LIGO Laboratory / LIGO Scientific Collaboration

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BRDF and Reflectivity Properties of Black Glass Beam Dumps and Baffles

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Table of Contents

Table of Tables

Table of Figures

Abstract

This note summarizes the measured BRDF and reflectivity properties of black glass, and uses these properties to simulate the reflective properties of beam dumps and baffles constructed of black, porcelainized metal, using Zemax.

1 Introduction

This note summarizes the measured BRDF and reflectivity properties of black glass, and uses these properties to simulate the properties of beam dumps and baffles constructed of black, porcelainized metal, using Zemax.

1.1 References

1. LIGO-T080064-00, Controlling Light Scatter in Advanced LIGO, Dan Riley and Michael Smith

1.2 BRDF Properties of Black Glass

The BRDF values of grade #10 welder's glass by Schott with s and p polarized 1064 nm light incident at various angles (deg.) were measured (see LIGO-T080064-00, Controlling Light Scatter in Advanced LIGO, Dan Riley and Michael Smith) and are shown in Figure 1.

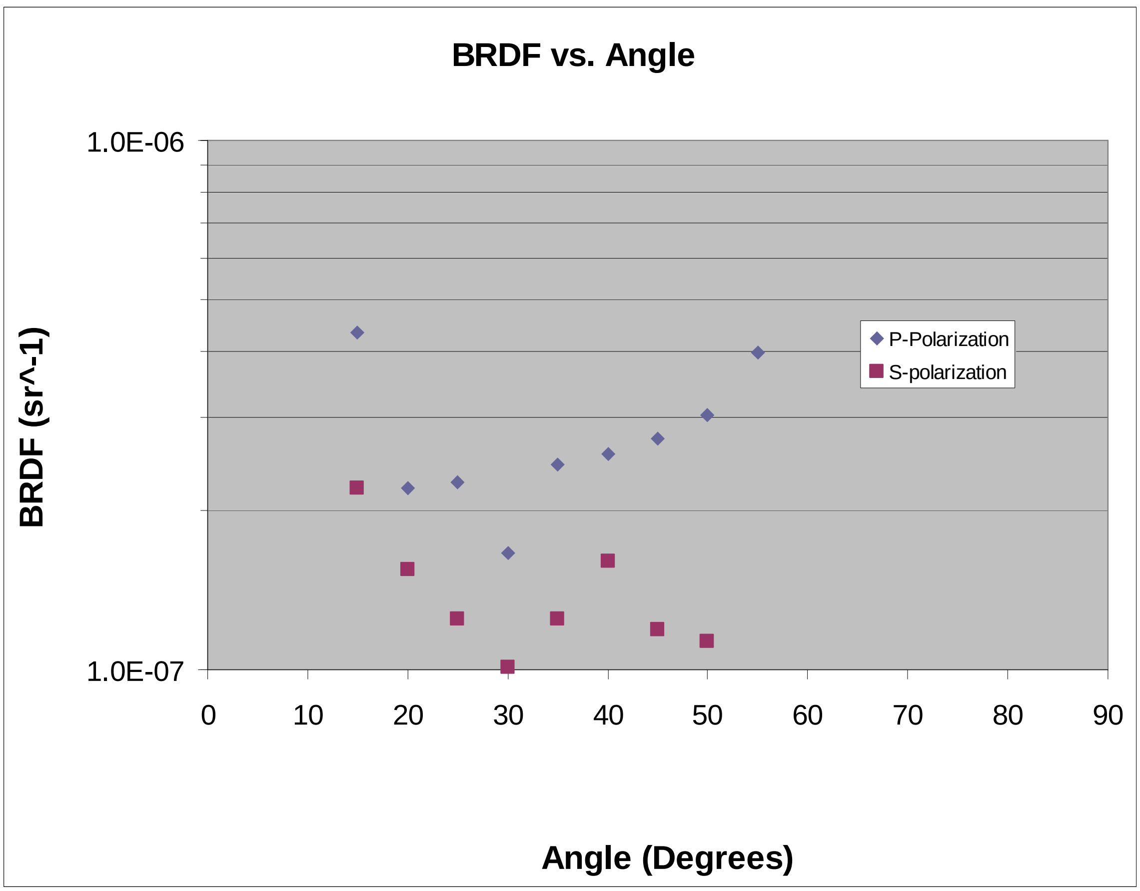

Figure 1: BRDF of Grade #10 Welder's Glass with s and p Polarized 1064 nm Light Incident at Various Angles

The BRDF values are scattered between 1-4 E-7 sr^-1, and do not seem to exhibit a dip at Brewster's angle, approximately 57 deg.

1.3 Reflectivity of Black Glass

The reflectivity of grade #10 welder's glass by Schott with s and p polarized 1064 nm light incident at various angles (deg.) was measured (see LIGO-T080064-00, Controlling Light Scatter in Advanced LIGO, Dan Riley and Michael Smith) and is shown in Figure 2.

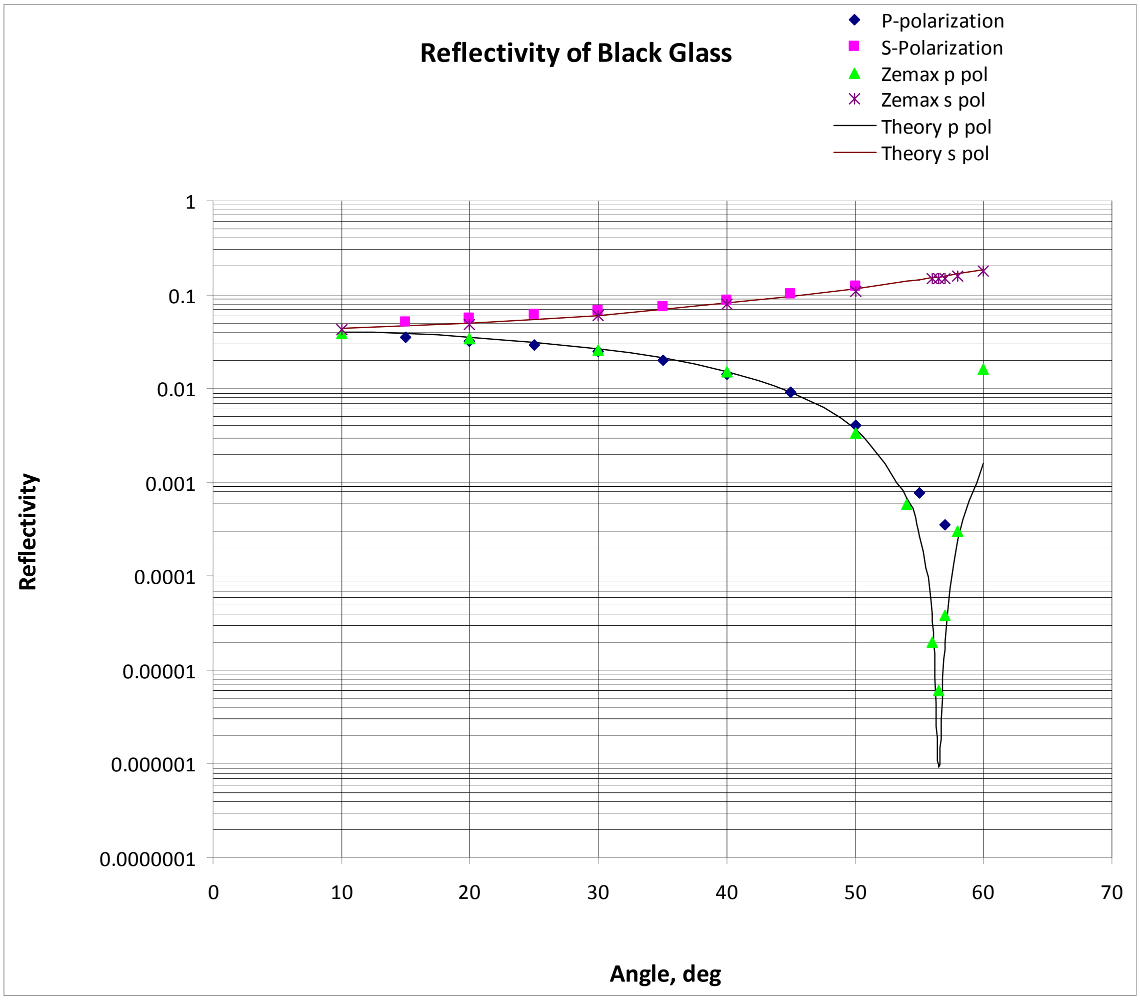

Figure 2: Reflectivity of Grade #10 Welder's Glass with s and p Polarized 1064 nm Light Incident at Various Angles

The magenta and blue symbols are the experimental data for s and p polarization respectively.

The green symbols are reflectivity from a "blkglass" optical surface modeled using Zemax. The "blkglass" material properties were created by using the index of refractive properties of BK7 taken from the Zemax glass catalog with the addition of 5254 m^-1 absorption coefficient.

The solid lines are the theoretical Fresnel reflectivity for an optical material with a complex index of refraction having a real refractive index of 1.516 (which is the same as BK7), and an imaginary extinction coefficient of 4.48 E-4 (which is the measured value for #10 black glass).

The Fresnel reflectivity for various incidence angles was calculated using the Fresnel equation with complex index of refraction given by

$$R(\theta_i) := \left(\frac{\left|n_C{}^2\right| \cdot \cos(\theta_i) - \sqrt{\left|n_C{}^2\right| - \sin(\theta_i)^2}}{\left|n_C{}^2\right| \cdot \cos(\theta_i) + \sqrt{\left|n_C{}^2\right| - \sin(\theta_i)^2}} \right)^2$$

Where the complex index of refraction was calculated from the measured transmissivity of the black glass, as shown in section 1.4.2.

It can be seen that the reflectivity of simulated "blkglass" matches the experimental and theoretical reflectivity reasonably well.

1.4 Transmissivity of Black Glass

The transmissivity of a 3.2 mm thick, grade #10 welder's glass was measured by Michael Smith on 4/6/98 (private communication). T = 5 E-8.

1.4.1 Absorption Coefficient

The absorption coefficient can be calculated

$$\alpha_\lambda := \frac{-\ln(T)}{x} \qquad \alpha_\lambda = 5.254 \times 10^3$$

1.4.2 Complex Index of Refraction

The extinction coefficient is defined as

$$n_I := \frac{\alpha_\lambda \cdot \lambda}{4 \cdot \pi} \qquad n_I = 4.448 \times 10^{-4}$$

And the complex index of refraction is

$$n_C := n_R + i \cdot n_I \qquad n_C = 1.516 + 4.448i \times 10^{-4}$$

The magnitude of the complex index of refraction is approximately the same as BK7, so the absorptivity of the black glass has a negligible effect on the reflectivity.

1.5 Simulated Baffles and Beam Dumps Modeled with Zemax "blkglass"

The ADLIGO baffles and beam dumps will be constructed from black, porcelainized steel. The scattering and reflectivity properties of black, porcelainized steel have not been measured. However, we will assume that the glassy dielectric surface has the same properties as "blkglass".

1.5.1 Arm Cavity Baffle

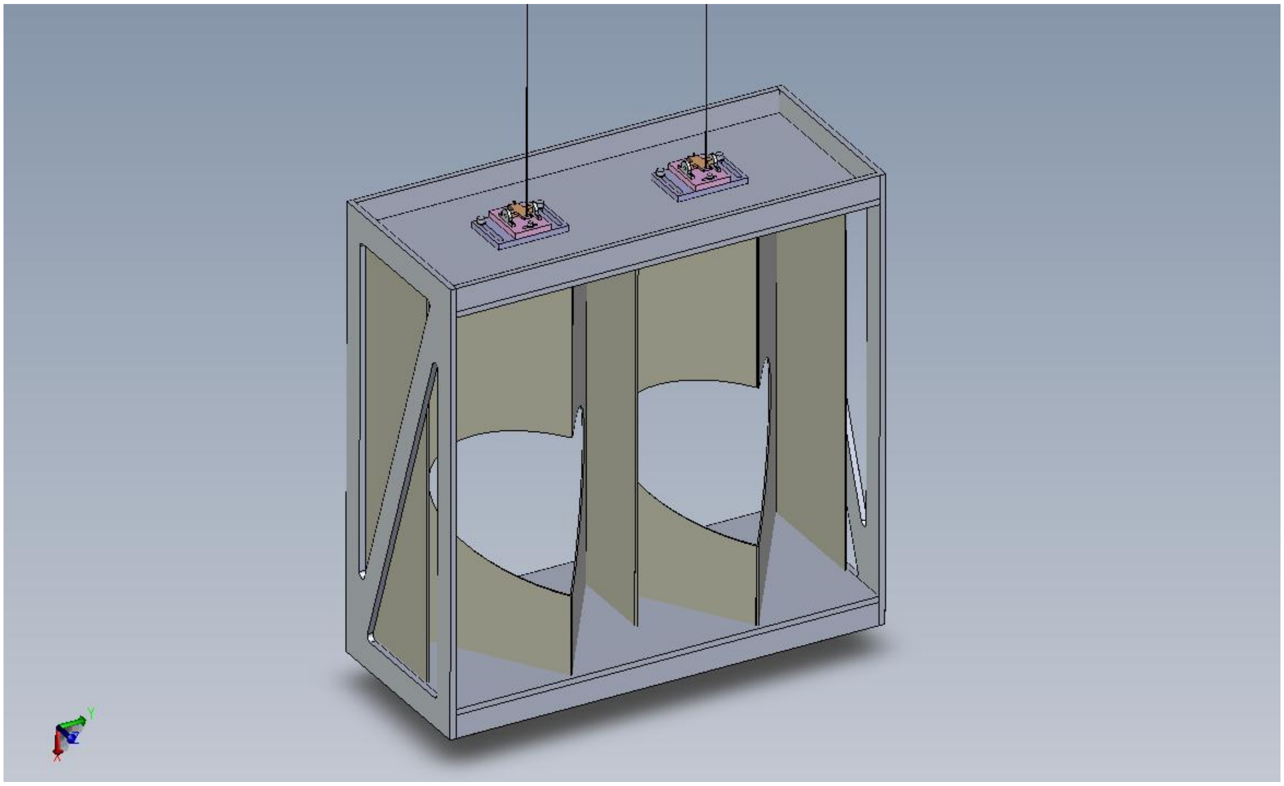

Figure 3: Arm Cavity Baffle

A Solidworks model of the louvered Arm Cavity Baffle is shown in Figure 3.

A Zemax ray trace model of a single horizontal cavity section of the louvered arm cavity baffle is shown in Figure 4. Rays are launched from the right, and after four or five reflections from the surface of the baffle, the rays emerge and hit the detector surface where the reflected power is measured.

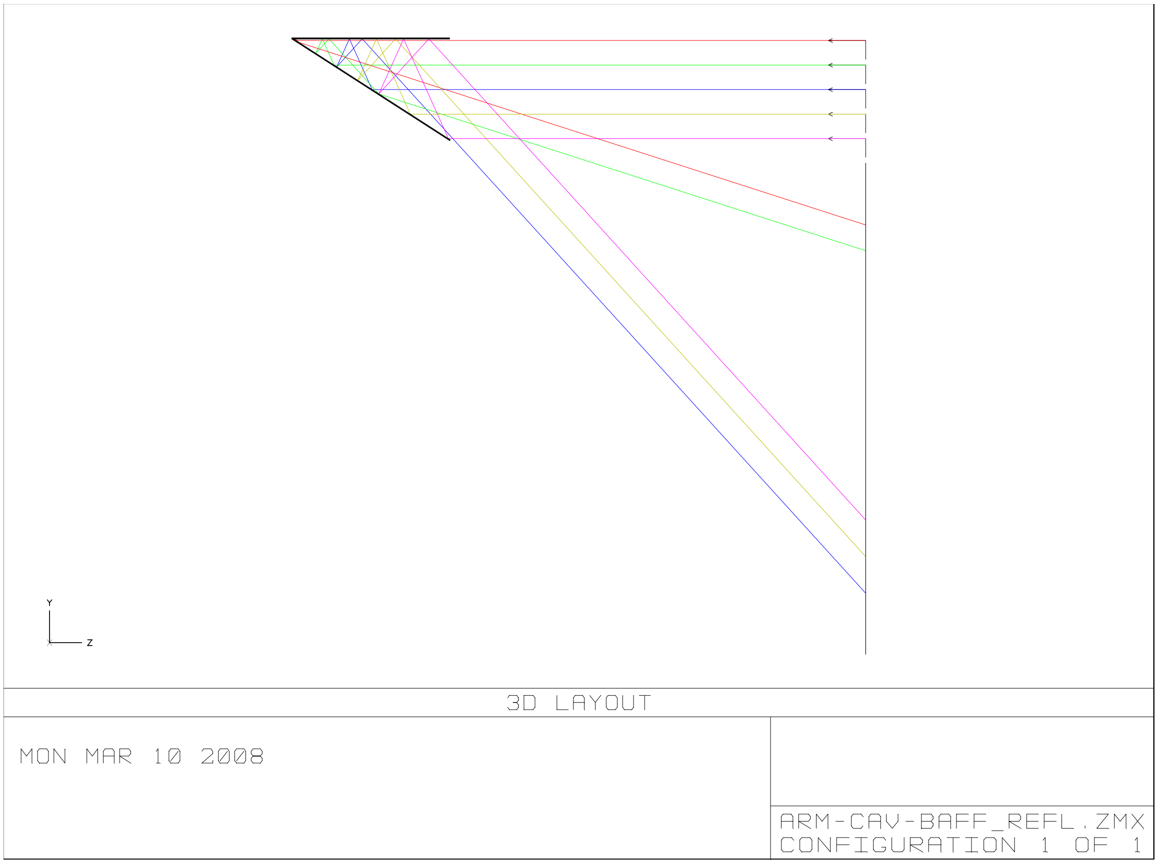

Figure 4: Zemax Ray Trace, Simulated Arm Cavity Baffle

The integrated incoherent irradiance hitting the detector surface is shown in Figure 5. The total incident power on the baffle is 5W. With p polarization @ 1064 nm wavelength, the reflected power is 1.85 E-9 W. Therefore the effective reflectivity of the baffle is 3.7 E-10.

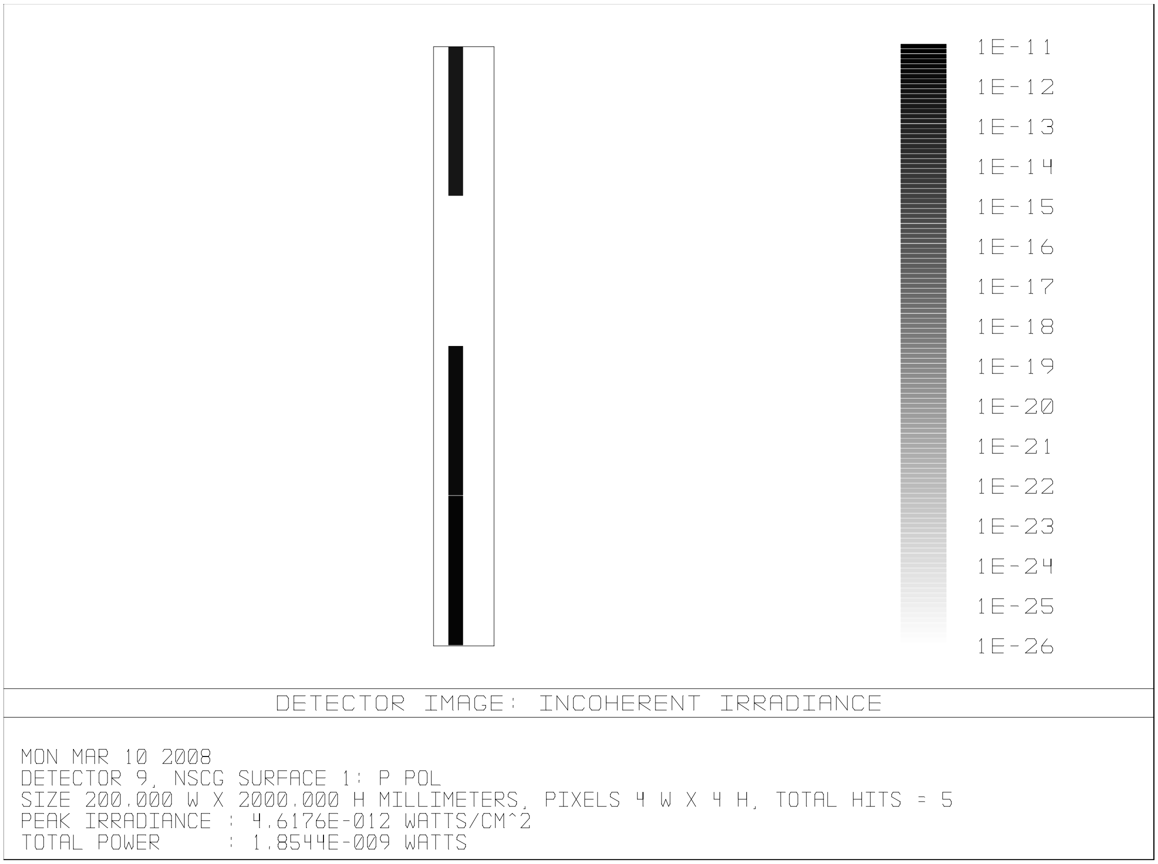

Figure 5: Integrated Incoherent Irradiance Hitting the Detector Surface

1.5.2 Cavity Beam Dumps

The reflectivity of the cavity beam dumps, which catch the BS and ITM ghost beams, is identical to the single horizontal cavity section of the louvered arm cavity baffle.

1.5.3 Elliptical Baffle

A Solidworks model of the elliptical baffle is shown in Figure 6. It consists of an inner cone and an outer cylinder that trap the light incident on the cone surface from the ITM HR direction. The baffle surfaces are porcelainized black glass over a steel base.

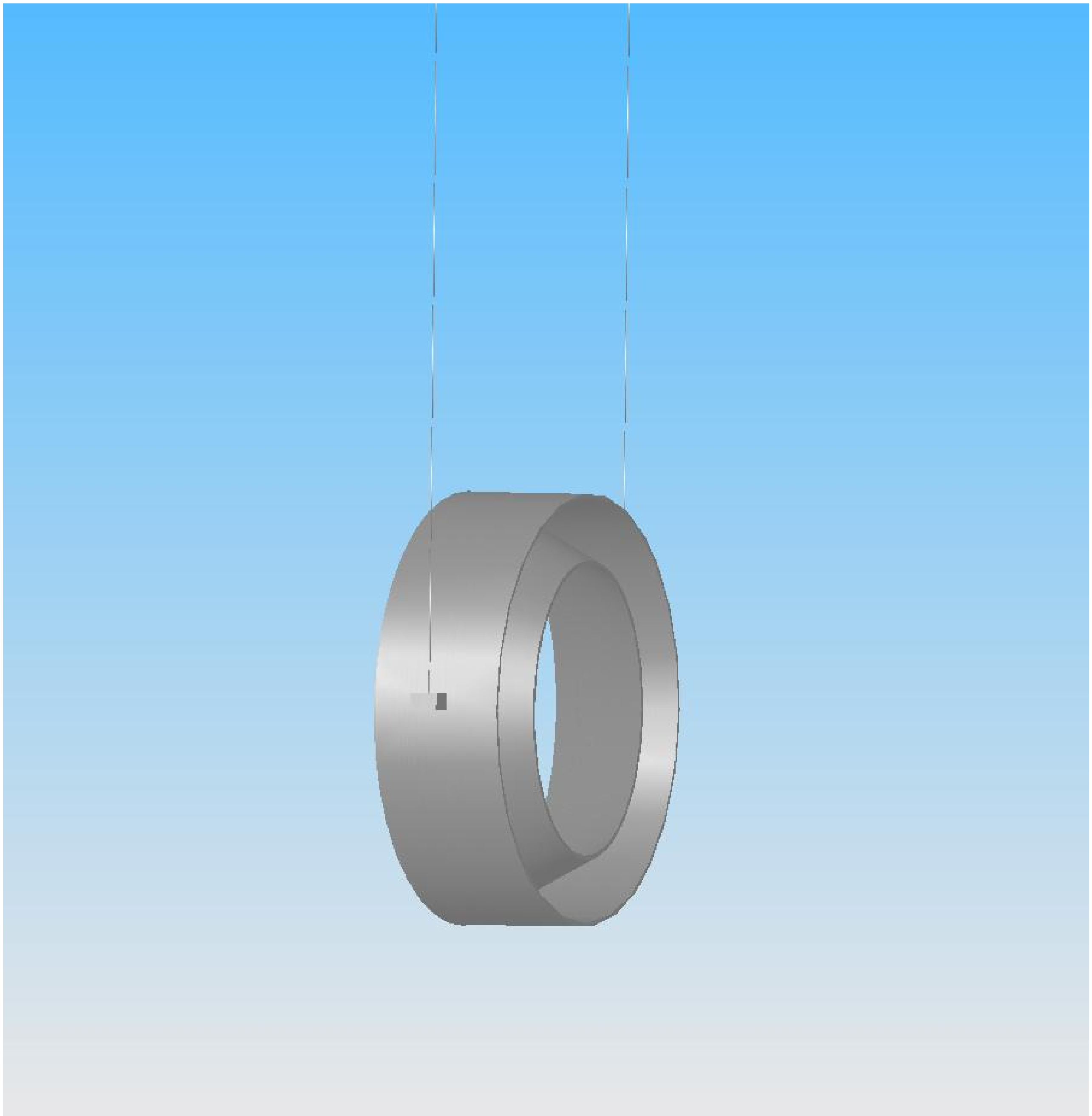

Figure 6: Suspended Elliptical Baffle

1.5.3.1 Elliptical Baffle Reflectivity

A Zemax ray trace model of the simulated elliptical baffle is shown in Figure 10. Rays are launched from the right, and after approximately five reflections from the surface of the baffle, the rays emerge and hit the detector surface where the reflected power is measured.

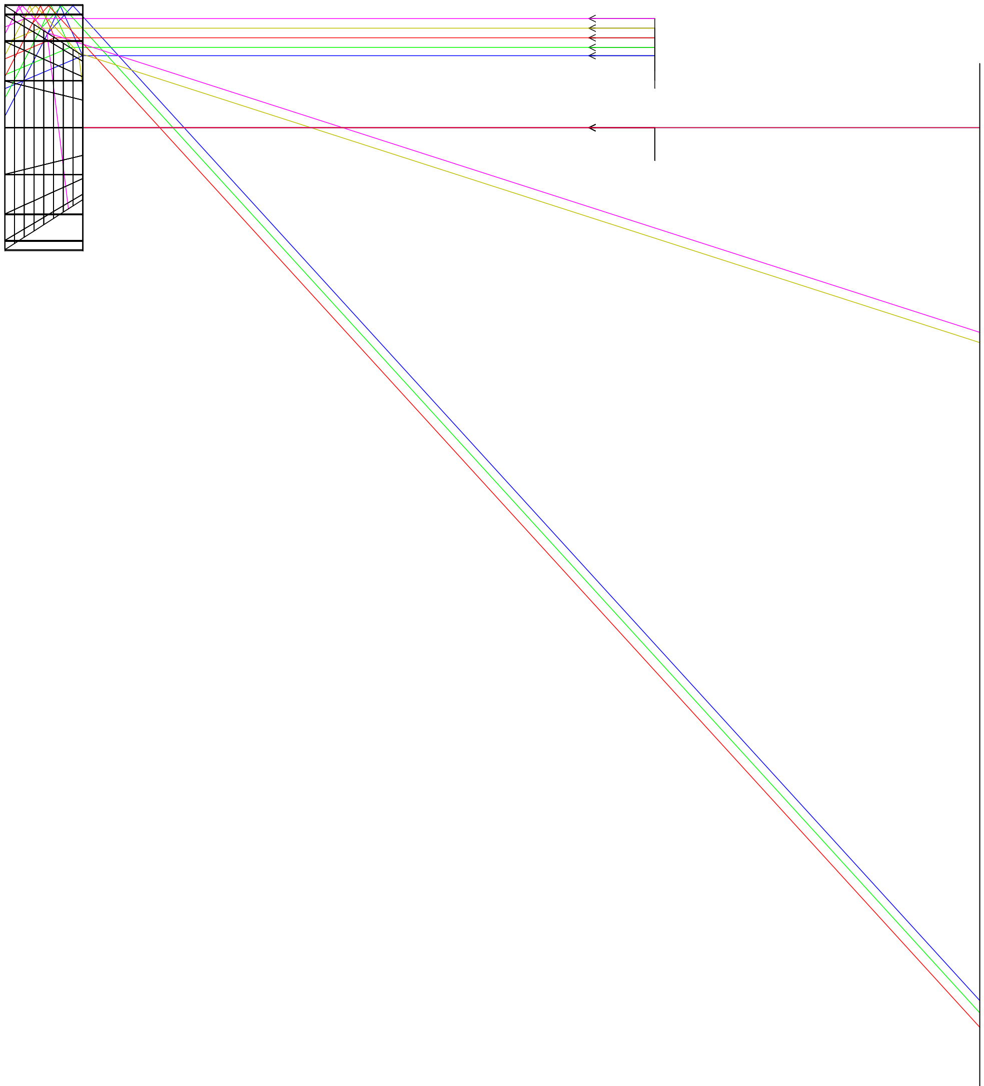

Figure 7: Zemax Ray trace, Simulated Elliptical Baffle

The total incident power on the baffle was set to 5W. With p polarization @ 1064 nm wavelength, the reflected power is 1.84 E-9 W. Therefore, the effective reflectivity of the baffle is 3.7 E-10.

With s polarization @ 1064 nm wavelength, the reflected power is 7.27 E-6 W. Therefore, the effective reflectivity of the baffle is 1.5 E-6.

The rays hitting the baffle surface are equally divided between p and s polarization. The average reflectivity will be 7.3 E-7.

1.5.4 Cryopump Baffle

A Solidworks model of the suspended cryopump baffle, integrated with the manifold baffle, is shown in Figure 8. The baffle consists of an outer cone and an inner cylinder that trap the light incident on the cone surface from the beam tube direction on the right. The baffle surfaces are porcelainized black glass over a steel base.

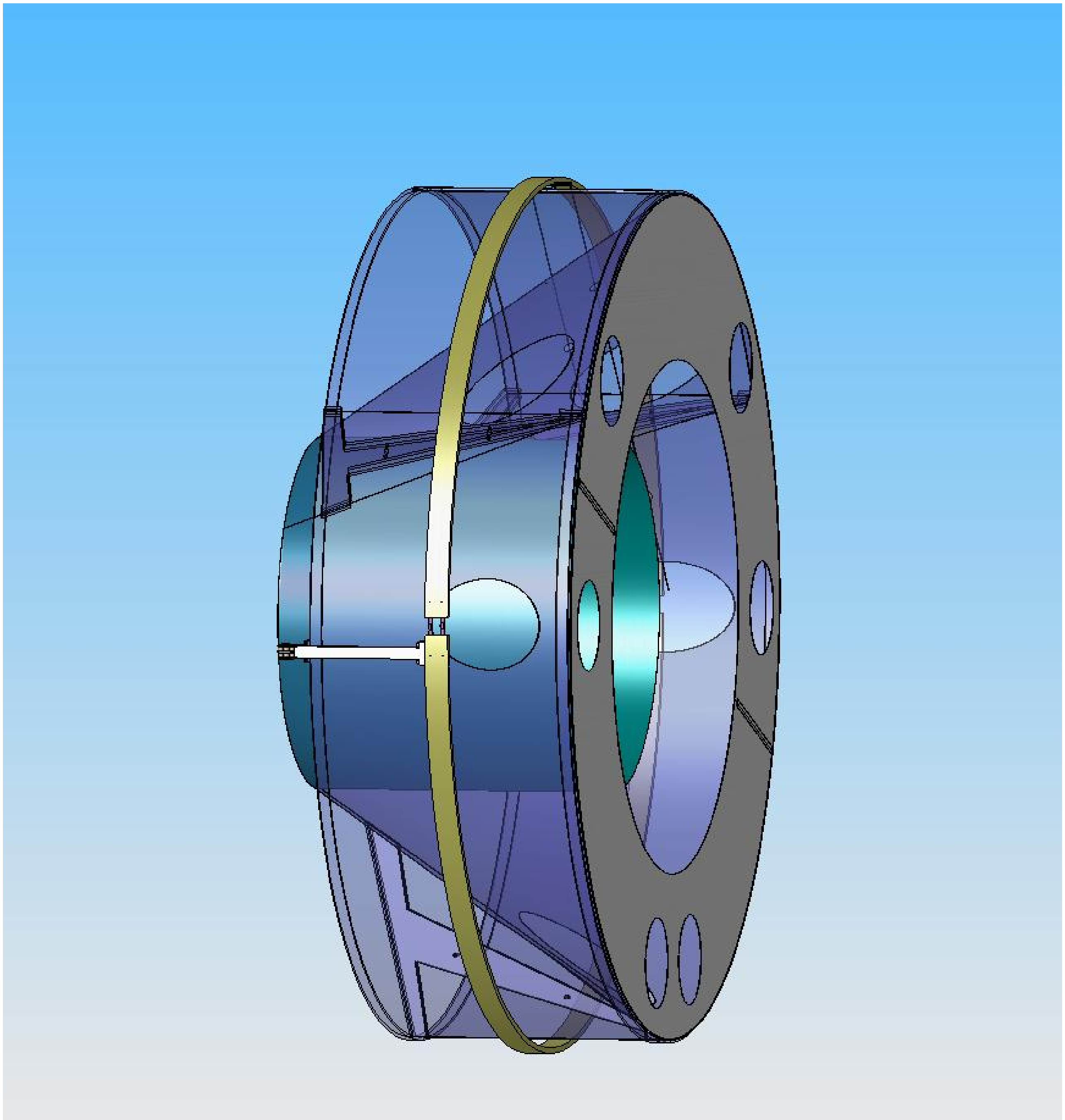

Figure 8: Suspended Cryopump Baffle with Baffle Plate

The baffle plate on the arm tube side of the baffle is hidden from the rays traversing from the far end of the arm tube. The baffle plate causes an additional four or five reflections inside the baffle before the rays emerge.

1.5.4.1 Cryopump Baffle Reflectivity with Baffle Plate

A Zemax ray trace model of the simulated baffle with the baffle plate is shown in Figure 9. Rays are launched from the right, and after approximately ten reflections from the surface of the baffle, the rays emerge and hit the detector surface where the reflected power is measured.

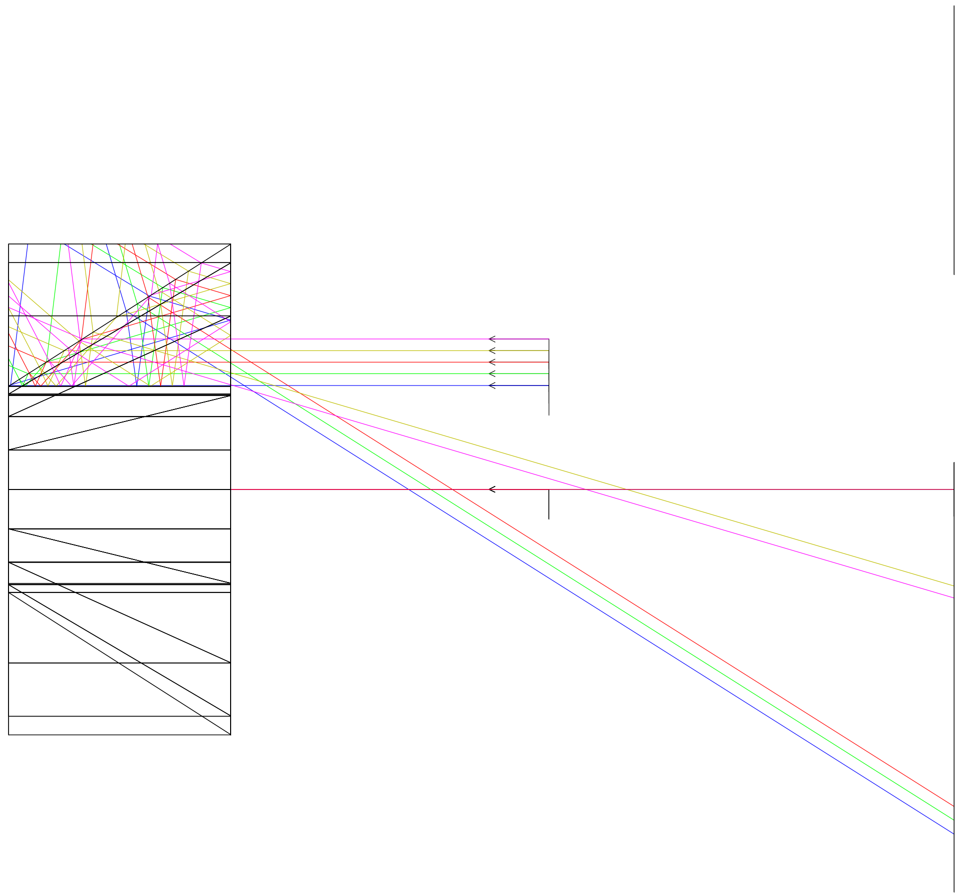

Figure 9: Zemax Ray trace, Simulated Cryopump Baffle with Baffle Plate

The total incident power on the baffle was set to 5000W. With p polarization @ 1064 nm wavelength, the reflected power is 5.3 E-12 W. Therefore, the reflectivity of the baffle is 1.1 E-15.

With s polarization @ 1064 nm wavelength, the reflected power is 5.3 E-6 W. Therefore, the reflectivity of the baffle is 1.1 E-9.

The rays hitting the baffle surface are equally divided between p and s polarization. The average reflectivity will be 5.3 E-10.

1.5.4.2 Cryopump Baffle Reflectivity without Baffle Plate

A Zemax ray trace model of the simulated porcelainized black glass baffle without the baffle plate is shown in Figure 10. Rays are launched from the right, and after approximately five reflections from the surface of the baffle, the rays emerge and hit the detector surface where the reflected power is measured.

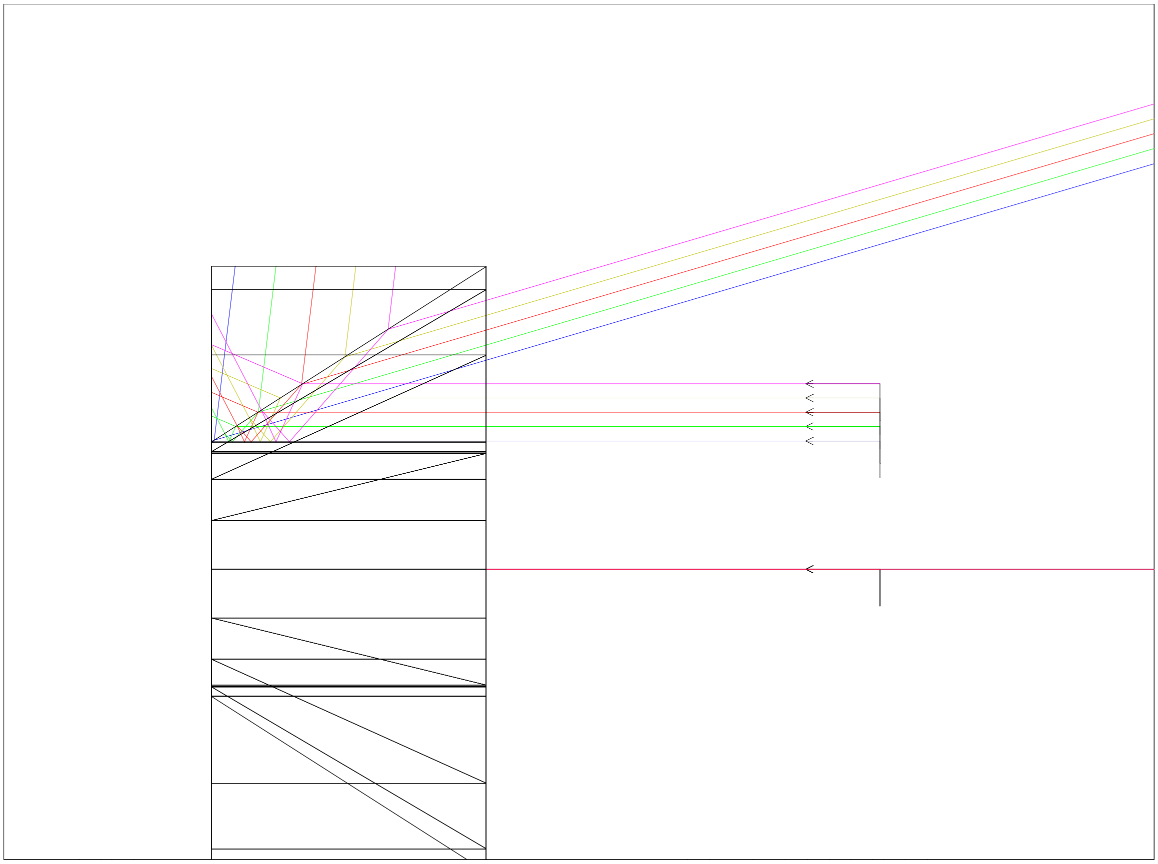

Figure 10: Zemax Ray trace, Simulated Cryopump baffle without Baffle Plate

The total incident power on the baffle was set to 5000W. With p polarization @ 1064 nm wavelength, the reflected power is 5.6 E-7 W. Therefore, the reflectivity of the baffle is 1.1 E-10.

With s polarization @ 1064 nm wavelength, the reflected power is 5.2 E-2 W. Therefore, the reflectivity of the baffle is 1.0 E-5.

The rays hitting the baffle surface are equally divided between p and s polarization. The average reflectivity will be 5.2 E-6.

2 Summary of Baffle and Beam Dump Reflectivity

Table 1: Summary of Reflectivity

BAFFLE/BD TYPE	R p-pol	R s-pol	R ave
Arm Cavity Baffle	3.7 E-10	NA	3.7 E-10
Cavity Beam Dump	3.7 E-10	NA	3.7 E-10
Elliptical Baffle	3.7 E-10	1.5 E-6	7.3 E-7
Cryopump Baffle, with baffle plate	1.1 E-15	1.1 E-9	5.3 E-10
Cryopump Baffle, without baffle plate	1.1 E-10	1.0 E-5	5.2 E-6