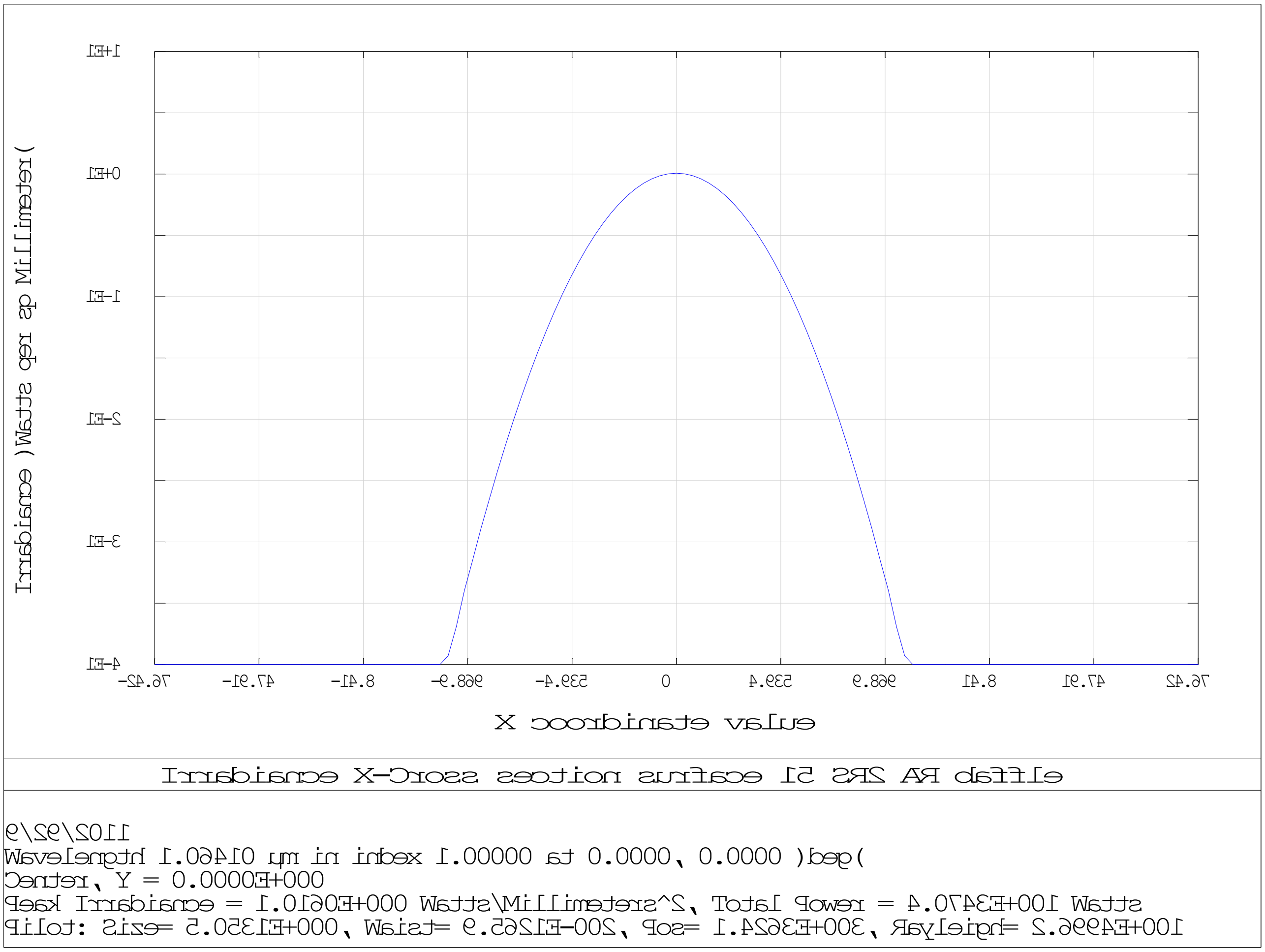

Figure 11: H1/L1 HAM Scraper Baffle (SR2 AR Baffle), Vertical Beam Profile

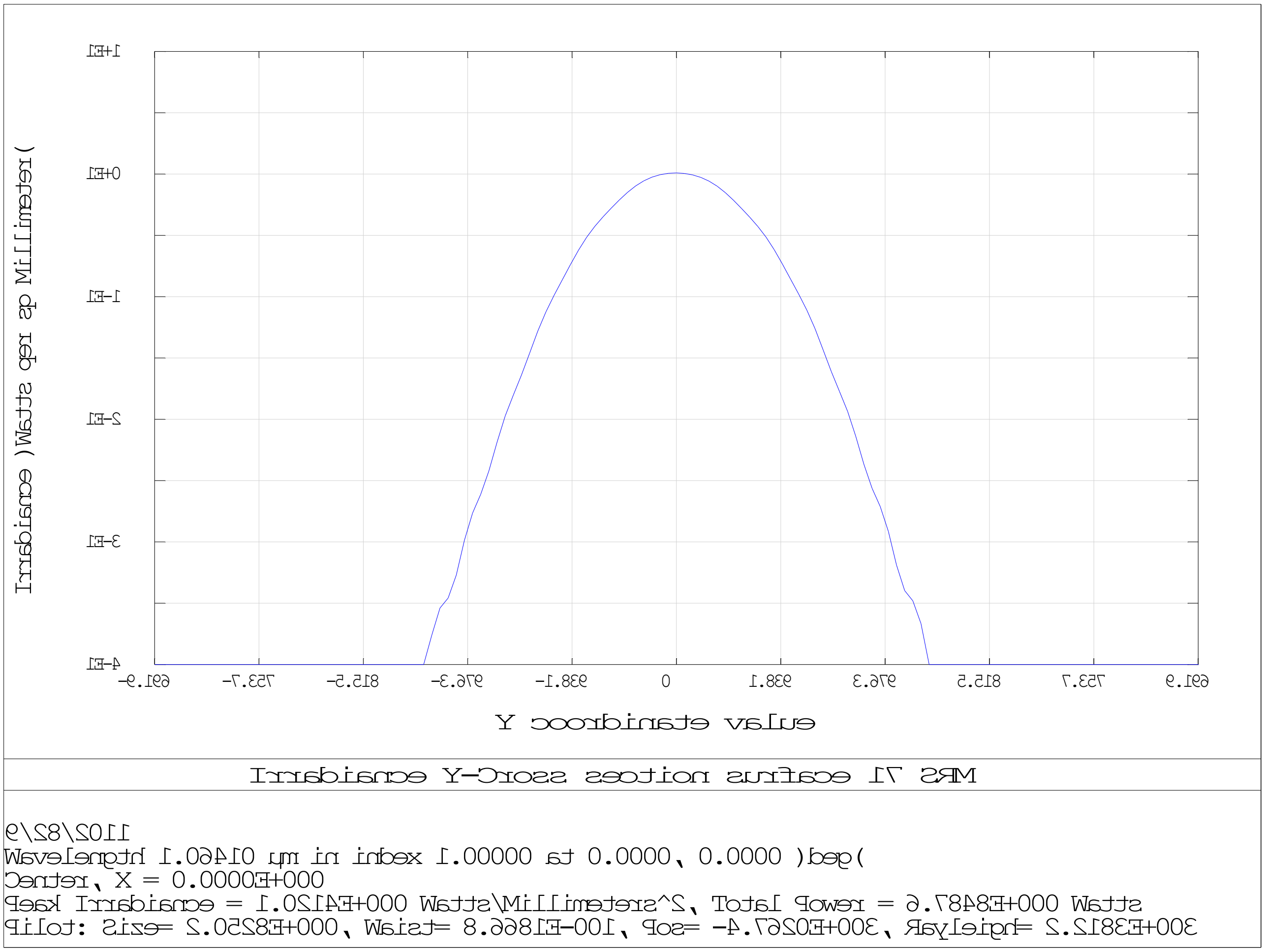

Figure 12: H1/L1 SRM, Horizontal Beam Profile

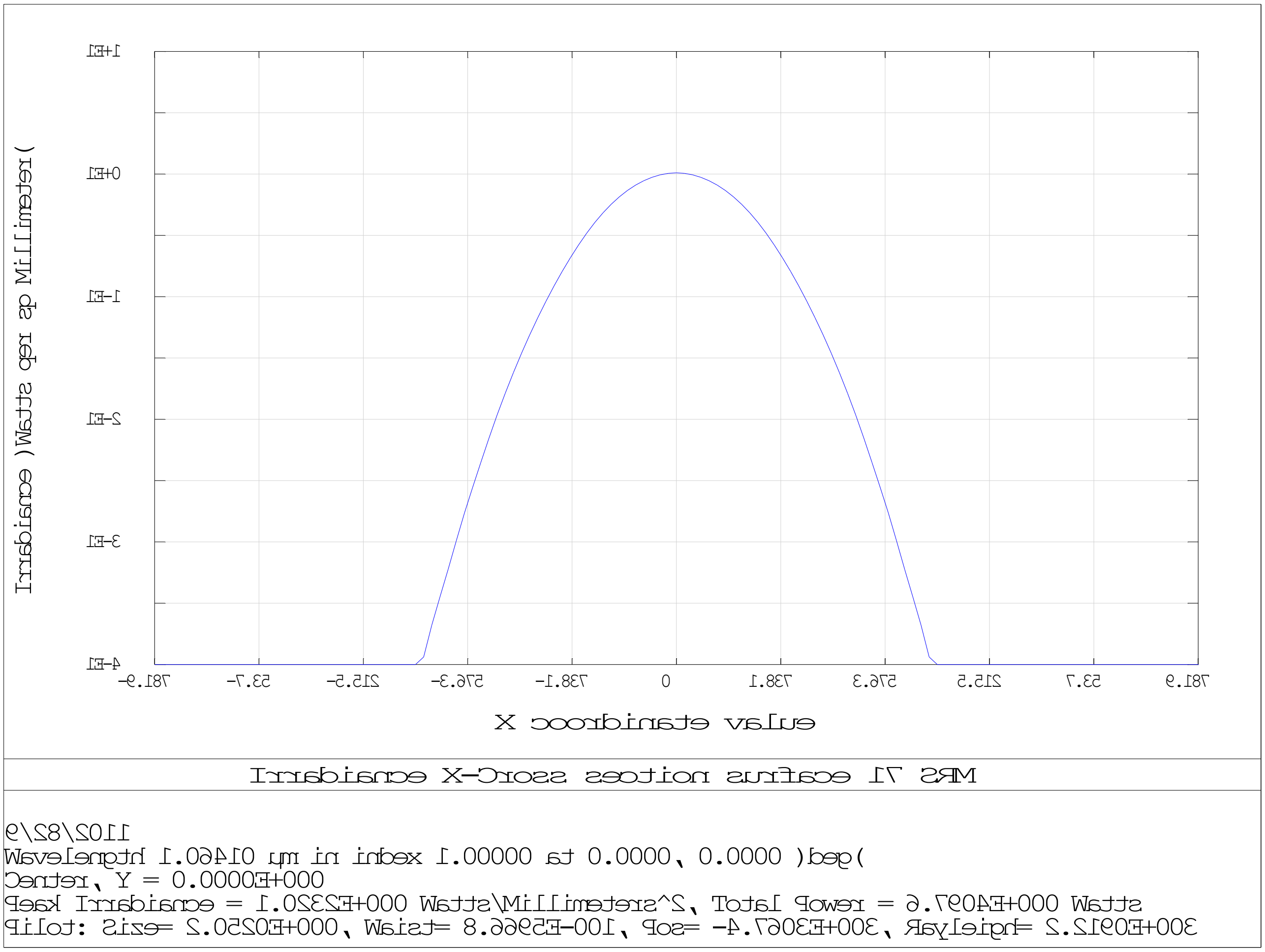

Figure 13: H1/L1 SRM, Vertical Beam Profile

2.3.2 H2 BEAM SIZES IN SIGNAL RECYCLING CAVITY

2.3.2.1 H2 ZEMAX PHYSICAL OPTICS PROPAGATION MODEL

The beam sizes in the signal recycling cavity were calculated using the ZEMAX physical optics program; a Gaussian beam with a 12mm waist located a distance 1835000m away from the ITM HR surface (approximately at the middle of the arm) was propagated down the signal recycling cavity optical train. The ZEMAX layout is shown in Figure 14.

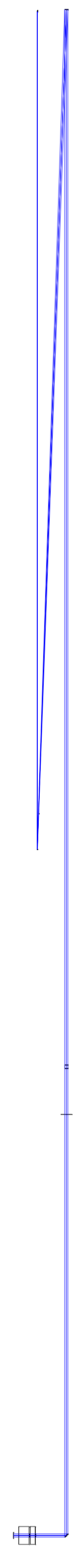

Figure 14: 3D Layout, H2 Physical Optics Propagation

The x (vertical) and y (horizontal) beam profiles at various surfaces within the signal recycling cavity optical train are shown in the following figures.

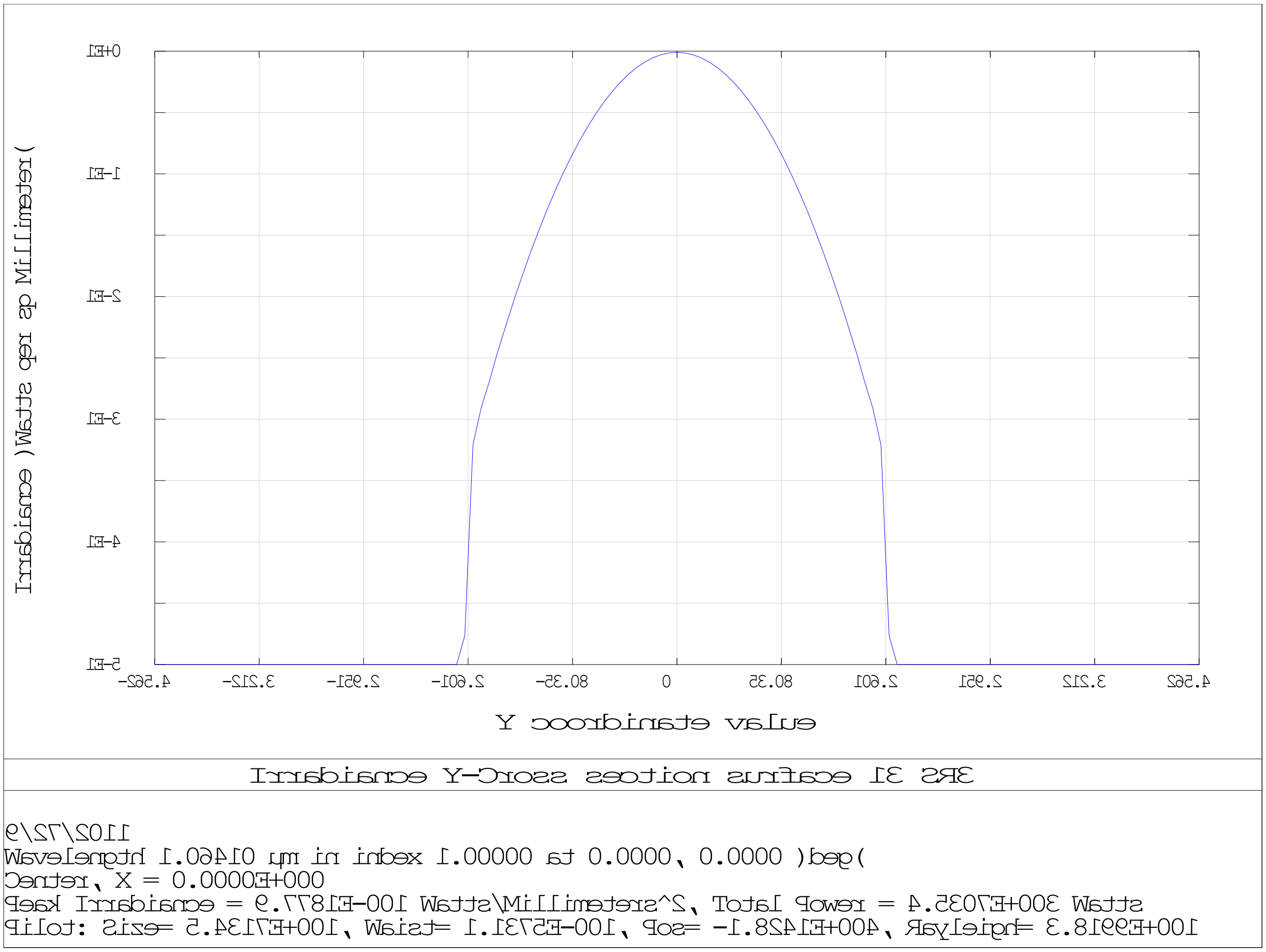

Figure 15: H2 SR3, Horizontal Beam Profile

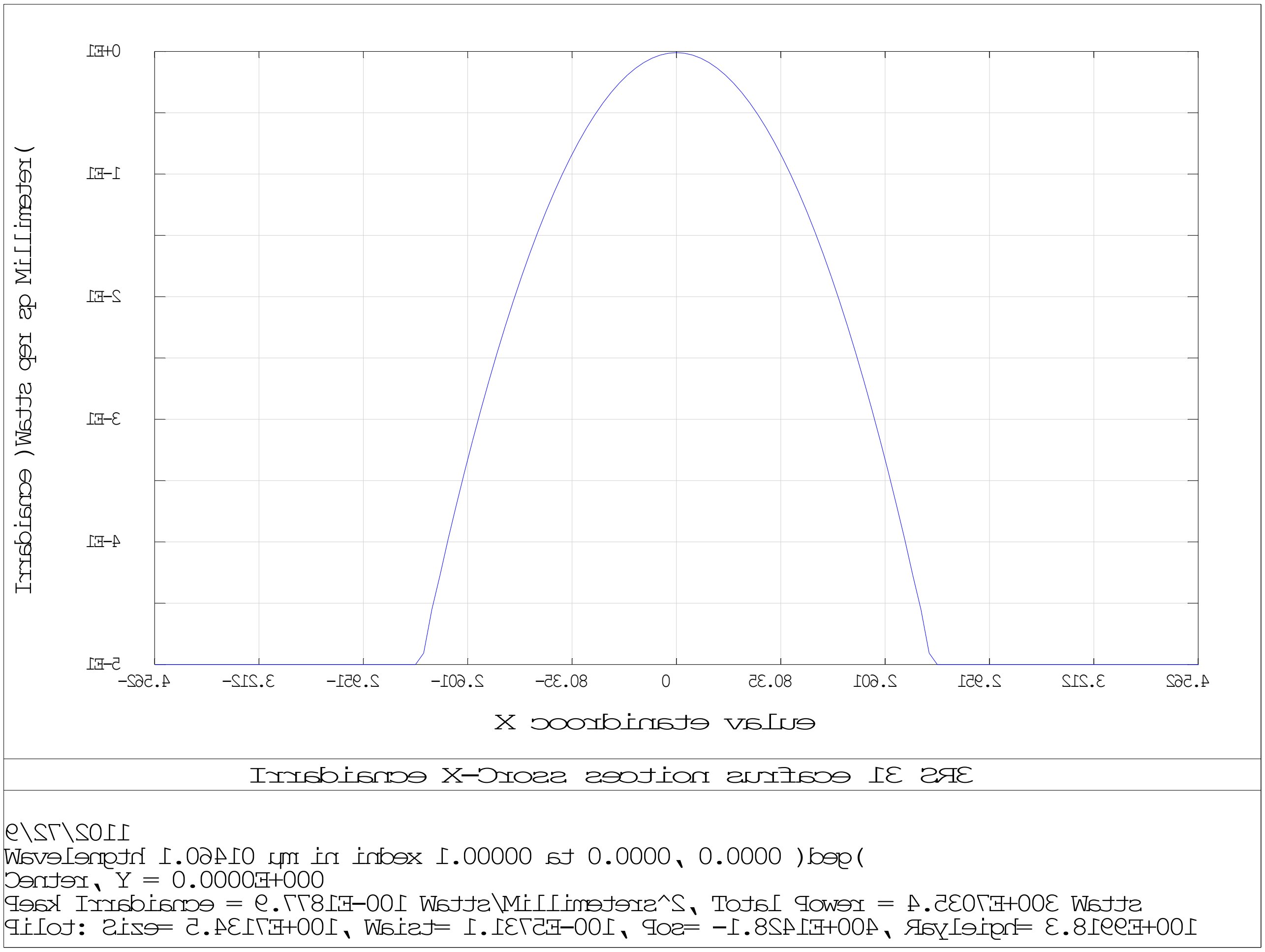

Figure 16: H2 SR3, Vertical Beam Profile

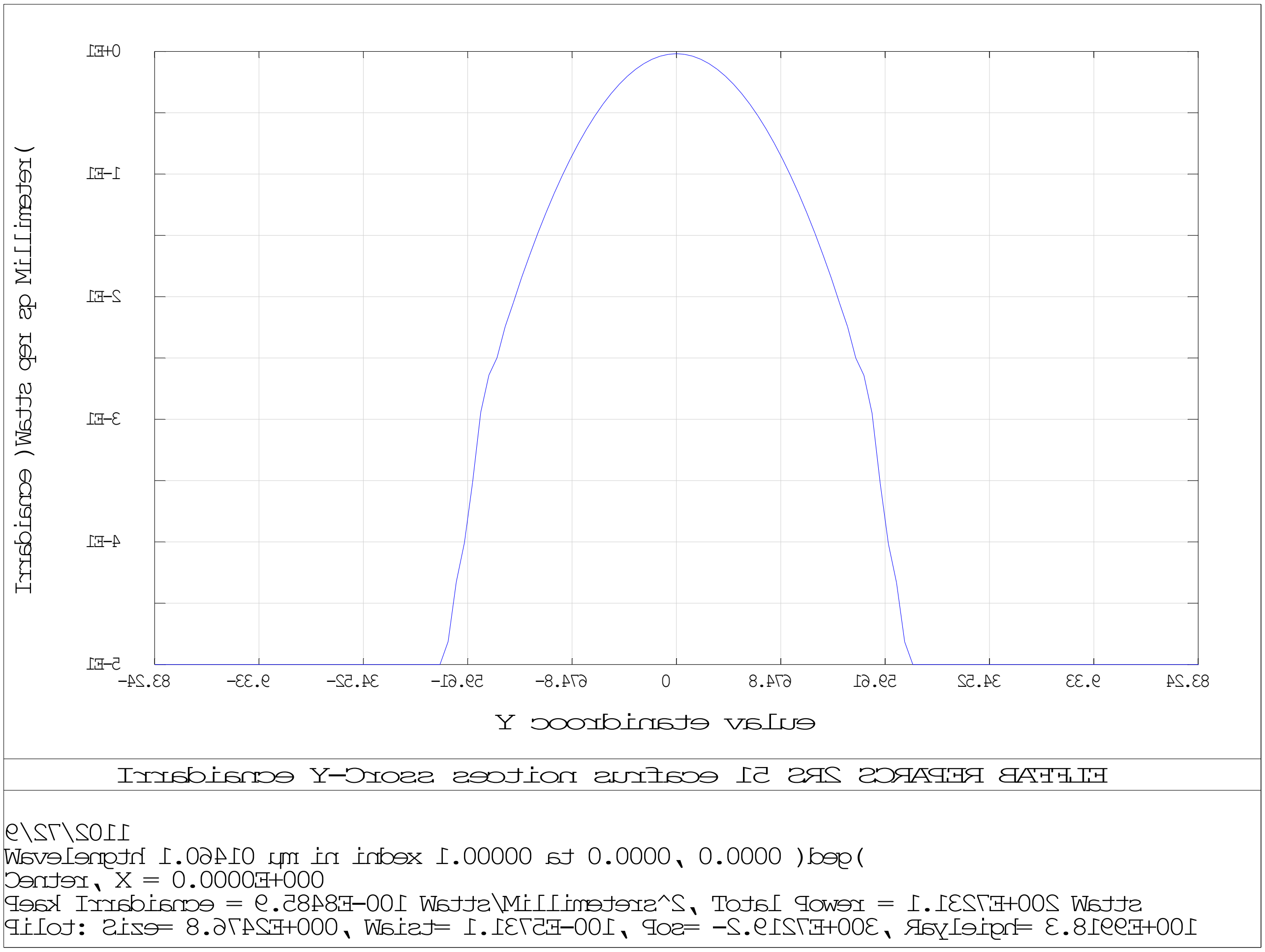

Figure 17: : H2 SR2 Scraper Baffle, Horizontal Beam Profile

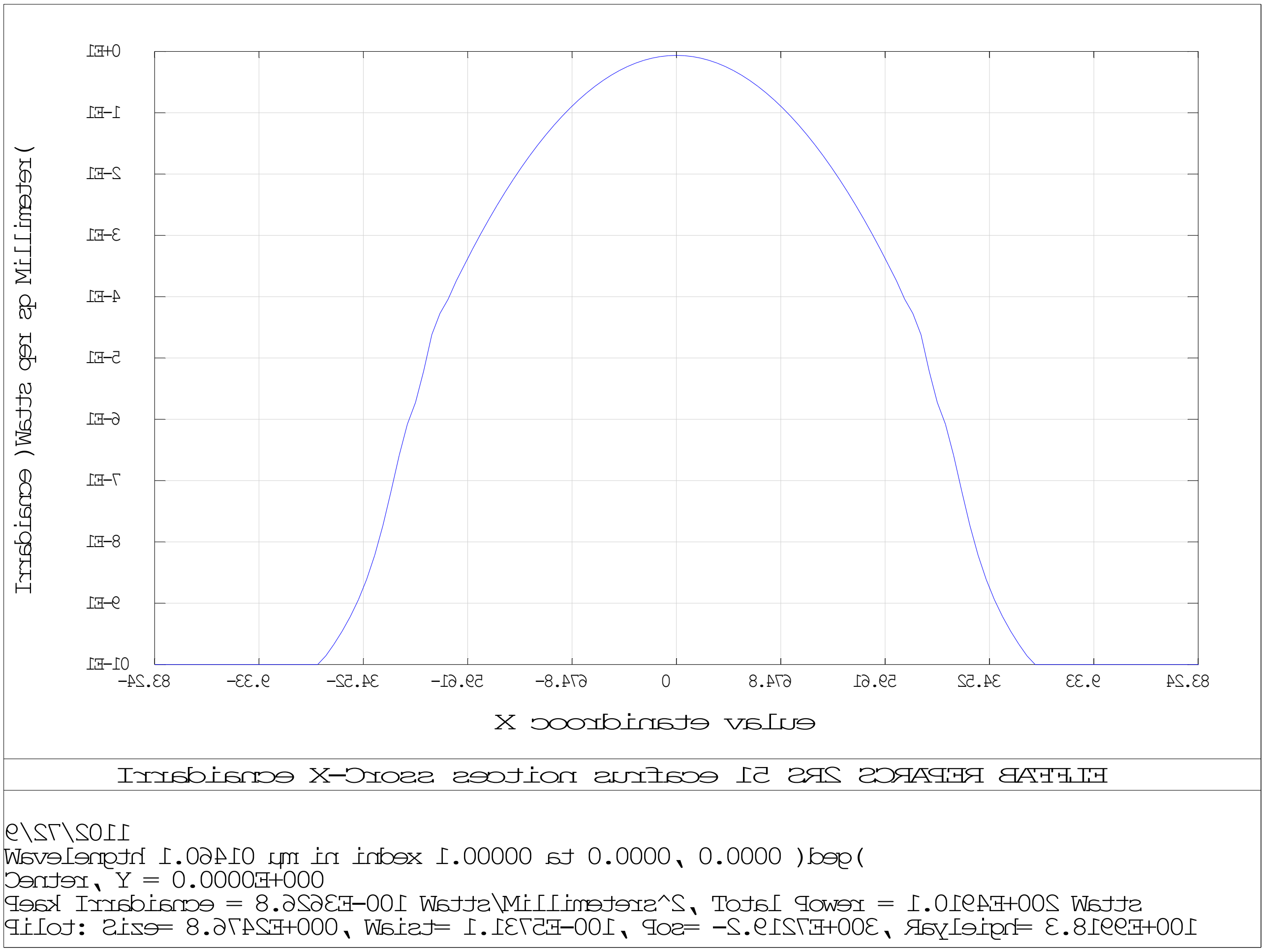

Figure 18: H2 SR2 Scraper Baffle, Vertical Beam Profile

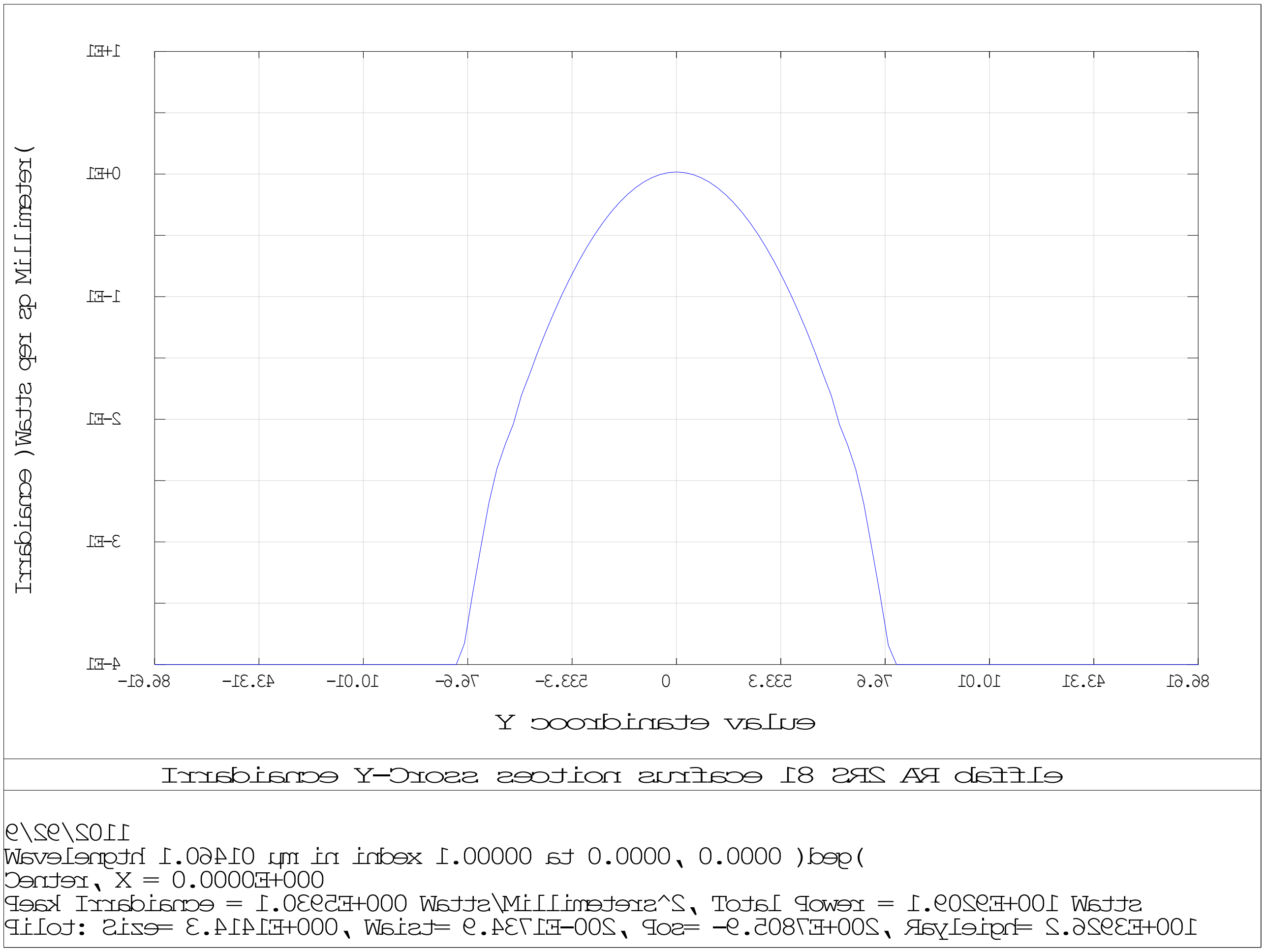

Figure 19: H2 HAM Scraper Baffle (SR2 AR Baffle), Horizontal Beam Profile

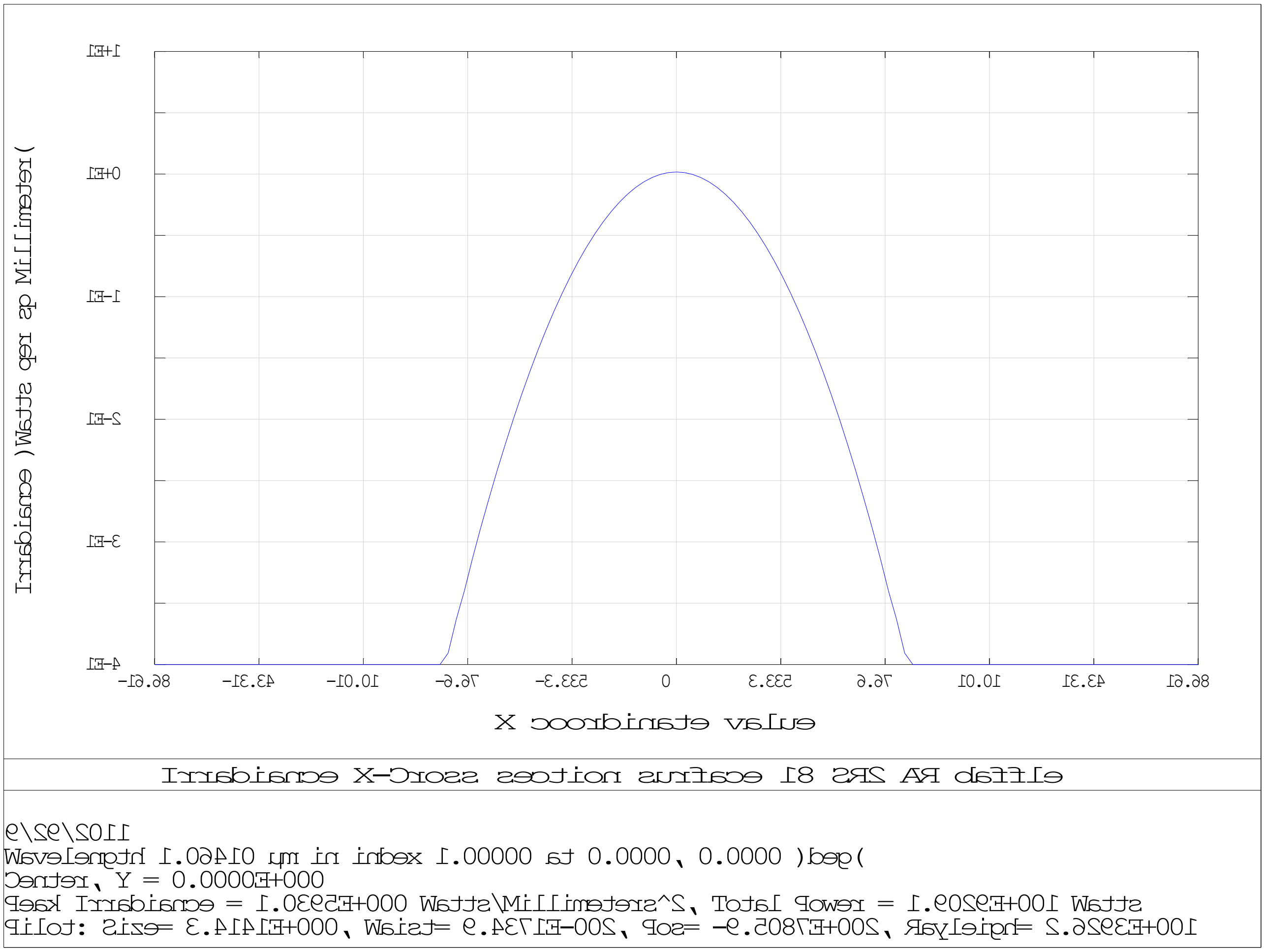

Figure 20: H2 HAM Scraper Baffle (SR2 AR Baffle), Vertical Beam Profile

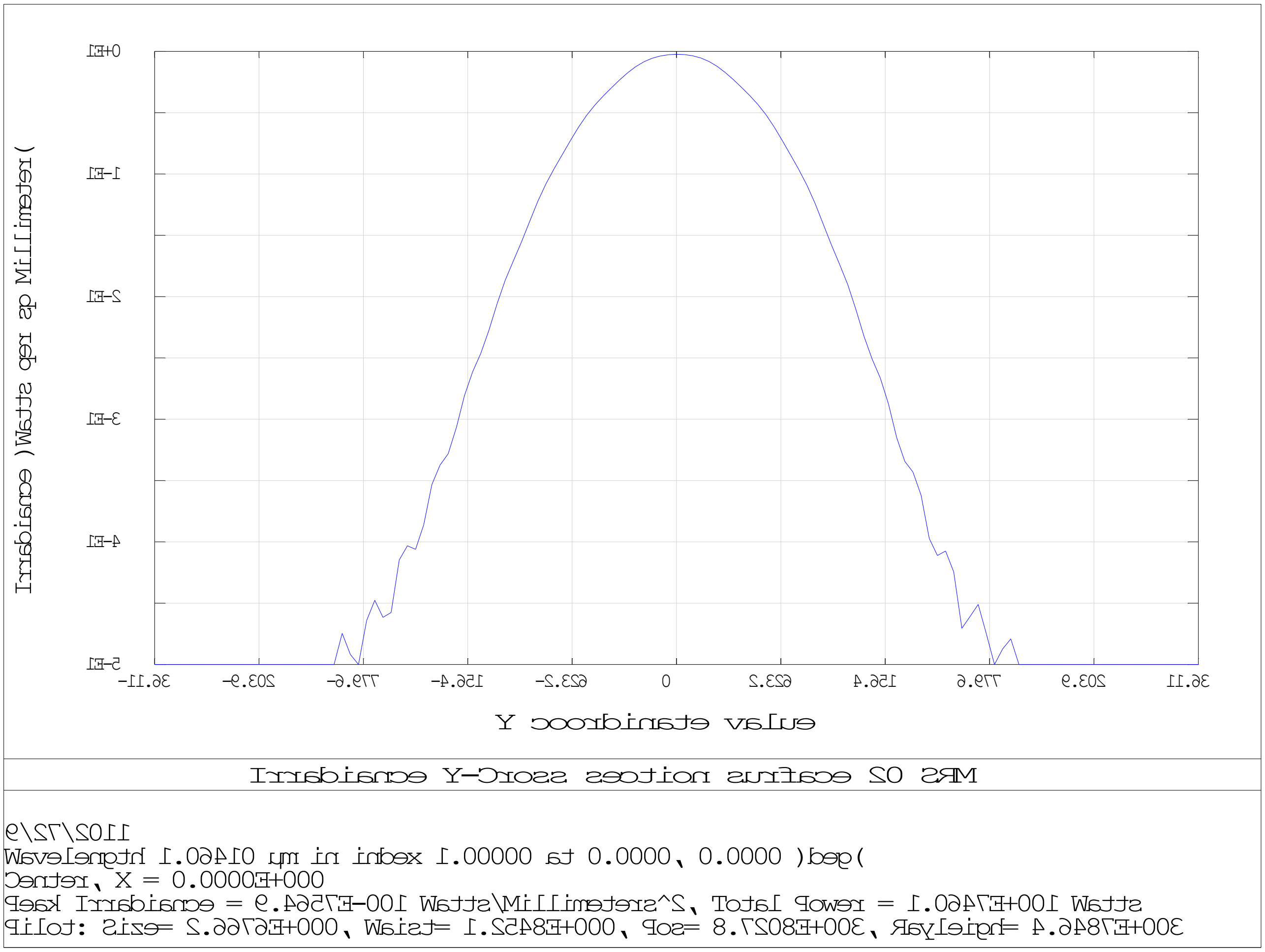

Figure 21: H2 SRM, Horizontal Beam Profile

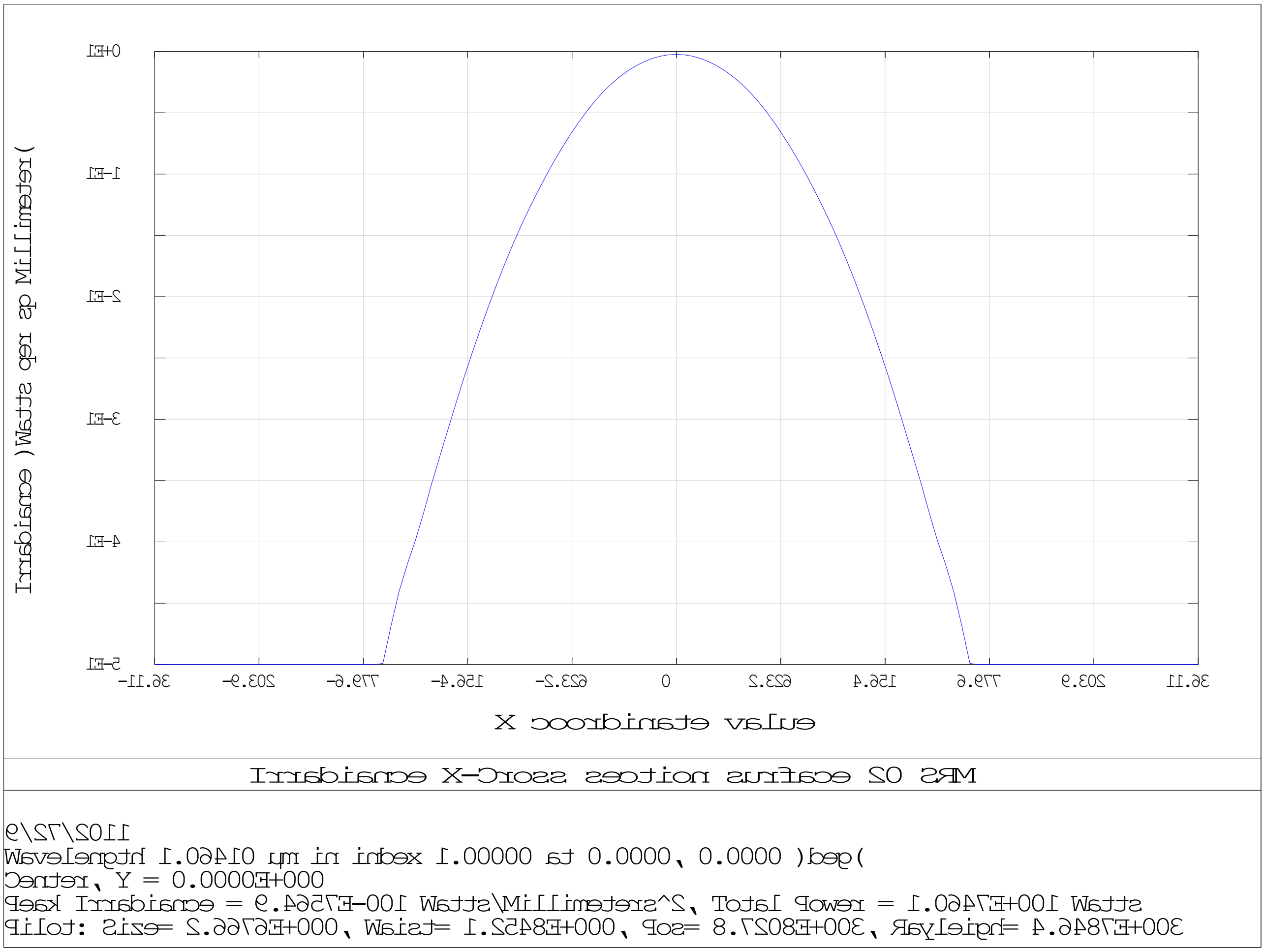

Figure 22: H2 SRM, Vertical Beam Profile

3 DESCRIPTIONS OF SIGNAL RECYCLING CAVITY BAFFLES

3.1 SR3 HR BAFFLE

A model of the SR3 HR Baffle is shown in Figure 23.

The hole diameter was chosen equal to the SR3 mirror diameter to maximize the extent of the Hartmann beam that reflects from the BS AR surface

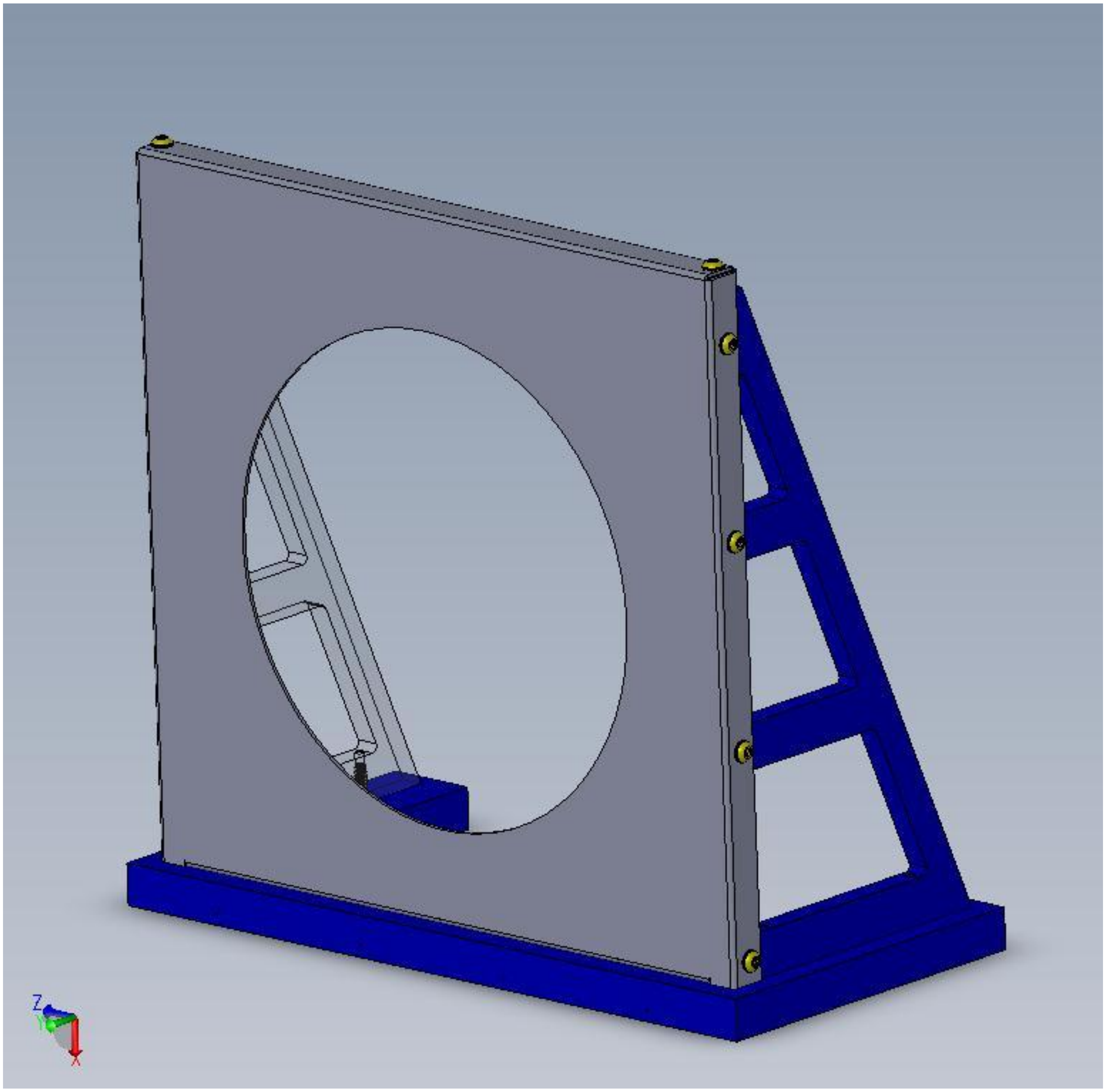

Figure 23: SR3 HR Baffle

3.2 SR3 AR BAFFLE

A model of the SR3 AR Baffle is shown in Figure 24. The baffle surface exceeds the dimensions of the SR3 mirror.

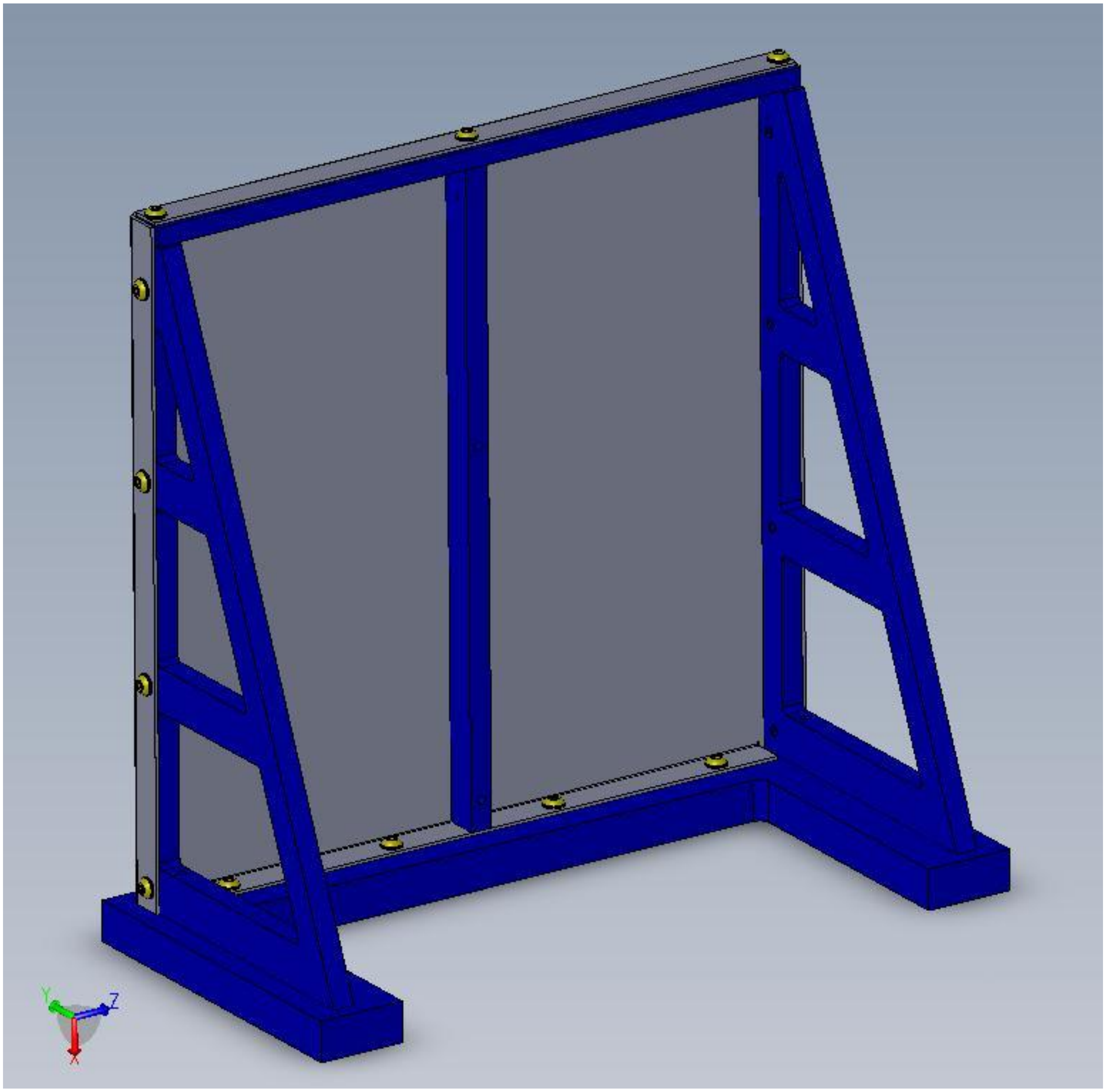

Figure 24: SR3 AR Baffle

3.3 SR2 SCRAPER BAFFLE

A model of the SR2 Scraper Baffle is shown in Figure 25. The recycling cavity beams pass through the hole on the right in the figure; the Hartmann pick-off beam passes through the hole in the left. The positions of the holes were determined from the ZEMAX layout.

The 36 mm minimum radius of the left hole in the baffle was determined by a diffraction analysis to cause a negligible vignetting of the Hartmann beam. (TBD see TCS reference); the hole radius was increased to 42mm to allow for misalignment of the baffle. The elliptical size of the right hole in the baffle allows passage of the incident and reflected signal recycling main beam without vignetting causing a signal recycling power loss > 100 ppm.

The results of the FEA model show that the lowest internal mode frequency of the baffle is > 150 Hz TBD.

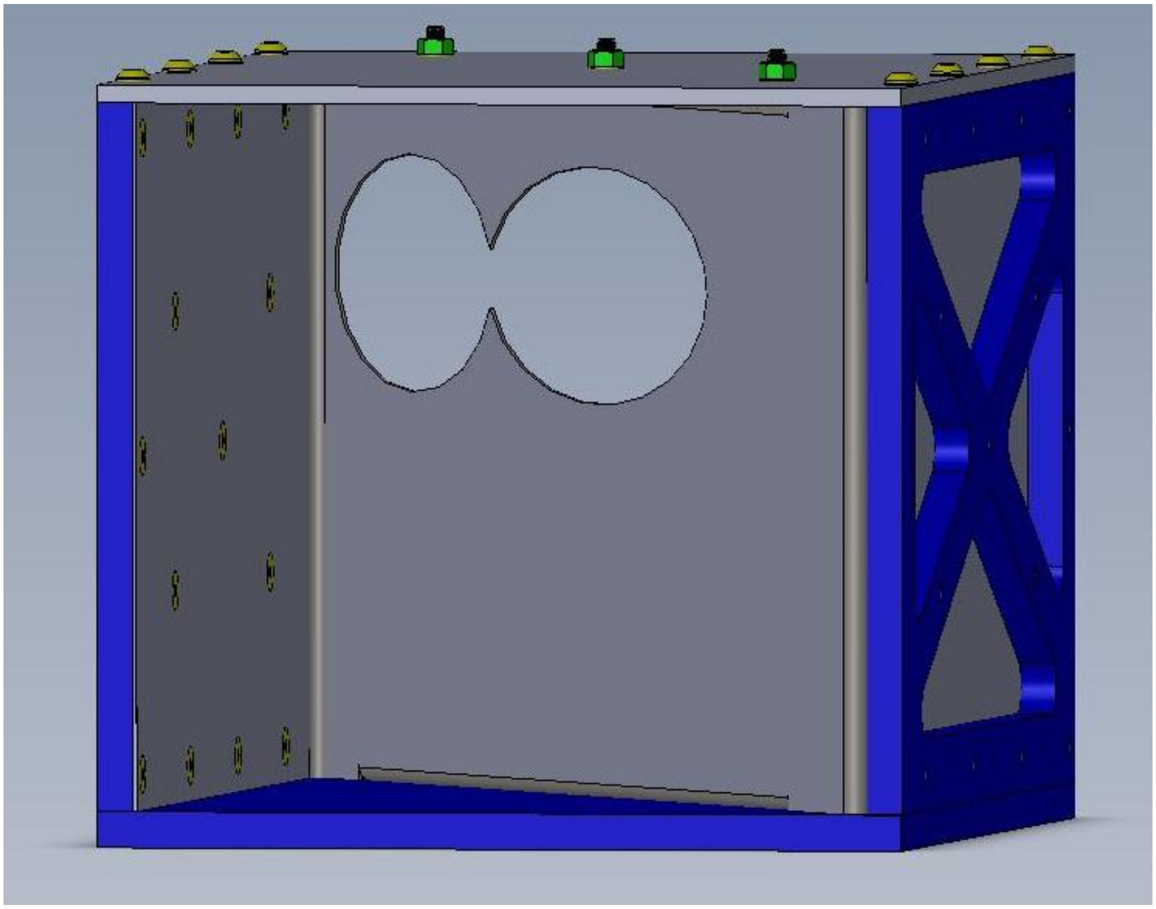

Figure 25: SR2 Scraper Baffle, H2

3.4 HAM SCRAPER BAFFLE

A model of the HAM Scraper Baffle is shown in Figure 26. The locations of the IFO beams and the Hartmann beam that traverse the HAM Scraper Baffle were determined from the ZEMAX layout.

The 30 mm minimum radius of the hole in the baffle causes a negligible vignetting of the Hartmann beam.

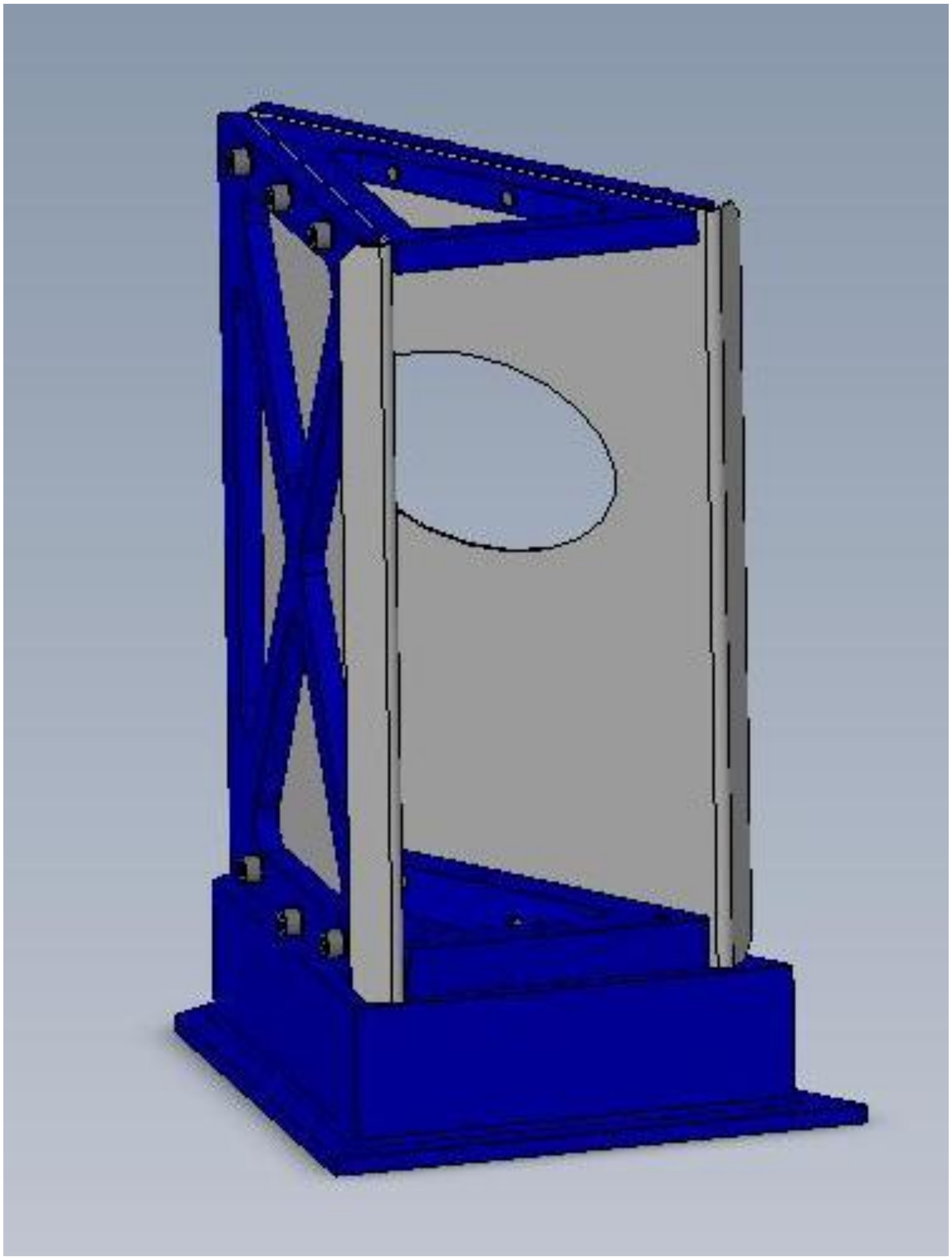

Figure 26: HAM Scraper Baffle

The baffle is mounted directly to the HAM ISI table and must meet the requirement that the lowest internal frequency be > 150 Hz.

The results of the FEA model show that the lowest internal mode frequency of the baffle is approximately 167 Hz, as shown in Figure 27, and meets the design requirement.

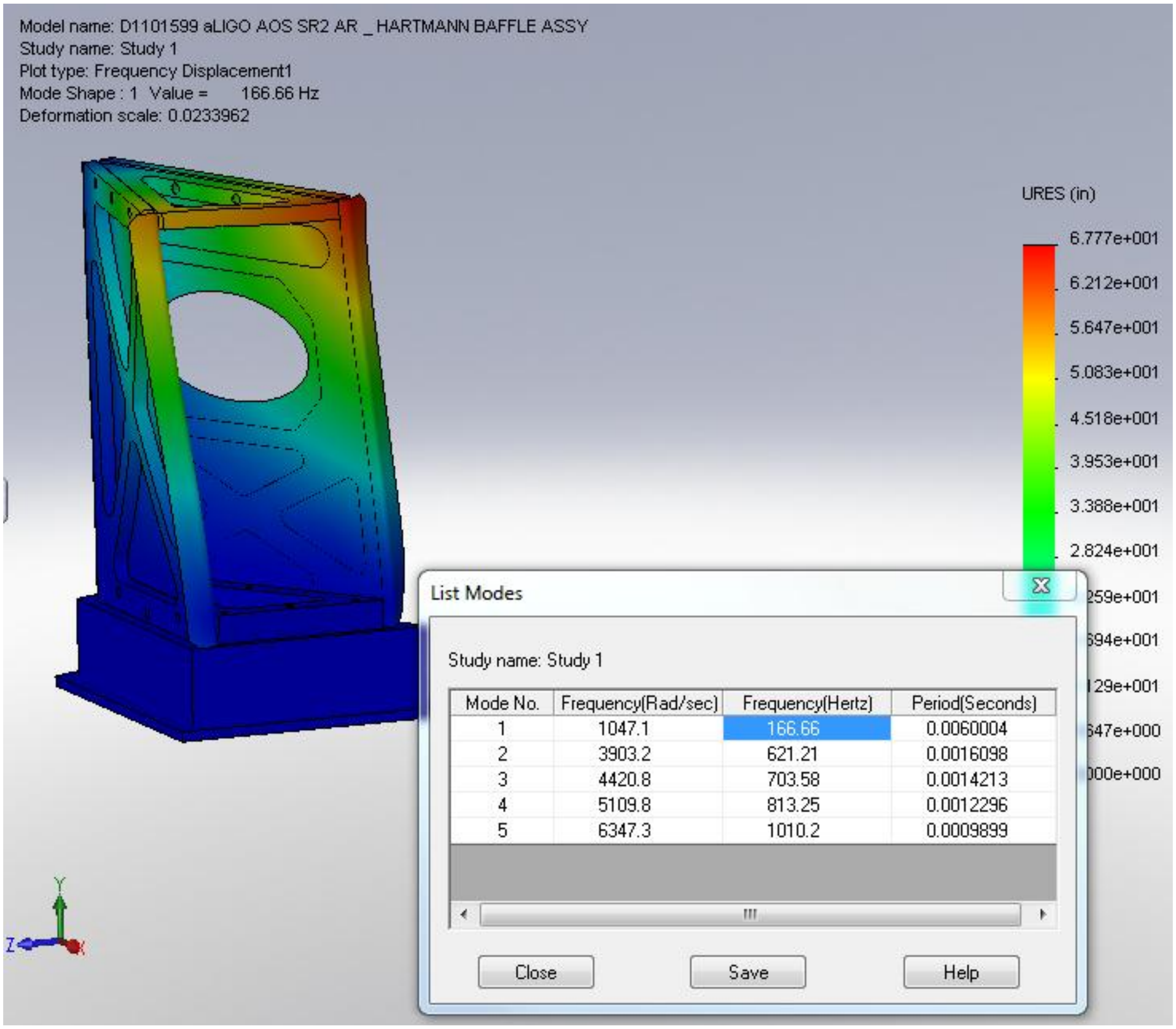

Figure 27: Internal Frequencies of HAM Scraper Baffle Assembly

3.5 SRM HR BAFFLE

A model of the SRM HR Baffle is shown in Figure 28. The locations of the IFO beams was determined from the ZEMAX layout.

The hole in the baffle is 25mm diameter, which is larger than the 20mm limiting aperture of the OFI.

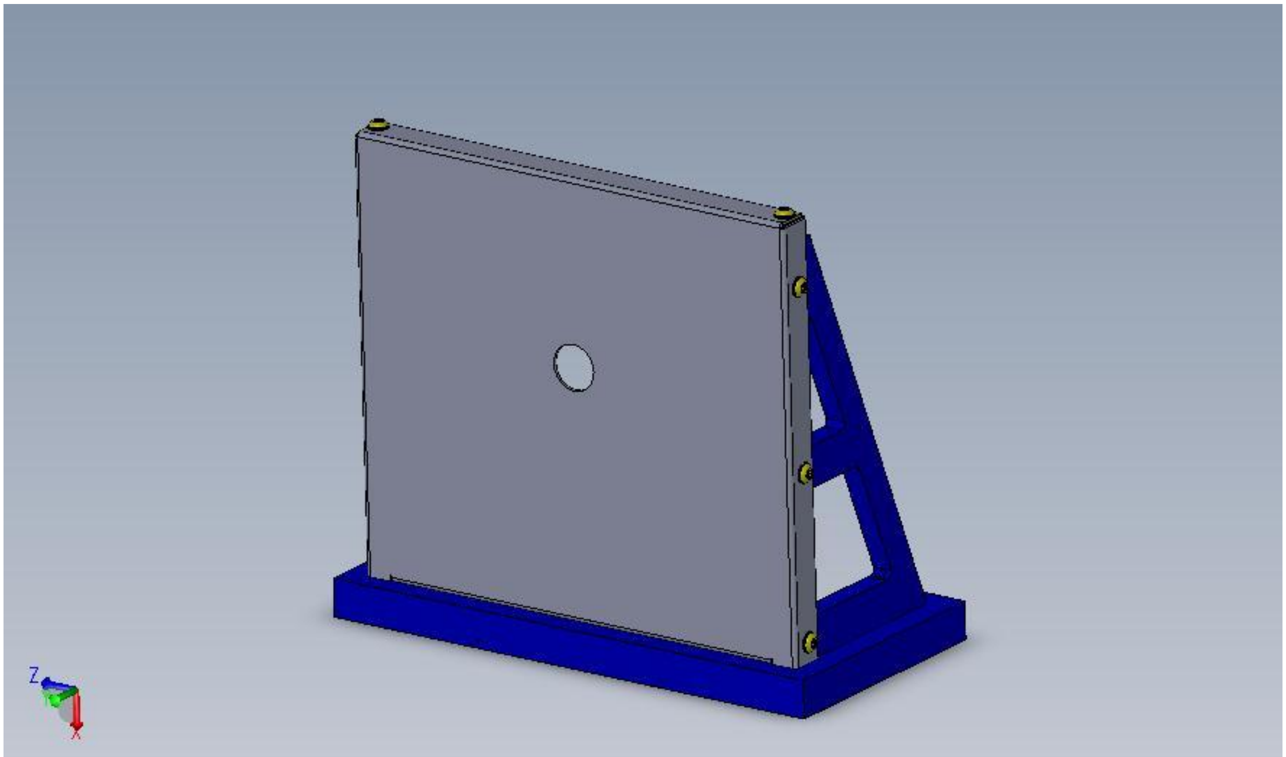

Figure 28: SRM HR Baffle

3.6 HARTMANN Beam Dump

A model of the Hartmann Beam Dump is shown in Figure 29.

The Hartmann Beam Dumps catch the 1064nm light that transmits through the first two dichroic steering mirrors in the Hartmann beam paths.

The results of the FEA model show that the lowest internal mode frequency of the baffle is 325 Hz; see **Error! Reference source not found.**.

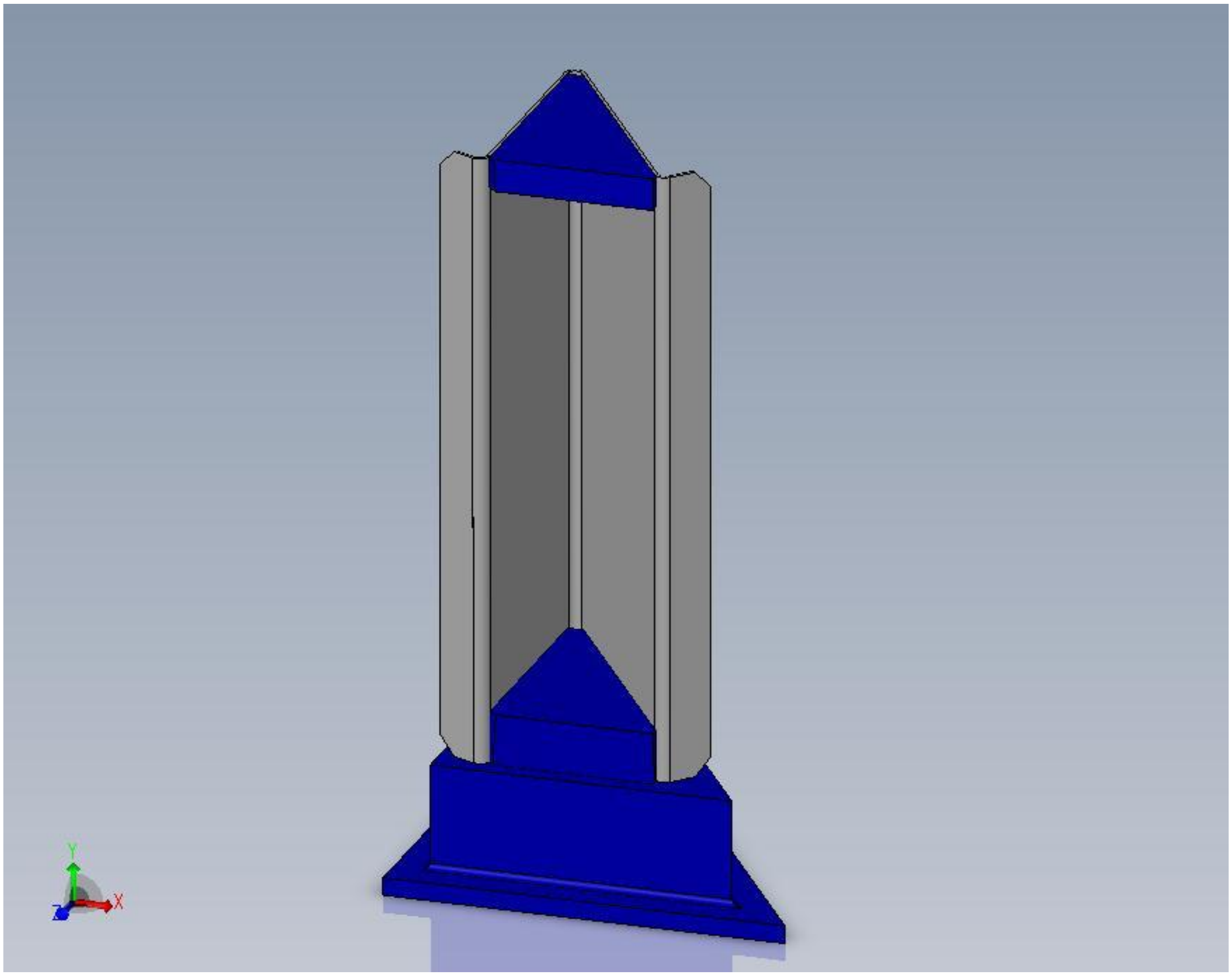

Figure 29: Hartmann Beam Dump

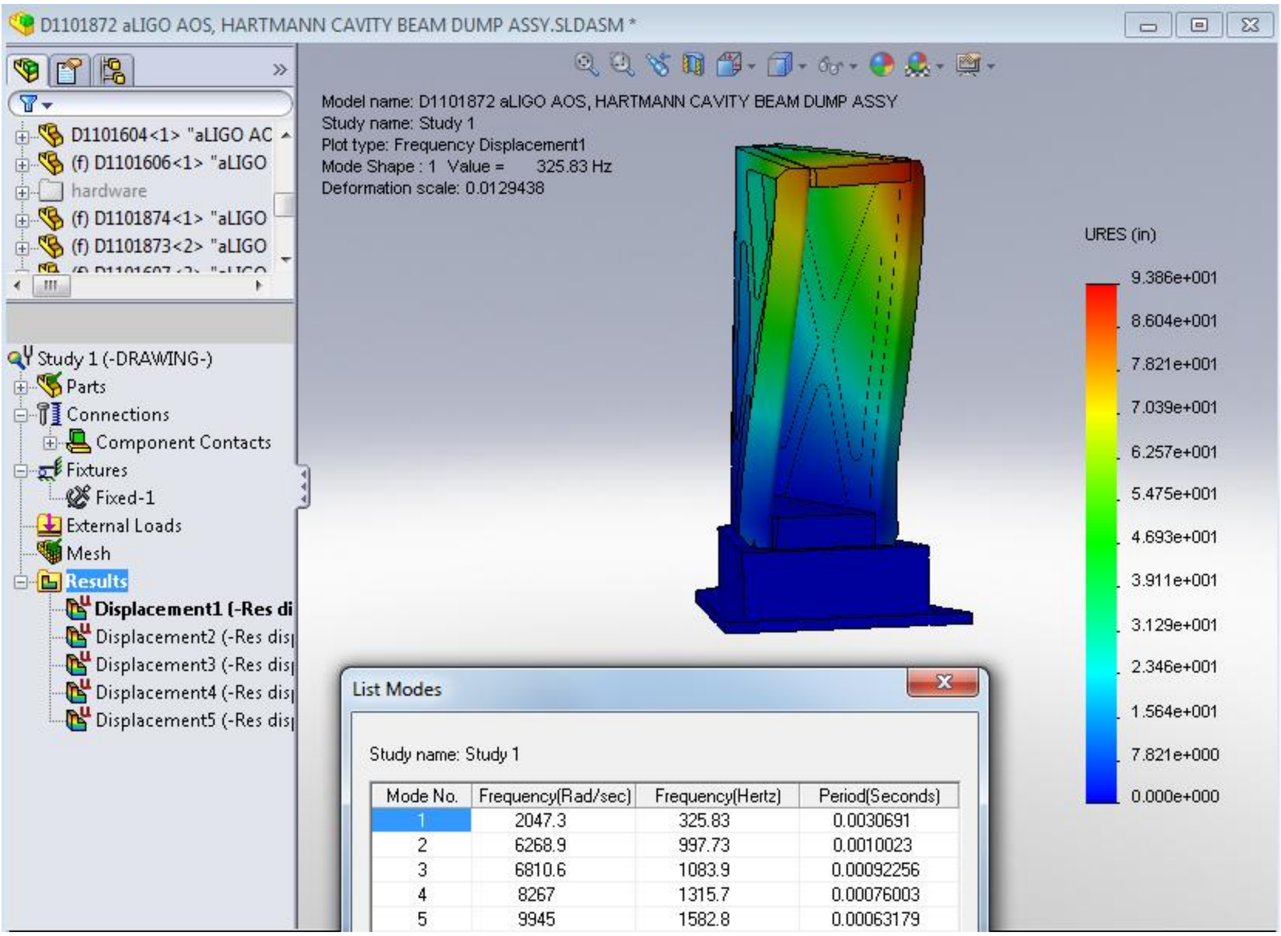

Figure 30: FEA Analysis of Hartmann Beam Dump

3.7 BAFFLE HEIGHTS

The heights of the signal recycling cavity baffles above the HAM ISI table and the hole dimensions are shown in Table 1.

3.8 OPTICAL INTERFACES

The locations of the IFO beams and the Hartmann beams that traverse the SR Baffle were determined from the ZEMAX layout, D0901920 H1 Zemax layout, D0902345 H2 Zemax Layout, and D0902216 L1 Zemax layout.

A sequential ZEMAX model was made for the signal recycling cavities of H2, H1, and L1 IFOs, and the physical optics propagation program was used to determine the diffraction beam profiles at the locations of the baffles.

The holes in the SR3 HR baffle, SR2 Scraper baffle, SR2 AR baffle, and SRM HR baffle are larger than the 1E-3 radius of the diffraction beam profile that propagates through the signal recycling cavity optical train and will not vignette the beam appreciably; in addition, the holes are large enough to allow passage of the diffracted Hartmann probe beams from the ITMX and ITMY mirror surfaces; see Table 1.

Table 1: Heights and Sizes of SR Baffles

IFO	Baffle	1/e^2 radius	ZEMAX 1E-4 radius	Hartmann beam radius requirement	Baffle hole radius	Height above table
H2						
	SR3 HR baffle	54.30	117.0	maximum	132.5	211.0
	SR2 HR scraper baffle	7.99	18.4	36.0	42	193.2
	HAM (SR2 AR) scraper baffle	4.22	N/A	30.0	30	187.4
	HAM (Hartmann) Scraper baffle	4.22	N/A	30.0	30	187.4
	SRM HR baffle	2.05	5.9		14	176.2
H1						
	SR3 HR baffle	54.30	118.6	85	132.5	230.2
	SR2 HR scraper baffle	9.59	21.3	36.0	42	220.9
	SR2 AR scraper baffle	5.06	N/A	30	30	220.0
	Hartmann Scraper baffle	5.06	N/A	30	30	220.0
	SRM HR baffle	2.05	4.5		14	210.9
L1						
	SR3 HR baffle	54.30	118.6	85	132.5	230.2
	SR2 HR scraper baffle	9.59	21.3	36.0	42	239.7
	SR2 AR scraper baffle	5.06	N/A	30	30	232.5
	Hartmann Scraper baffle	5.06	N/A	30.0	30	232.5
	SRM HR baffle	2.05	4.5		14	230.1

In every instance, the hole radius is 8mm greater than the 1E-4 radius of signal recycling cavity beam; therefore, the horizontal and vertical tolerance in placement of the baffles is +/- 8mm. This meets the clear aperture requirement.

4 SCATTERED LIGHT DISPLACEMENT NOISE

4.1 Scattered Light Requirement

A DARM signal is obtained when the differential arm length is modulated as a result of a gravity wave strain. The DARM signal was calculated in reference, T060073-00 Transfer Functions of Injected Noise, and is defined by the following expression:

$$V_{signal} := DARM \cdot L \cdot h_{SRD} \cdot \sqrt{P_0}$$

Where L is the arm length, hSRD is the minimum SRD gravity wave strain spectral density requirement, P0 is the input laser power into the IFO, and DARM is the signal transfer function.

In a similar manner, an apparent signal (scattered light noise) occurs when a scattered light field with a phase shift is injected into the IFO at some particular location, e.g. through the back of the ETM mirror. The scattered light noise is defined by the following expression:

$$V_{noise} := SNXXX \cdot \delta_{SN} \cdot \sqrt{P_{SNi}}$$

P_{SNi} is the scattered light power injected into the IFO mode, δ_{SN} is the phase shift of the injected field, and SNXXX is the noise transfer function for that particular injection location.

The phase shift spectral density of the injected field due to the motion of the scattering surface is given by

$$\delta_{SNi} := \frac{4 \cdot \pi \cdot x_s}{\lambda}$$

where x_s is the spectral density of the longitudinal motion of the scattering surface.

In general, the different scattering sources are not coherent and must be added in quadrature. The requirement for total scattered light displacement noise can be stated with the following inequality:

$$\sqrt{\sum_{i=1}^{n} \left(\frac{SNXXX}{DARM} \cdot \frac{4 \cdot \pi \cdot x_s}{\lambda} \cdot \sqrt{\frac{P_{SNi}}{P_0}} \right)^2} < \frac{1}{10} \cdot L \cdot h_{SRI}$$

The SNXXX/DARM scattered light noise transfer function ratios for various injection locations within the IFO are shown in Figure 31: Scattered Light Noise Transfer Functions.

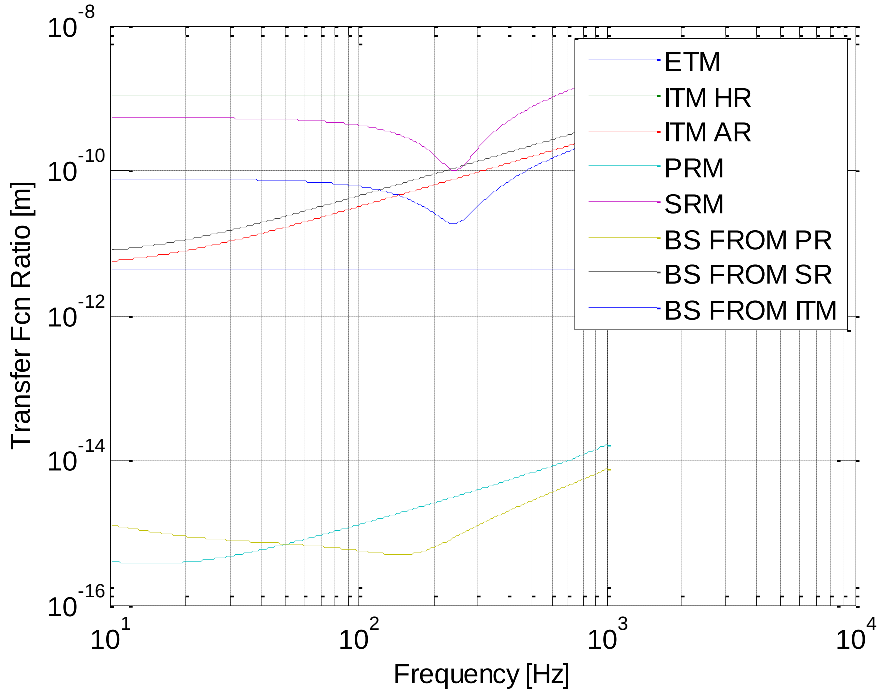

Figure 31: Scattered Light Noise Transfer Functions

4.1.1 Scattered Light Parameters

The arm cavity power was taken from T070303 with an arm cavity gain of 13000 referenced to the PSL input power of 125 W.

Motion of HEPI @ 200 Hz, m/rt Hz	$x_{hepi} := 2 \cdot 10^{-10}$	
Motion of HAM table @ 100 Hz, m/rt Hz	$x_{ham} := 1.3 \cdot 10^{-11}$	
solid angle of IFO mode, sr	$\Delta_{ifo} := 2.72 \cdot 10^{-9}$	
laser wavelength, m	$\lambda := 1.064 \cdot 10^{-6}$	
wave number, m^-1	$k := 2 \cdot \frac{\pi}{\lambda}$	$k = 5.905 \times 10^{6}$
Transfer function @ 100 Hz, BS from SR	$TF_{srbs} := 4.46 \cdot 10^{-11}$	
IFO waist size, m	$w_{ifo} := 0.012$	

Gaussian power parameter in recycling cavity $P_{0rc} := 1.0542\times 10^{3}$

input laser power, W $P_{psl} := 125.($

arm cavity gain $G_{ac} := 1300($

arm cavity power, W $P_a := \frac{P_{psl}}{2}\cdot G_{ac}$ $P_a = 8.125\times 10^{5}$

power in power recycling cavity both arms, W $P_{rc} := \frac{2P_a \cdot T_{itmhr}}{4}$ $P_{rc} = 5.688\times 10^{3}$

power in recycling cavity arm, W $P_{rca} = 2.844\times 10^{3}$

refl port signal ratio $G_{refl} := 0.001($

as port signal ratio $G_{as} := 0.00108$

power after SRM, W $P_{srm} := G_{as}\cdot P_{psl}$

reflectivity of BS HR $R_{bshr} := 0.5($

reflectivity of BS AR $R_{bsar} := 50\cdot 10^{-6}$

Reflectivity of ITM HR $R_{itmhr} := 0.986($

Reflectivity of ITM AR $R_{itmar} := 50\cdot 10^{-6}$

transmissivity of SRM HR $T_{srmhr} := 0.20($

power in signal recycling cavity, W $P_{src} := \frac{P_{srm}}{T_{srmhr}}$ $P_{src} = 3.375$

transmissivity of SR2 AR $T_{sr2ar} := T_{pr2ar}$ $T_{sr2ar} = 0.99995$

Reflectivity of dichroic HWSX M1 $R_{HWSXM1} := 0.01$

Reflectivity of dichroic HWSX M2 $R_{HWSXM2} := 0.01$

Reflectivity of HWSX M3 $R_{HWSXM3} := 1$

Reflectivity of HWSY M4 $R_{HWSXM4} := 1$

Reflectivity of HPX-F1 $R_{HPXF1} := 1$

Reflectivity of HWSY M5 $R_{HWSXM5} := 1$

BRDF of HPX-F1 @ 3 deg, sr^-1 $BRDF_{hartm} = 0.01$

Beam Waist after H1 SR3 $w_{sr30} := 0.000114$

Beam waist after H1 SR2 $w_{sr20} := 0.000094$

Beam Waist after H1 HPYF1 $w_{hpyf10} := 0.000085$

Beam waist after H1 HPXF1 $w_{hpxf10} := 0.000065$

Beam Waist after H2 SR3 $w_{sr30} := 0.000114$

Beam waist after H2 SR2 $w_{sr20} := 0.000094$

Beam Waist after H2 HPYF1 $w_{hpyf10} := 0.000928$

Beam waist after H2 HPXF1 $w_{hpxf10} := 0.000076$

transmissivity of SR2 HR $T_{sr2hr} = 10 \times 10^{-5}$

4.1.2 BRDF of Baffle Surfaces

The baffle surfaces are oxidized polished stainless steel, with a measured BRDF < 0.03 sr^-1 @ > 5 deg incidence angle.

4.1.3 HAM ISI Seismic Motion

The seismic motion of the HAM ISI optical table at LLO and the HAM chamber viewport motions are shown below in Figure 32.

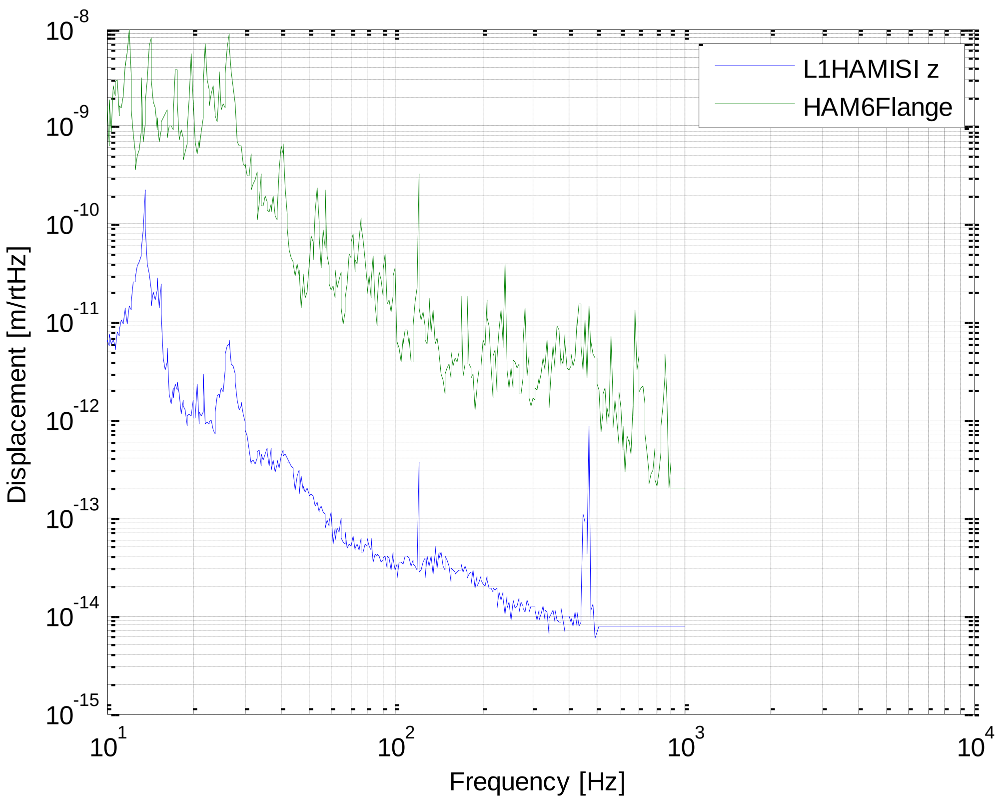

Figure 32: HAM optics table Seismic Motion, m/rtHz

4.1.4 Naming Convention for Wedged Optics

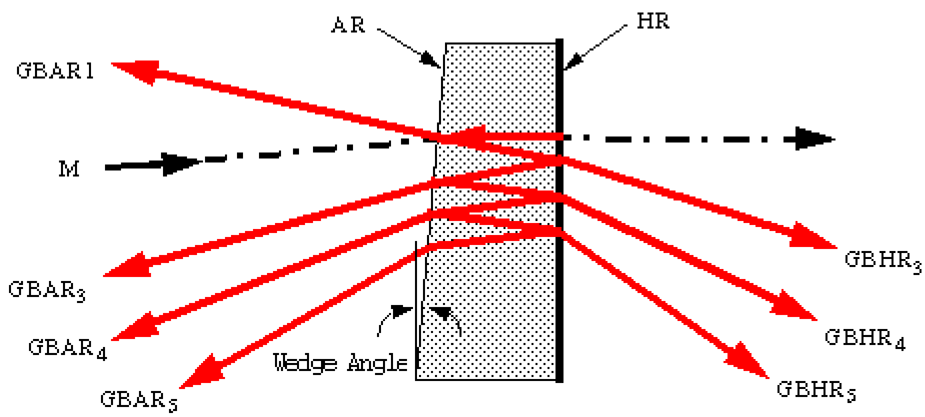

Figure 33: Wedged Core Optic ghost beam naming convention

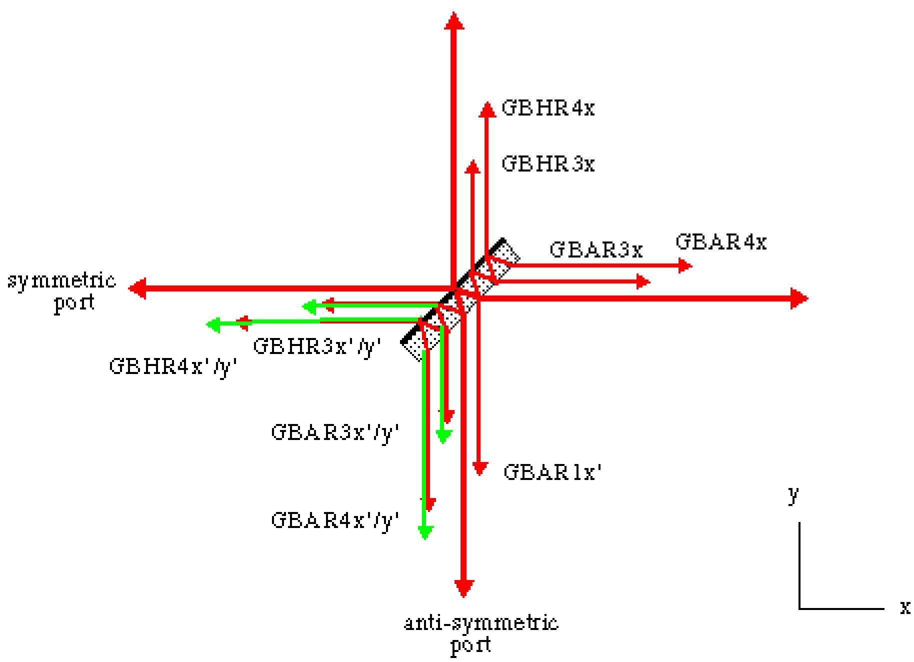

Figure 34: BS ghost beam naming convention

4.1.5 SR3 HR Baffle Scatter

The SR3 HR Baffle catches ghost beams of order GB4 and higher, and the scattered light displacement noise from these beams is negligible.

4.1.6 SR3 AR Baffle Scatter

The SR3 AR Baffle catches 1) the transmission of the main through the SR3 AR surface and scatters light back toward the BS, and 2) the SR3 GBAR3 ghost beam.

The scattered light displacement noise caused by scattering from the SR3 AR Baffle is calculated below.

4.1.6.1 Transmission of Signal Recycling Cavity Main Beam through SR3 HR

The signal recycling cavity has two counter propagating beams that strike the SR3 HR surface.

power incident on SR3 AR Baffle
(forward and backward beams), W

$$P_{sr3arbaf} := 2P_{src} \cdot T_{sr3hr} \cdot T_{sr3ar}$$

$$P_{sr3arbaf} = 1.35 \times 10^{-4}$$

The beam incident from the BS is scattered by the SR3 AR Baffle back toward the BS, directly into the mode of the IFO.

power scattered from SR3 AR Baffle toward BS, W

$$P_{sr3arbafbss} := \frac{P_{sr3arbaf}}{2} \cdot BRDF_{bd} \cdot \Delta_{ifo} \cdot T_{sr3hr} \cdot T_{sr3ar}$$

$$P_{sr3arbafbss} = 8.445 \times 10^{-19}$$

The beam incident from SR2 is scattered by the SR3 AR Baffle back toward SR2, into the mode of the beam waist created by the SR3 mirror curvature.

power scattered from SR3 AR Baffle toward SR2 W

$$P_{sr3arbafsr2s} := \frac{P_{sr3arbaf}}{2} \cdot BRDF_{bd} \cdot \Delta_{ifo} \cdot \frac{w_{ifo}^{2}}{w_{sr30}^{2}} \cdot T_{sr3hr} \cdot T_{sr3ar}$$

$$P_{sr3arbafsr2s} = 9.357 \times 10^{-15}$$

The total power scattered is given by

power scattered from SR3 AR Baffle, W

$$P_{sr3arbafs} := P_{sr3arbafbss} + P_{sr3arbafsr2s}$$

This scattered light from the signal recycling cavity enters the IFO mode through the BS; the displacement noise is given by

displacement noise @ 100 Hz, m/rtHz

$$DN_{sr3arbaf} := TF_{srbs} \cdot \left(\frac{P_{sr3arbafs}}{P_{psl}}\right)^{0.5} \cdot x_{ham} \cdot 2 \cdot k$$

$$DN_{sr3arbaf} = 1.139 \times 10^{-25}$$

4.1.6.2 SR3 GBAR3 Ghost Beam

The SR3 GBAR3 ghost beams from the two counter propagating signal recycling cavity beams are caught on the SR3 AR Baffle.

The scattered light displacement noise caused by scattering from the SR3 AR Baffle is calculated below.

power incident on GBAR3 AR Baffle
(forward and backward beams), W

$$P_{sr3gbar3} := 2 \cdot P_{src} \cdot T_{sr3hr} \cdot R_{sr3ar} \cdot R_{sr3hr} \cdot T_{sr3ar}$$

$$P_{sr3gbar3} = 6.749 \times 10^{-9}$$

The GBAR3 beam incident from the BS is scattered back toward the BS, directly into the mode of the IFO.

power scattered from SR3 AR Baffle toward BS, W

$$P_{sr3gbar3bss} := \frac{P_{sr3gbar3}}{2} \cdot BRDF_{bd} \cdot \Delta_{ifo} \cdot T_{sr3hr} \cdot R_{sr3ar} \cdot R_{sr3hr} \cdot T_{sr3ar}$$

$$P_{sr3gbar3bss} = 2.111 \times 10^{-27}$$

The other GBAR3 beam, incident from the SR2, scatters back toward SR2 into the mode of the beam waist created by the SR3 mirror curvature.

power scattered from SR3 AR Baffle toward SR2, W

$$P_{sr3gbar3sr2s} := \frac{P_{sr3gbar3}}{2} \cdot BRDF_{bd} \cdot \Delta_{ifo} \cdot \frac{w_{ifo}^{2}}{w_{sr30}^{2}} \cdot T_{sr3hr} \cdot R_{sr3ar} \cdot R_{sr3hr} \cdot T_{sr3ar}$$

$$P_{sr3gbar3sr2s} = 2.339 \times 10^{-23}$$

The total power scattered is given by:

total power scattered from SR3 AR Baffle, W

$$P_{sr3gbar3s} := P_{sr3gbar3bss} + P_{sr3gbar3sr2s}$$

$$P_{sr3gbar3s} = 2.339 \times 10^{-23}$$

This scattered light from the signal recycling cavity enters the IFO mode through the BS; the displacement noise is given by

displacement noise @ 100 Hz, m/rtHz

$$DN_{sr3gbar3} := TF_{srbs} \cdot \left(\frac{P_{sr3gbar3s}}{P_{psl}}\right)^{0.5} \cdot x_{ham} \cdot 2 \cdot k$$

$$DN_{sr3gbar3} = 5.697 \times 10^{-30}$$

4.1.6.3 SR3 GBHR3 Ghost Beam

The SR3 GBHR3 ghost beams from the two counter propagating signal recycling cavity beams will hit the mode cleaner tube wall and scatter back toward the signal recycling cavity.

power incident on SR3 GBHR3
(forward and backward beams), W

$$P_{sr3gbhr3} := 2 \cdot P_{src} \cdot T_{sr3hr} \cdot R_{sr3ar} \cdot T_{sr3hr}$$

$$P_{sr3gbhr3} = 6.75 \times 10^{-13}$$

The GBHR3 beam incident from the BS is scattered back toward the BS, directly into the mode of the IFO.

power scattered from SR3 GBHR3 toward BS, W

$$P_{sr3gbhr3bss} := \frac{P_{sr3gbhr3}}{2} \cdot BRDF_{wall} \cdot \Delta_{ifo} \cdot T_{sr3hr} \cdot R_{sr3ar} \cdot T_{sr3hr}$$

$$P_{sr3gbhr3bss} = 4.223 \times 10^{-35}$$

The other GBHR3 beam, incident from the SR2, scatters back toward SR2 into the mode of the beam waist created by the SR3 mirror curvature.

power scattered from SR3 GBHR3 toward SR2 W

$$P_{sr3gbhr3sr2s} := \frac{P_{sr3gbhr3}}{2} \cdot BRDF_{wall} \cdot \Delta_{ifo} \cdot \frac{w_{ifo}^{2}}{w_{sr30}^{2}} \cdot \left(T_{sr3hr} \cdot R_{sr3ar} \cdot T_{sr3hr}\right)$$

$$P_{sr3gbhr3sr2s} = 4.679 \times 10^{-31}$$

The total scattered power is given by

total power scattered from SR3 GBHR3

$$P_{sr3gbhr3s} := P_{sr3gbhr3bss} + P_{sr3gbhr3sr2s}$$

$$P_{sr3gbhr3s} = 4.68 \times 10^{-31}$$

This scattered light from the signal recycling cavity enters the IFO mode through the BS; the displacement noise is given by

displacement noise @ 100 Hz, m/rtHz

$$DN_{sr3gbhr3} := TF_{srbs} \cdot \left(\frac{P_{sr3gbhr3s}}{P_{psl}}\right)^{0.5} \cdot x_{hamflange} \cdot 2 \cdot k$$

$$DN_{sr3gbhr3} = 5.479 \times 10^{-31}$$

4.1.7 SR2 Scraper Baffle Scatter

The SR2 scraper baffles on HAM4, and HAM10 traps half of the ghost beams from the ITM, CP, and BS; the other half of the ghost beams is trapped by the PR2 scraper baffles located on HAM3 and HAM9.

The scattered light displacement noise caused by scattering from the SR2 Scraper Baffle is calculated below.

4.1.7.1 ITM Ghosts Beams

The X and Y ITM ghost beams are coherent but may have different phase. For the worst case, we will assume that the fields add in phase.

ITM_GBAR1 H1

Power incident on SR2 Scraper Baffle from both arms, W

$$P_{itmar1bd} := P_{rc} \cdot R_{bshr} \cdot R_{itmar}$$

$$P_{itmar1bd} = 0.142$$

both ITM AR1 BD scattered power into BS from SR2 Scraper baffle, W

$$P_{itmar1bds} := P_{itmar1bd} \cdot BRDF_{bd} \cdot \frac{w_{ifo}^{2}}{w_{sr30}^{2}} \cdot \Delta_{ifo} \cdot R_{bshr}^{0} \cdot R_{itmar}$$

$$P_{itmar1bds} = 9.857 \times 10^{-12}$$

displacement noise @ 100 Hz, m/rtHz

$$DN_{itmar1bd} := TF_{srbs} \cdot \left(\frac{P_{itmar1bds}}{P_{psl}}\right)^{0.5} \cdot x_{ham} \cdot 2 \cdot k$$

$$DN_{itmar1bd} = 3.698 \times 10^{-24}$$

ITM_GBAR3 H1

power incident on SR2 Scraper Baffle from both arms, W

$$P_{itmar3bd} := P_{rc} \cdot R_{bshr} \cdot R_{itmhr}^{2} \cdot R_{itmar} \cdot \left(1 - R_{itmar}\right)^{2}$$

$$P_{itmar3bd} = 0.1382$$

power scattered from SR2 Scraper Baffle, W

$$P_{itmar3bds} := P_{itmar3bd} \cdot BRDF_{bd} \cdot \frac{w_{ifo}^{2}}{w_{sr30}^{2}} \cdot \Delta_{ifo} \cdot R_{bshr}^{0} \cdot R_{itmhr}^{2} \cdot R_{itmar} \cdot \left(1 - R_{itmar}\right)^{2}$$

$$P_{itmar3bds} = 1.009 \times 10^{-11}$$

displacement noise @ 100 Hz, m/rtHz

$$DN_{itmar3bd} := TF_{srbs} \cdot \left(\frac{P_{itmar3bds}}{P_{psl}}\right)^{0.5} \cdot x_{ham} \cdot 2 \cdot k$$

$$DN_{itmar3bd} = 3.595 \times 10^{-24}$$

4.1.7.2 BS Ghosts Beam

The beam splitter ghost beams from both arms are almost anti-resonant and the wave fronts overlap; therefore, their coherent sum is reduced by the square of the asymmetry coefficient for common mode field rejection.

BS_GBAR3P H1

$$P_{bsar3sr2baf} := P_{rc} \cdot \left[\left(1 - R_{bsar}\right) \cdot R_{bshr} + \left(1 - R_{bshr}\right) \cdot R_{bsar}\right] \cdot R_{bshr} \cdot \left(1 - R_{bsar}\right) \cdot C_{assy}^{\ 2}$$

$$P_{bsar3sr2baf} = 0.169$$

power scattered from SR2 Scraper Baffle, W

$$P_{bsar3sr2bafs} := P_{bsar3sr2baf} \cdot BRDF_{bd} \cdot \frac{w_{ifo}^{\ 2}}{w_{sr30}^{\ 2}} \cdot \Delta_{ifo} \cdot \left(1 - R_{bsar}\right) \cdot R_{bshr} \cdot R_{bsar} \cdot \left[\left(1 - R_{bshr}\right) + R_{bshr} \cdot \left(1 - R_{bsar}\right)\right]$$

$$P_{bsar3sr2bafs} = 5.848 \times 10^{-12}$$

displacement noise @ 100 Hz, m/rtHz

$$DN_{bsar3sr2baf} := TF_{itmar} \cdot \left(\frac{P_{bsar3sr2bafs}}{P_{psl}}\right)^{0.5} \cdot x_{ham} \cdot 2 \cdot k$$

$$DN_{bsar3sr2baf} = 2.018 \times 10^{-24}$$

4.1.7.3 CP Ghosts Beam

The X and Y CP ghost beams are coherent but may have different phase. For the worst case, we will assume that the fields add in phase.

4.1.7.3.1 CP_GBAR1 H1

power incident on SR2 Scraper Baffle from both arms, W

$$P_{cpar1sr2baf} := P_{rc} \cdot R_{bshr} \cdot R_{cpar}$$

$$P_{cpar1sr2baf} = 0.142$$

power scattered from SR2 Scraper Baffle, W

$$P_{cpar1sr2bafs} := P_{cpar1sr2baf} \cdot BRDF_{bd} \cdot \frac{w_{ifo}^{2}}{w_{sr30}^{2}} \cdot \Delta_{ifo} \cdot R_{bshr}^{0} \cdot R_{cpar}$$

$$P_{cpar1sr2bafs} = 9.857 \times 10^{-12}$$

displacement noise @ 100 Hz, m/rtHz

$$DN_{cpar1sr2baf} := TF_{itmar} \cdot \left(\frac{P_{cpar1sr2bafs}}{P_{psl}}\right)^{0.5} \cdot x_{ham} \cdot 2 \cdot k$$

$$DN_{cpar1sr2baf} = 2.62 \times 10^{-24}$$

4.1.7.3.1.1 CP_GBAR3 H1

power incident on SR2 Scraper Baffle from both arms, W

$$P_{cpar3sr2baf} = 0.14$$
$$P_{cpar3sr2baf} := P_{rc} \cdot R_{bshr} \cdot R_{itmhr} \cdot R_{cpar}$$

power scattered from SR2 Scraper Baffle, W

$$P_{cpar3sr2bafs} := P_{cpar3sr2baf} \cdot BRDF_{bd} \cdot \frac{w_{ifo}^{2}}{w_{sr30}^{2}} \cdot \Delta_{ifo} \cdot R_{bshr}^{0} \cdot R_{itmhr} \cdot R_{cpar}$$

$$P_{cpar3sr2bafs} = 9.583 \times 10^{-12}$$

displacement noise @ 100 Hz, m/rtHz

$$DN_{cpar3sr2baf} := TF_{itmar} \cdot \left(\frac{P_{cpar3sr2bafs}}{P_{psl}}\right)^{0.5} \cdot x_{ham} \cdot 2 \cdot k$$

$$DN_{cpar3sr2baf} = 2.583 \times 10^{-24}$$

4.1.7.4 Summary SR2 Scraper Baffle Scatter

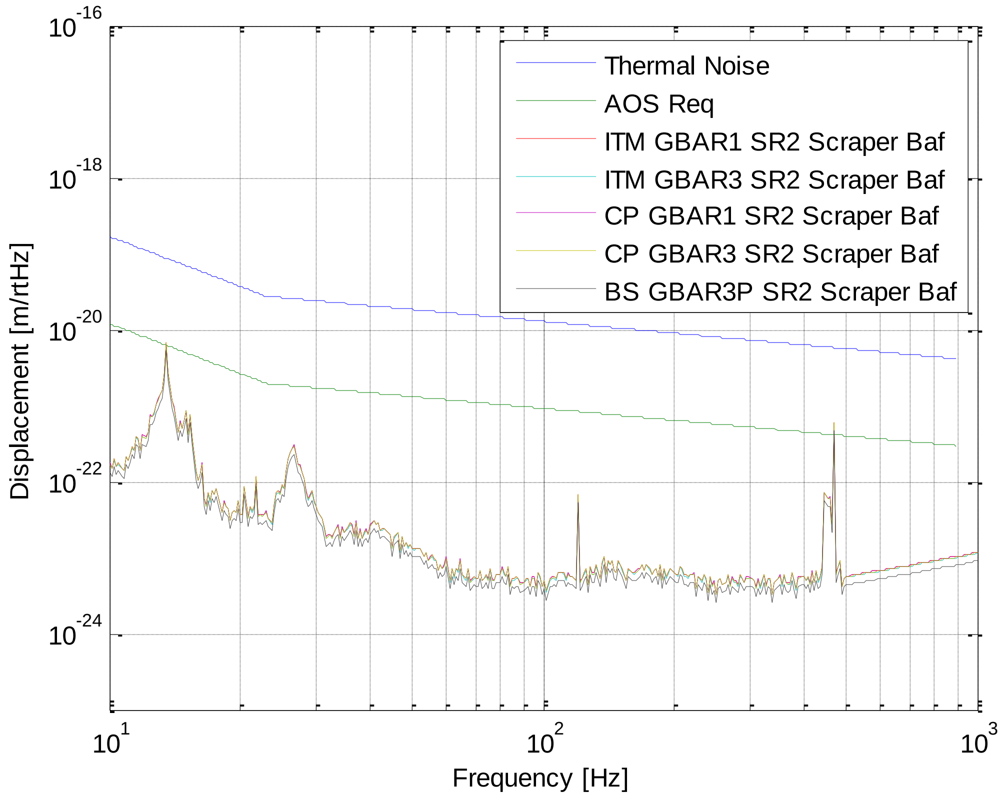

Figure 35: SR2 Scraper Baffle Scatter

4.1.7.5 SRM GBAR3 Ghost Beam

The SRM GBAR3 ghost beam is caught on the input baffle of the Output Faraday; it will scatter from the baffle toward the SRM and enter the signal recycling cavity.

power incident on SRM AR Baffle, W

$$P_{srmarbaf} := P_{srm} \cdot R_{srmar} \cdot R_{srmhr} \cdot T_{srmar}$$

$$P_{srmarbaf} = 5.4 \times 10^{-6}$$

The GBAR3 beam is scattered back toward SRM, into the mode of the beam waist created by the SRM mirror transmission.

power scattered from SRM AR Baffle, W

$$P_{srmarbafs} := P_{srmarbaf} \cdot BRDF_{bd} \cdot \frac{w_{ifo}^{2}}{w_{srm0}^{2}} \cdot \Delta_{ifo} \cdot R_{srmar} \cdot R_{srmhr} \cdot T_{srmar}$$

$$P_{srmarbafs} = 5.502 \times 10^{-18}$$

The scattered light enters the IFO mode through SRM; the displacement noise is given by

displacement noise @ 100 Hz, m/rtHz

$$DN_{srmarbafs} := TF_{srm} \cdot \left(\frac{P_{srmarbafs}}{P_{psl}}\right)^{0.5} \cdot x_{ham} \cdot 2 \cdot k$$

$$DN_{srmarbafs} = 2.614 \times 10^{-26}$$

4.1.7.6 SRM GBHR3 Ghost Beam

The SRM GBHR3 ghost beam is caught on the Mode Cleaner Tube Baffle; it will scatter from the baffle back toward the SRM and enter the signal recycling cavity.

power of SRM GBHR3, W

$$P_{srmhr3} := P_{srm} \cdot R_{srmar} \cdot T_{srmhr}$$

$$P_{srmhr3} = 1.35 \times 10^{-6}$$

The SRM GBHR3 beam is scattered back toward SRM, into the mode of the beam waist created by transmission through the SRM.

power scattered from SRM GBHR3 Mode Cleaner Tube Baffle, W

$$P_{srmhr3bafs} := P_{srmhr3} \cdot BRDF_{bd} \cdot \frac{w_{ifo}^{2}}{w_{srm0}^{2}} \cdot \Delta_{ifo} \cdot R_{srmar} \cdot T_{srmhr}$$

$$P_{srmhr3bafs} = 3.439 \times 10^{-19}$$

The scattered light enters the IFO mode through SRM; the displacement noise is given by

displacement noise @ 100 Hz, m/rtHz

$$DN_{srmhr3bafs} := TF_{srm} \cdot \left(\frac{P_{srmhr3bafs}}{P_{psl}} \right)^{0.5} \cdot x_{ham} \cdot 2 \cdot k$$

$$DN_{srmhr3bafs} = 6.536 \times 10^{-27}$$

4.1.7.7 Summary SR3, SR2, SRM Ghost Beam Scatter

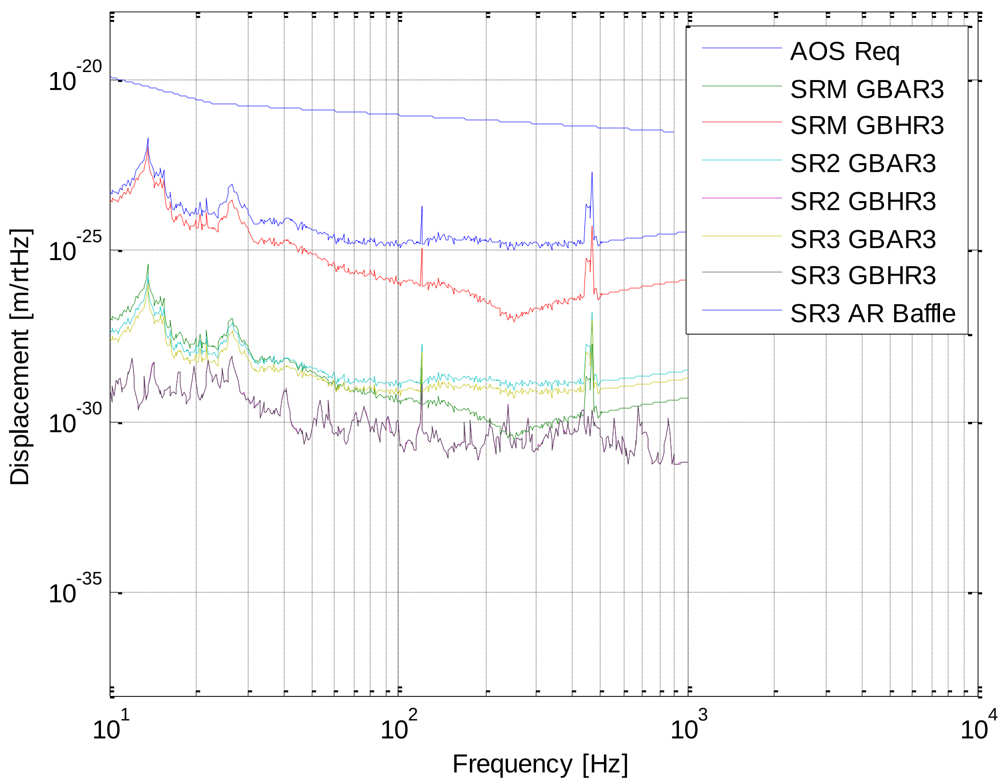

Figure 36: Summary of SR Ghost Beam Scatter

4.1.8 H2 Hartmann Y Scatter

The 1064nm power recycling cavity beam from the Y-arm follows the Hartmann Y path: 1) reflection from the BS AR, 2) reflection from dichroic mirror HWSYM1, 3) reflection from dichroic mirror HWSYM2, 4) reflection from HWSYM3, 5) reflection from HWSYM4, 6) reflection from HWPYF1, and 7) reflection from HWSYM5; see Figure 3. The scattered light enters the IFO mode through the ITMy AR surface.

4.1.8.1 Scattered Light Displacement Noise from H2 HWSYM1

The Hartmann Y beam will scatter from the HWSYM1 mirror back toward the ITM AR, into the mode of the beam waist created by the SR3 mirror.

power in signal recycling cavity, W

$$P_{src} := \frac{P_{srm}}{T_{srmhr}} \qquad P_{src} = 0.675$$

power incident on HWSY M1, W

$$P_{hwsym1} := R_{bsar} \cdot P_{rca}$$

$$P_{hwsym1} = 0.142$$

power scattered from HWSY M1, W

$$P_{hwsym1s} := R_{bsar} \cdot P_{hwsym1} \cdot BRDF_{hartm} \cdot \frac{w_{ifo}^{2}}{w_{sr30}^{2}} \cdot \Delta_{ifo}$$

$$P_{hwsym1s} = 1.971 \times 10^{-12}$$

The scattered light enters the IFO mode through the ITM AR side; the displacement noise is given by

displacement noise @ 100 Hz, m/rtHz

$$DN_{hwsym1sifo} := TF_{itmar} \cdot \left(\frac{P_{hwsym1s}}{P_{psl}}\right)^{0.5} \cdot x_{ham} \cdot 2 \cdot k$$

$$DN_{hwsym1sifo} = 6.341 \times 10^{-22}$$

4.1.8.2 Scattered Light Displacement Noise from H2 HWSYM2

The Hartmann Y beam will scatter from the HWSYM2 mirror back toward the ITM AR, into the mode of the beam waist created by the SR3 mirror.

power incident on HWSY M2, W

$$P_{hwsym2} := R_{HWSYM1} \cdot R_{bsar} \cdot P_{rca}$$

$$P_{hwsym2} = 1.422 \times 10^{-3}$$

power scattered from HWSY M2, W

$$P_{hwsym2s} := R_{HWSYM1} \cdot R_{bsar} \cdot P_{hwsym2} \cdot BRDF_{hartm} \cdot \frac{w_{ifo}^{2}}{w_{sr30}^{2}} \cdot \Delta_{ifo}$$

$$P_{hwsym2s} = 1.971 \times 10^{-16}$$

The scattered light enters the IFO mode through the ITM AR side; the displacement noise is given by

displacement noise @ 100 Hz, m/rtHz

$$DN_{hwsym2sifo} := TF_{itmar} \cdot \left(\frac{P_{hwsym2s}}{P_{psl}} \right)^{0.5} \cdot x_{ham} \cdot 2 \cdot k$$

$$DN_{hwsym2sifo} = 6.093 \times 10^{-24}$$

4.1.8.3 Scattered Light Displacement Noise from H2 HPY-F1

The Hartmann Y beam will scatter from the HPY-F1mirror back toward the ITM AR, into the mode of the beam waist created by the SR3 mirror.

power incident on HPY-F1, W

$$P_{hpyf1} := R_{HWSYM2} R_{HWSYM1} R_{bsar} \cdot P_{rca}$$

$$P_{hpyf1} = 1.422 \times 10^{-5}$$

power scattered from HPY-F1, W

$$P_{hpyf1s} := R_{HWSYM2} R_{HWSYM1} R_{bsar} \cdot P_{hpyf1} \cdot BRDF_{hartm} \cdot \frac{w_{ifo}^{2}}{w_{sr30}^{2}} \cdot \Delta_{ifo}$$

$$P_{hpyf1s} = 1.971 \times 10^{-20}$$

The scattered light enters the IFO mode through the ITM AR side; the displacement noise is given by

displacement noise @ 100 Hz, m/rtHz

$$DN_{hpyf1sifo} := TF_{itmar} \cdot \left(\frac{P_{hpyf1s}}{P_{psl}} \right)^{0.5} \cdot x_{ham} \cdot 2 \cdot k$$

$$DN_{hpyf1sifo} = 6.093 \times 10^{-26}$$

4.1.8.4 H2 Hartmann Y Viewport Scatter

The Hartmann Y beam will scatter from the HAM chamber viewport back toward the ITM AR surface, into the mode of the beam waist created by the HPYF1 mirror.

power incident on Hartmann Y viewport, W

$$P_{hyvp} := R_{HWSYM4} R_{HWSYM3} R_{HPYF1} R_{HWSYM2} R_{HWSYM1} R_{bsar} \cdot P_{rca}$$

$$P_{hyvp} = 1.422\times 10^{-5}$$

power scattered from Hartmann y viewport, W

$$P_{hyvps} := R_{HWSYM4} R_{HWSYM3} R_{HPYF1} R_{HWSYM2} R_{HWSYM1} R_{bsar} \cdot P_{hyvp} \cdot BRDF_{vp} \cdot \frac{w_{ifo}^{2}}{w_{hpyf10}^{2}} \cdot \Delta_{ifo}$$

$$P_{hyvps} = 1.487\times 10^{-22}$$

The scattered light enters the IFO mode through the ITM AR side; the displacement noise is given by

displacement noise @ 100 Hz, m/rtHz

$$DN_{hyvpsifo} := TF_{itmar} \cdot \left(\frac{P_{hyvps}}{P_{psl}}\right)^{0.5} \cdot x_{hamflange} \cdot 2 \cdot k$$

$$DN_{hyvpsifo} = 6.921\times 10^{-27}$$

4.1.8.5 H2 Hartmann Y Viewport Reflection, HAM Chamber Scatter

Part of the Hartmann Y beam will reflect from the HAM chamber viewport and scatter from the chamber wall back toward the ITM AR surface, into the mode of the beam waist created by the HPYF1 mirror.

power incident on Hartmann Y viewport reflected wall, W

$$P_{hyvprwall} := R_{vp} \cdot R_{HWSYM4} R_{HWSYM3} R_{HPYF1} R_{HWSYM2} R_{HWSYM1} R_{bsar} \cdot P_{rca}$$

$$P_{hyvprwall} = 3.555\times 10^{-8}$$

power scattered from Hartmann y viewport
reflected wall, W

$$P_{hyvprwalls} := R_{vp} \cdot R_{HWSYM4} R_{HWSYM3} R_{HPYF1} R_{HWSYM2} R_{HWSYM1} R_{bsar} \cdot P_{hyvprwall} \cdot BRDF_{wall} \cdot \frac{w_{ifo}^{2}}{w_{hpyf10}^{2}} \cdot \Delta_{ifo}$$

$$P_{hyvprwalls} = 1.859\times 10^{-26}$$

The scattered light enters the IFO mode through the ITM AR side; the displacement noise is given by

displacement noise @ 100 Hz, m/rtHz $DN_{hyvprwallsifo} := TF_{itmar} \cdot \left(\frac{P_{hyvprwalls}}{P_{psl}} \right)^{0.5} \cdot x_{hamflange} \cdot 2 \cdot k$

$$DN_{hyvprwallsifo} = 7.738 \times 10^{-29}$$

4.1.8.6 Summary of H2 Hartmann Y Scatter

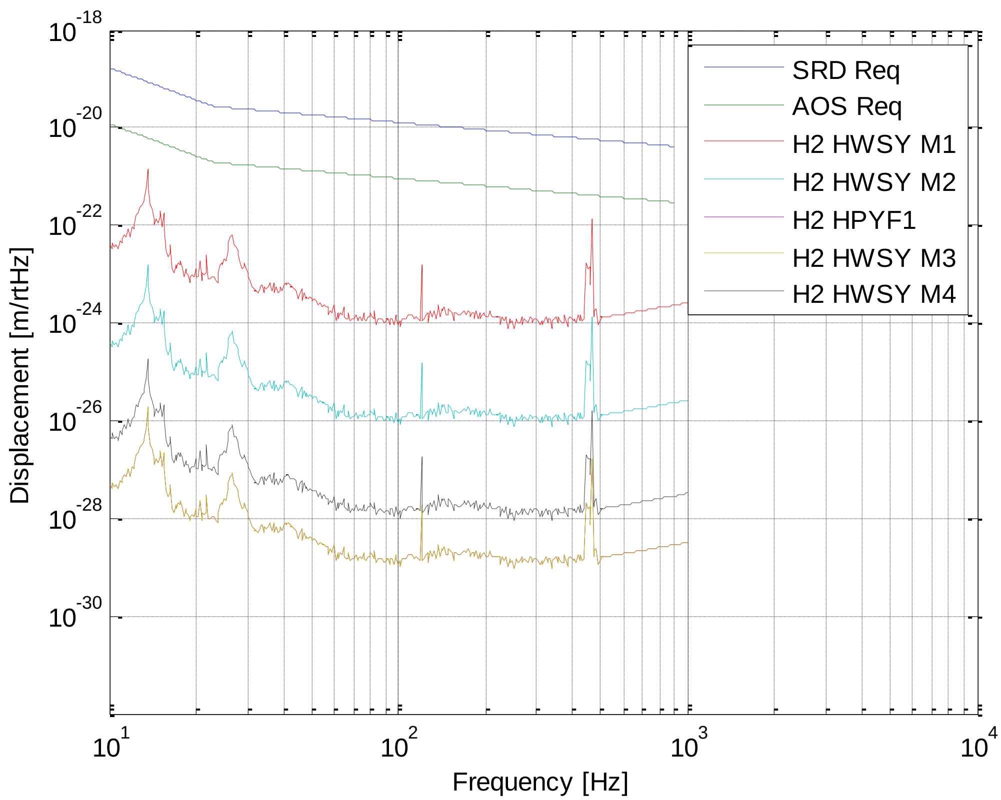

Figure 37: Summary of H2 Hartmann Y Surfaces Scatter

4.1.9 H2 Hartmann X Scatter

The 1064nm signal recycling cavity beam transmitted through the BS from the X-arm follows the Hartmann X path 1) transmission through the SR2 AR, 2) reflection from dichroic mirror HWSXM1, 3) reflection from dichroic mirror HWSXM2, 4) reflection from mirror HWSXM3, 5) reflection from mirror HWSXM4, 6) reflection from HWPXF1, and 7) reflection from HWSXM5, as seen in Figure 3.

The scattered light enters the IFO mode through the BS from the signal recycling cavity side.

The signal power transmitting through the SRM mirror is $P_{srm} = 0.135$

The power inside the signal recycling cavity is given by

power in signal recycling cavity, W $P_{src} := \frac{P_{srm}}{T_{srmhr}}$ $P_{src} = 3.375$

4.1.9.1 Scattered Light Displacement Noise from H2 HWSXM1

The Hartmann X beam will scatter from the HWSXM1 mirror back toward the BS, into the mode of the beam waist created by the SR2 mirror.

power incident on HWSX M1, W $P_{hwsxm1} := T_{sr2hr} \cdot P_{src}$

$P_{hwsxm1} = 6.75 \times 10^{-5}$

power scattered from HWSX M1, W $P_{hwsxm1s} := T_{sr2hr} \cdot P_{hwsxm1} \cdot BRDF_{hartm} \cdot \frac{w_{ifo}^2}{w_{sr20}^2} \cdot \Delta_{ifo}$

$P_{hwsxm1s} = 2.753 \times 10^{-15}$

The scattered light enters the IFO mode from the signal recycling cavity through the BS AR side; the displacement noise is given by

displacement noise @ 100 Hz, m/rtHz $DN_{hwsxm1sifo} := TF_{srbs} \cdot \left(\frac{P_{hwsxm1s}}{P_{psl}} \right)^{0.5} \cdot x_{ham} \cdot 2 \cdot k$

$DN_{hwsxm1sifo} = 3.214 \times 10^{-23}$

4.1.9.2 Scattered Light Displacement Noise from H2 HWSXM2

The Hartmann X beam will scatter from the HWSXM2 mirror back toward the BS, into the mode of the beam waist created by the SR2 mirror.

power incident on HWSX M2, W

$$P_{hwsxm2} := R_{HWSXM1} \cdot T_{sr2hr} \cdot P_{src}$$

$$P_{hwsxm2} = 6.75 \times 10^{-7}$$

power scattered from HWSX M2, W

$$P_{hwsxm2s} := R_{HWSXM1} \cdot T_{sr2hr} \cdot P_{hwsxm2} \cdot BRDF_{hartm} \cdot \frac{w_{ifo}^{2}}{w_{sr20}^{2}} \cdot \Delta_{ifo}$$

$$P_{hwsxm2s} = 2.753 \times 10^{-19}$$

The scattered light enters the IFO mode from the signal recycling cavity through the BS AR side; the displacement noise is given by

displacement noise @ 100 Hz, m/rtHz

$$DN_{hwsxm2sifo} := TF_{srbs} \cdot \left(\frac{P_{hwsxm2s}}{P_{psl}} \right)^{0.5} \cdot x_{ham} \cdot 2 \cdot k$$

$$DN_{hwsxm2sifo} = 3.214 \times 10^{-25}$$

4.1.9.3 H2 Scattered Light Displacement Noise from HWSXM3

The Hartmann X beam will scatter from the HWSXM2 mirror back toward the BS, into the mode of the beam waist created by the SR2 mirror.

power incident on HWSX M3, W

$$P_{hwsxm3} := R_{HWSXM2} \cdot R_{HWSXM1} \cdot T_{sr2hr} \cdot P_{src}$$

$$P_{hwsxm3} = 6.75 \times 10^{-9}$$

power scattered from HWSX M3, W

$$P_{hwsxm3s} := R_{HWSXM2} \cdot R_{HWSXM1} \cdot T_{sr2hr} \cdot P_{hwsxm3} \cdot BRDF_{hartm} \cdot \frac{w_{ifo}^{2}}{w_{sr20}^{2}} \cdot \Delta_{ifo}$$

$$P_{hwsxm3s} = 2.753 \times 10^{-23}$$

The scattered light enters the IFO mode from the signal recycling cavity through the BS AR side; the displacement noise is given by

displacement noise @ 100 Hz, m/rtHz

$$DN_{hwsxm3sifo} := TF_{srbs} \cdot \left(\frac{P_{hwsxm3s}}{P_{psl}}\right)^{0.5} \cdot x_{ham} \cdot 2 \cdot k$$

$$DN_{hwsxm3sifo} = 3.214 \times 10^{-27}$$

4.1.9.4 H2 Scattered Light Displacement Noise from HWSXM4

The Hartmann X beam will scatter from the HWSXM2 mirror back toward the BS, into the mode of the beam waist created by the SR2 mirror.

power incident on HWSX M4, W

$$P_{hwsxm4} := R_{HWSXM3} R_{HWSXM2} R_{HWSXM1} T_{sr2hr} \cdot P_{src}$$

$$P_{hwsxm4} = 6.75 \times 10^{-9}$$

power scattered from HWSX M4, W

$$P_{hwsxm4s} := R_{HWSXM3} R_{HWSXM2} R_{HWSXM1} T_{sr2hr} \cdot P_{hwsxm4} BRDF_{hartm} \cdot \frac{w_{ifo}^{2}}{w_{sr20}^{2}} \cdot \Delta_{ifo}$$

$$P_{hwsxm4s} = 2.753 \times 10^{-23}$$

The scattered light enters the IFO mode from the signal recycling cavity through the BS AR side; the displacement noise is given by

displacement noise @ 100 Hz, m/rtHz

$$DN_{hwsxm4sifo} := TF_{srbs} \cdot \left(\frac{P_{hwsxm4s}}{P_{psl}}\right)^{0.5} \cdot x_{ham} \cdot 2 \cdot k$$

$$DN_{hwsxm4sifo} = 3.214 \times 10^{-27}$$

4.1.9.5 H2 Scattered Light Displacement Noise from HPXF1

The Hartmann X beam will scatter from the HWSXM2 mirror back toward the BS, into the mode of the beam waist created by the SR2 mirror.

power incident on HPXF1, W

$$P_{hpfx1} := R_{HWSXM4} R_{HWSXM3} R_{HWSXM2} R_{HWSXM1} \cdot T_{sr2hr} \cdot P_{src}$$

$$P_{hpfx1} = 6.75 \times 10^{-9}$$

power scattered from HPXF1, W

$$P_{hpfx1s} := R_{HWSXM4} R_{HWSXM3} R_{HWSXM2} R_{HWSXM1} \cdot T_{sr2hr} \cdot P_{hpfx1} \cdot BRDF_{hartm} \cdot \frac{w_{ifo}^{2}}{w_{hpyf10}^{2}} \cdot \Delta_{ifo}$$

$$P_{hpfx1s} = 2.824 \times 10^{-25}$$

The scattered light enters the IFO mode from the signal recycling cavity through the BS AR side; the displacement noise is given by

displacement noise @ 100 Hz, m/rtHz

$$DN_{hpfx1sifo} := TF_{srbs} \cdot \left(\frac{P_{hpfx1s}}{P_{psl}} \right)^{0.5} \cdot x_{ham} \cdot 2 \cdot k$$

$$DN_{hpfx1sifo} = 3.255 \times 10^{-28}$$

4.1.9.6 H2 Hartmann X Viewport Scatter

The Hartmann X beam will scatter from the HAM chamber viewport back into the signal recycling cavity, and into the mode of the beam waist created by the HPXF1 mirror.

power incident on Hartmann X viewport, W

$$P_{hxvp} := R_{HWSXM5} R_{HPXF1} R_{HWSXM4} R_{HWSXM3} R_{HWSXM2} R_{HWSXM1} \cdot T_{sr2hr} \cdot P_{src}$$

$$P_{hxvp} = 6.75 \times 10^{-9}$$

power scattered from Hartmann x viewport, W

$$P_{hxvps} := R_{HWSXM5} R_{HPXF1} R_{HWSXM4} R_{HWSXM3} R_{HWSXM2} R_{HWSXM1} \cdot T_{sr2hr} \cdot P_{hxvp} \cdot BRDF_{vp} \cdot \frac{w_{ifo}^{2}}{w_{hpxf10}^{2}} \cdot \Delta_{ifo}$$

$$P_{hxvps} = 2.106\times 10^{-23}$$

The scattered light enters the IFO mode from the signal recycling cavity through the BS AR side; the displacement noise is given by

displacement noise @ 100 Hz, m/rtHz

$$DN_{hxvpsifo} := TF_{srbs} \cdot \left(\frac{P_{hxvps}}{P_{psl}}\right)^{0.5} \cdot x_{hamflange} \cdot 2 \cdot k$$

$$DN_{hxvpsifo} = 3.675\times 10^{-27}$$

4.1.9.7 H2 Hartmann X Viewport Reflection, HAM Chamber Scatter

Part of the Hartmann X beam will reflect from the HAM chamber viewport and scatter from the chamber wall back into the signal recycling cavity, and into the mode of the beam waist created by the HPXF1 mirror.

power incident on Hartmann X viewport reflected wall, W

$$P_{hxvprwall} := R_{vp} \cdot R_{HWSXM5} R_{HPXF1} R_{HWSXM4} R_{HWSXM3} R_{HWSXM2} R_{HWSXM1} \cdot \left(T_{sr2hr} \cdot P_{src}\right)$$

$$P_{hxvprwall} = 1.687\times 10^{-11}$$

power scattered from Hartmann y viewport
reflected wall, W

$$P_{hxvprwalls} := R_{vp} \cdot R_{HWSXM5} R_{HPXF1} R_{HWSXM4} R_{HWSXM3} R_{HWSXM2} R_{HWSXM1} \cdot T_{sr2hr} \cdot P_{hxvprwall} \cdot BRDF_{wall} \cdot \frac{w_{ifo}^{2}}{w_{hpxf10}^{2}} \cdot \Delta_{ifo}$$

$$P_{hxvprwalls} = 2.632\times 10^{-27}$$

The scattered light enters the IFO mode from the signal recycling cavity through the BS AR side; the displacement noise is given by

displacement noise @ 100 Hz, m/rtHz

$$DN_{hxvprwallsifo} := TF_{srbs} \cdot \left(\frac{P_{hxvprwalls}}{P_{psl}} \right)^{0.5} \cdot x_{hamflange} \cdot 2 \cdot k$$

$$DN_{hxvprwallsifo} = 4.109 \times 10^{-29}$$

4.1.9.8 Summary of H2 Hartmann X Scatter

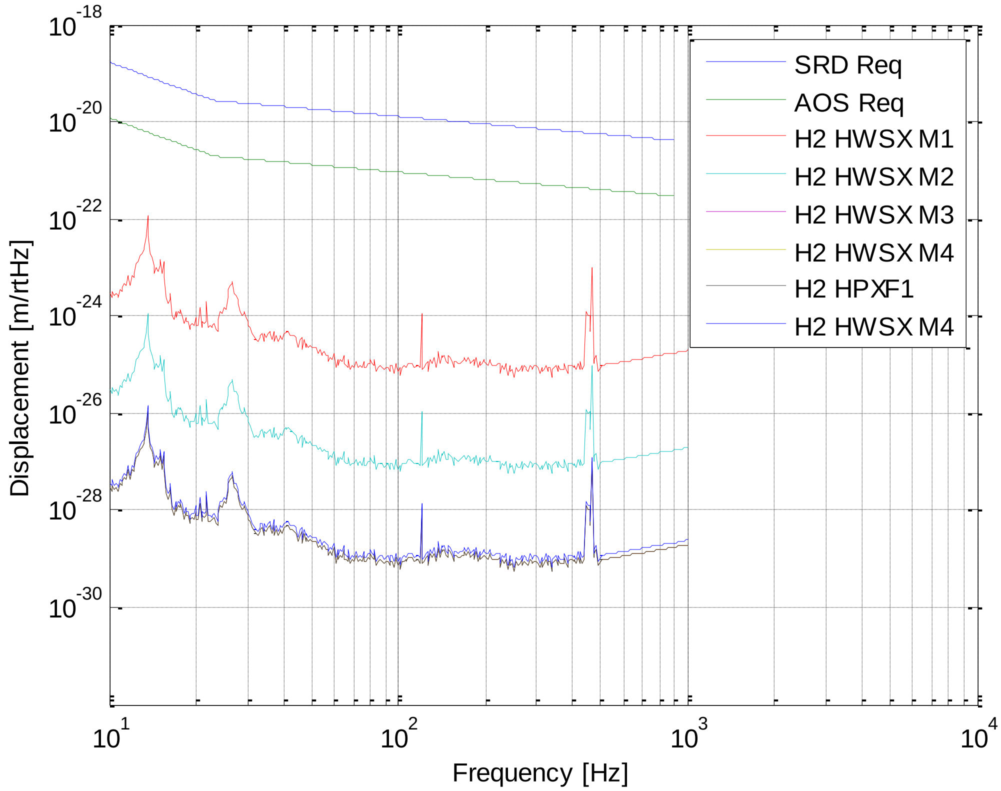

Figure 38: Summary of H2 Hartmann X Surfaces Scatter

4.1.9.9 Summary of H2 Hartmann X Viewport Scatter

The scattered light displacement noise from the Hartmann beam viewports is negligible, as shown in Figure 39. **Therefore, the Hartmann Viewport Beam dumps will be eliminated**.

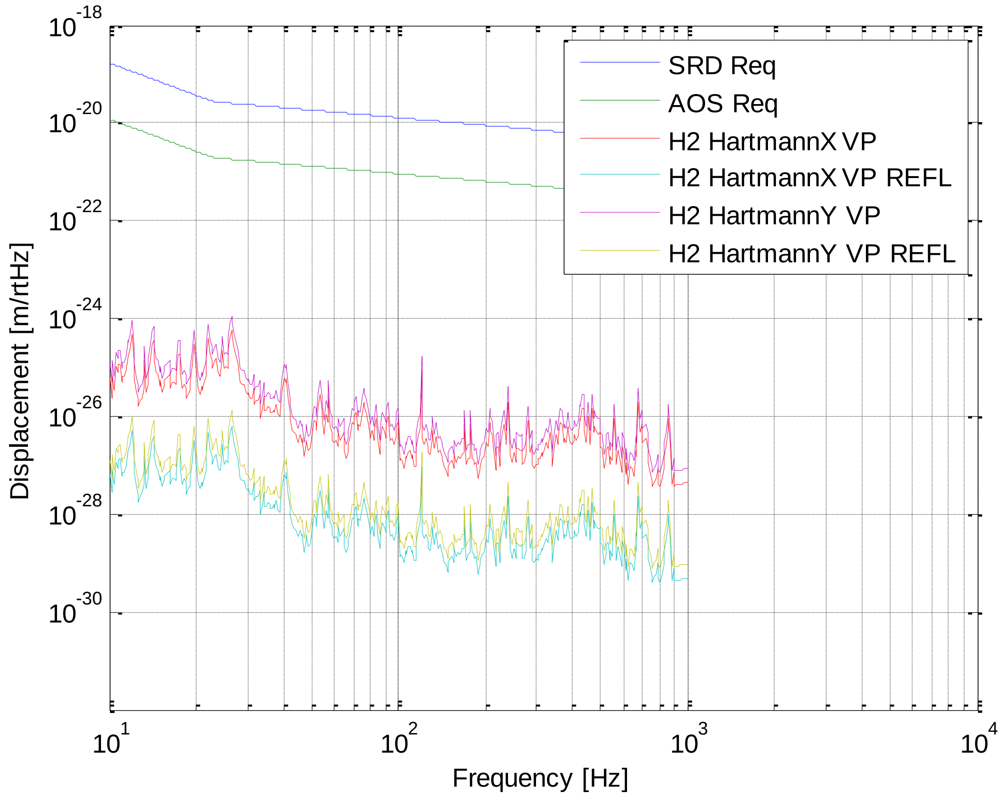

Figure 39: Summary of H2 Hartmann Viewport Scatter

4.1.10 H1 & L1 Hartmann Beam Scatter

The scattered light displacement noise calculations for H1, and L1 are similar to those presented for H2. The results of the calculations will be presented in the following.

4.1.10.1 H1 & L1 Hartmann X Arm

The 1064nm power recycling cavity beam from the X-arm follows the Hartmann X path: 1) reflection from the BS AR, 2) reflection from dichroic mirror HWSXM1, 3) reflection from dichroic mirror HWSXM2, 4) reflection from HPXF1, 5) reflection from HWSXM4, and 6) reflection from HWSXM5, as seen in Figure 1. The scattered light enters the IFO mode through the ITM AR surface.

HWSX M1

displacement noise @ 100 Hz, m/rtHz

$$DN_{hwsxm1sifo} := TF_{itmar} \cdot \left(\frac{P_{hwsxm1s}}{P_{psl}} \right)^{0.5} \cdot x_{ham} \cdot 2 \cdot k$$

$$DN_{hwsxm1sifo} = 6.093 \times 10^{-22}$$

HWSX M2

displacement noise @ 100 Hz, m/rtHz

$$DN_{hwsxm2sifo} := TF_{itmar} \cdot \left(\frac{P_{hwsxm2s}}{P_{psl}}\right)^{0.5} \cdot x_{ham} \cdot 2 \cdot k$$

$$DN_{hwsxm2sifo} = 6.093 \times 10^{-24}$$

HPX-F1

displacement noise @ 100 Hz, m/rtHz

$$DN_{hpxf1sifo} := TF_{itmar} \cdot \left(\frac{P_{hpxf1s}}{P_{psl}}\right)^{0.5} \cdot x_{ham} \cdot 2 \cdot k$$

$$DN_{hpxf1sifo} = 6.093 \times 10^{-26}$$

Hartmann X viewport scatter

displacement noise @ 100 Hz, m/rtHz

$$DN_{hxvpsifo} := TF_{itmar} \cdot \left(\frac{P_{hxvps}}{P_{psl}}\right)^{0.5} \cdot x_{hamflange} \cdot 2 \cdot k$$

$$DN_{hxvpsifo} = 9.881 \times 10^{-26}$$

Hartmann X viewport reflected wall scatter

displacement noise @ 100 Hz, m/rtHz

$$DN_{hxvprwallsifo} := TF_{itmar} \cdot \left(\frac{P_{hxvprwalls}}{P_{psl}}\right)^{0.5} \cdot x_{hamflange} \cdot 2 \cdot k$$

$$DN_{hxvprwallsifo} = 1.105 \times 10^{-27}$$

4.1.10.2 H1 & L1 Hartmann Y Arm

The 1064nm signal recycling cavity beam transmitted through the BS from the Y-arm follows the Hartmann Y path: 1) transmission through the SR2 AR, 2) reflection from dichroic mirror HWSYM1, 3) reflection from dichroic mirror HWSYM2, 4) reflection from mirror HWSYM3, 5) reflection from mirror HWSYM4, 6) reflection from HPYF1, and 7) reflection from HWSYM5, as seen in Figure 1. The scattered light enters the IFO mode through the BS from the signal recycling cavity side.

HWSY M1

displacement noise @ 100 Hz, m/rtHz

$$DN_{hwsym1sifo} := TF_{srbs} \cdot \left(\frac{P_{hwsym1s}}{P_{psl}}\right)^{0.5} \cdot x_{ham} \cdot 2 \cdot k$$

$$DN_{hwsym1sifo} = 3.214 \times 10^{-23}$$

The scattered light displacement noise from HWSY M2, HWSY M3, HWSY M4, HPYF1, HWSY M5, Hartmann viewport scatter, and Hartmann viewport reflected wall scatter are negligible because the incident power has been attenuated by the dichroic mirrors and the AR surface of the viewport.

4.1.10.3 Summary of H1 & L1 Hartmann Scatter

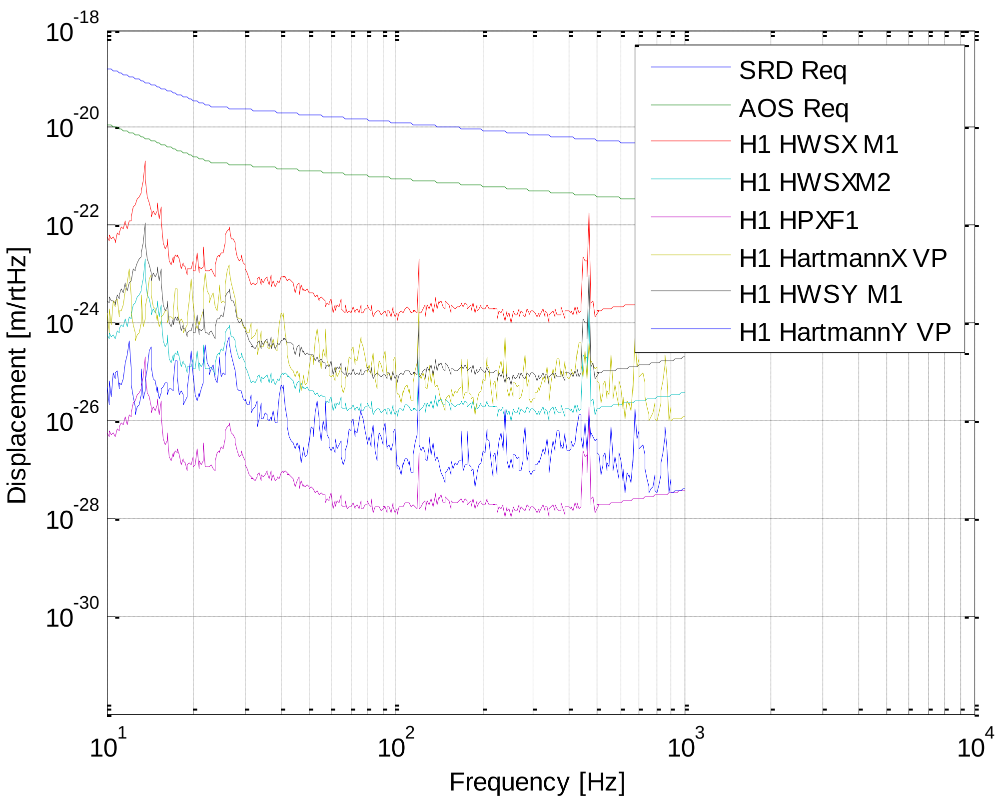

Figure 40: Summary of H1 & L1 Hartmann X and Y Scatter

5 INTERFACE CONTROL DOCUMENT

The mechanical and optical interfaces of the Manifold/cryopump Baffle and the Mode Cleaner Tube Baffles are described in E1100583 SLC Manifold/Cryopump Baffle Interface Control Document.

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