A. Egidi

Attenuation of back-scattered optical signals by off-axis and variable aperture slits – a simulation

R.T. 10/2021 April 2021

I.N.RI.M. TECHNICAL REPORT

Summary

Abstract

This technical report is focused on the investigation of the simulated behaviour of optical signals retro-reflected by S-LAH79 glass spheres [1] and intercepted by a rectangular slit (with variable apertures and off-axis positions), before being collected by a detector. A suitable opto-mechanical layout has been implemented in the context of a specific activity of the EMPIR project **LaVA** [2] (scheduled in the JRP Protocol as "*Activity number 5.2.1"*), in order to size a proper mechanical apparatus for the modulation of the signals to be processed to infer the position of the target. In Figure 1 a conceptual scheme of the required set up is shown. The simulations were performed by using the last version of the commercial software *Zemax Optic Studio* [3].

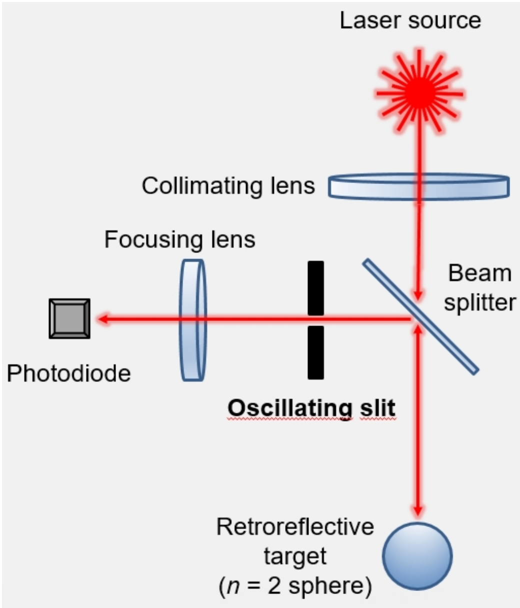


Figure 1: conceptual scheme for the detection of optical signals back-scattered from S-LAH79 glass spheres

Optical set up in Zemax software

The optical layouts used for simulating the behavior of a 10 mW collimated gaussian laser beam (λ = 635 nm, r_{1/e^2} = 2 mm) impinging on a 16 mm *n* = 2 sphere and back-reflected by the same sphere, 90°-deflected by a beam splitter and sensed by a detector are reported in Figure 2 (arrangement without any slit) and in Figure 4 (in presence of a slit); the patterns of the corresponding signals (in false colors and with proper contrast enhancement) are shown in Figure 3 and in Figure 5.

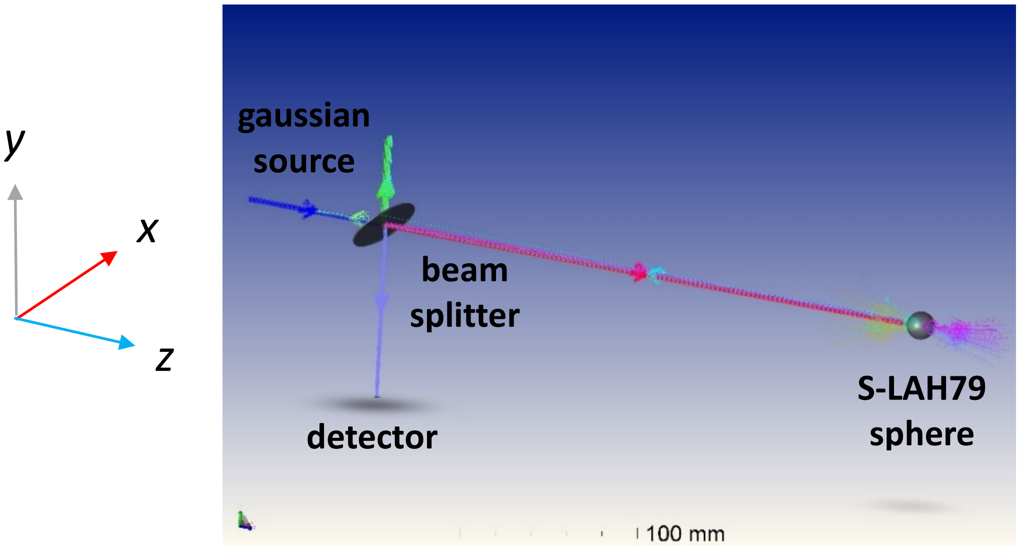


Figure 2: basic Zemax layout, without any slit in the propagation direction of the beam

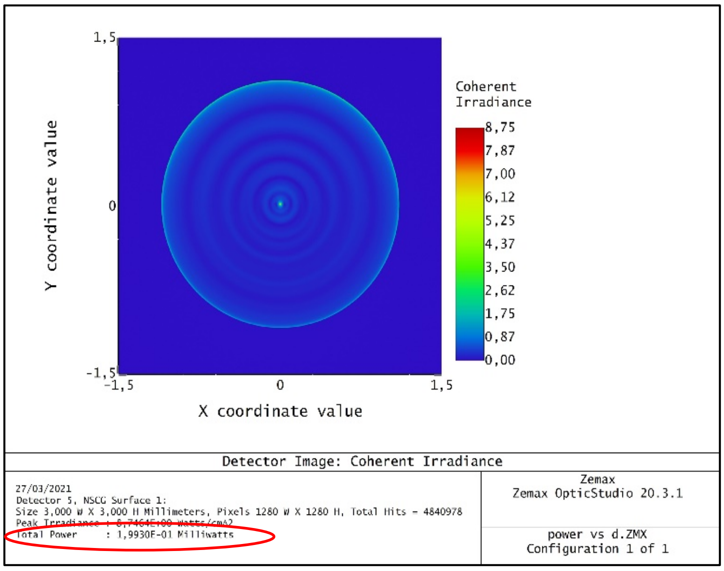


Figure 3: signal visualized on the detector in the absence of any slit

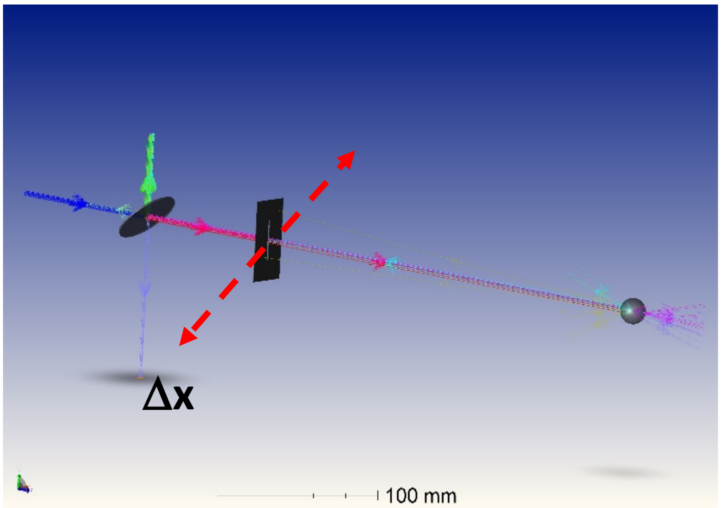


Figure 4: Zemax layout with the slit in axis with the propagation direction of the beam

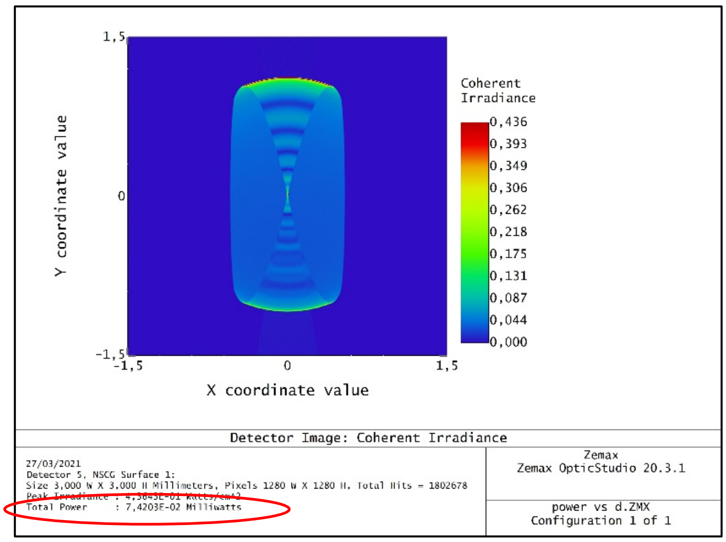


Figure 5: signal visualized on the detector when the slit is in axis with the beam

Simulation results in non-sequential mode

The physical dimension under investigation is the **total power**[1] of the optical signal collected by the rectangular detector; in particular, its attenuation (in decibel scale[2]) was calculated in two situations:

1. **slit aligned with the beam** (perfect coincidence of the two axes), with two sub-cases:
   a. fixed slit aperture, with variable sphere-detector distances (Figure 6, on the left); in this case, the trend of the attenuation is fairly linear in the range of interest (0.5 ÷ 5 m).
   b. Fixed sphere-detector distance (1 m), with variable slit apertures (from 0.5 to 8 mm) (Figure 6, on the right); in this case the trend is manifestly exponential, and it seems clear that ≃ -17 dB is the attenuation threshold of the signal in the absence of any slit at all at the chosen distance: this number shows that the most part of the optical signal is lost and scattered away from the sphere, after the beam impinges on it, so that only a very small portion of the signal itself can be furtherly exploited for target localization [4].
2. **Discretized misalignments of the slit** (Figure 7) perpendicular to the beam direction, with three different slit apertures (1, 1.25 and 1.5 mm wide) and three different distances between sphere and detector (0.5, 1 and 1.5 m). In this situation, all the three different slit apertures have similar impact on the signal reduction, even if the smallest one (1 mm wide) seems to exhibit the best sensitivity: in this case, in fact, the rapidity of change of the signal power on the detector with respect to the misalignment is maximum in all the three positions explored; by the way, in the real world a very small slit has to deal with the too few photons interrogating the detector, and with all the environmental optical disturbances that inevitably deteriorate the useful – weak – signal: for this reason, a compromise between the best theoretical sensitivity and the amount of photons allowed by the aperture of the slit is needed in the implementation of the real set up.

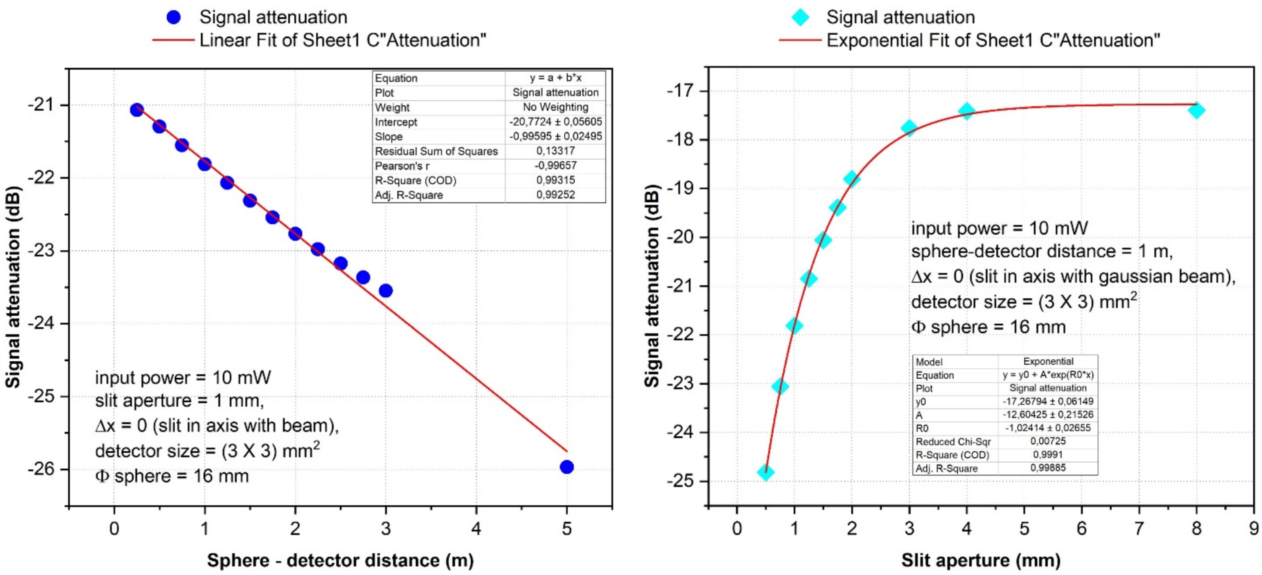


Figure 6: Attenuation of the signals by different slit positions and apertures, when the slit is in axis with the beam

[1] In the absence of a suitable physical model explaining the pattern of the diverging beam exiting the sphere and then – in an even more complicated way – interacting with a slit and undergoing diffraction, the most coherent choice to qualitatively investigate the behaviour of the signal when some physical parameters are changed is to estimate, by simulation, the *integral of the irradiance over the entire beam*.

[2] Attenuation = $10 \cdot \log_{10} \frac{P_{det}}{P_{in}}$

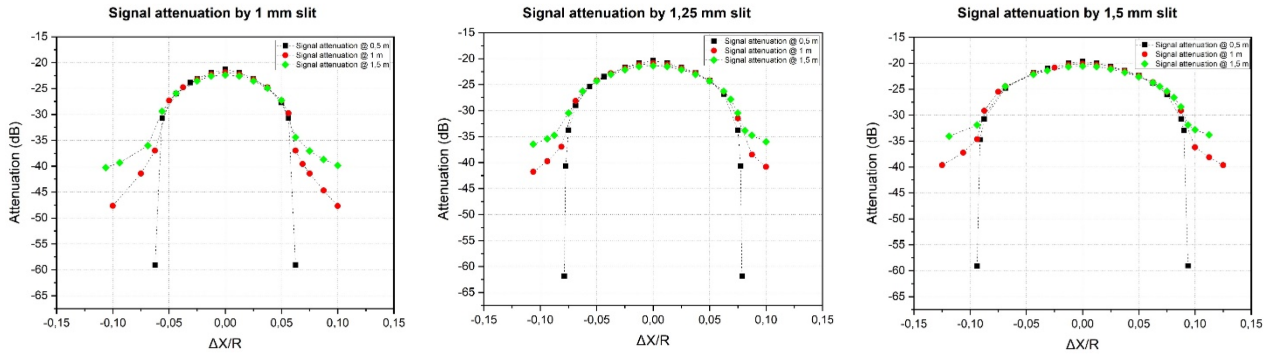


Figure 7: Attenuation of the signals by different slit positions and apertures, with several discretized misalignments of the slit with the beam

Conclusions

The simulations performed were useful to estimate the amplitude of the periodic motion of the slit, in the real set up to be implemented: since the signals caught by the detector appear to be strongly attenuated also when the misalignment between the beam and the slit is small (just few tenths of millimetre, as it can be inferred from Figure 7), a sinusoidal motion with the maximum amplitude of ± 5 mm driven by the simple crank and connecting rod mechanism made (Figure 8) is a good choice to provide the needed modulation to the continuous signal coming from the sphere and impacting on the photodiode; this fact allows a significant shrinking of the final set up (in Figure 9 the actual implementation is shown, but its downsizing is currently under investigation), in a context where the aim is to design an opto-mechanical device suitable to be integrated in large machine tools, in order to develop a metrology system for the improvement of their spindle positioning accuracy.

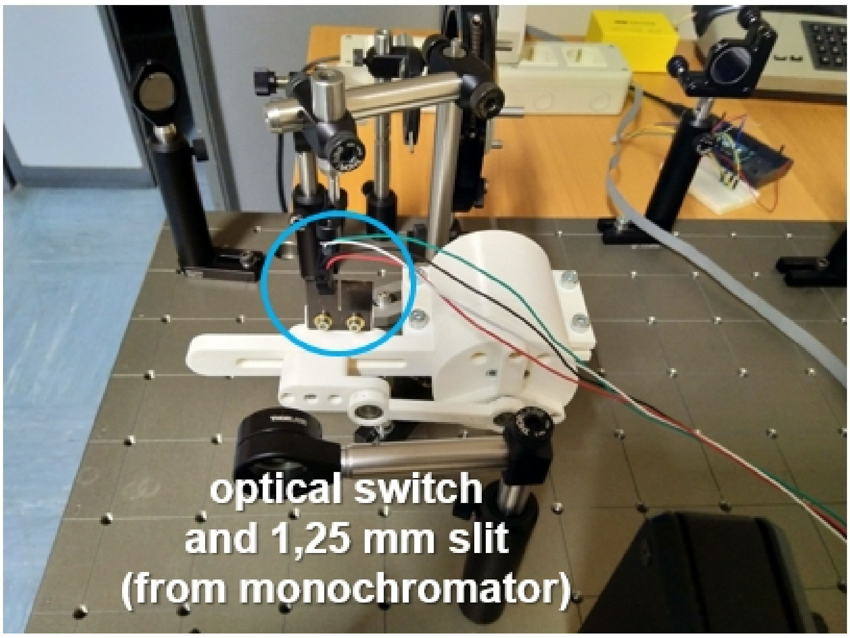


Figure 8: detail of motorized crank and connecting rod mechanism used for alternate slit oscillation

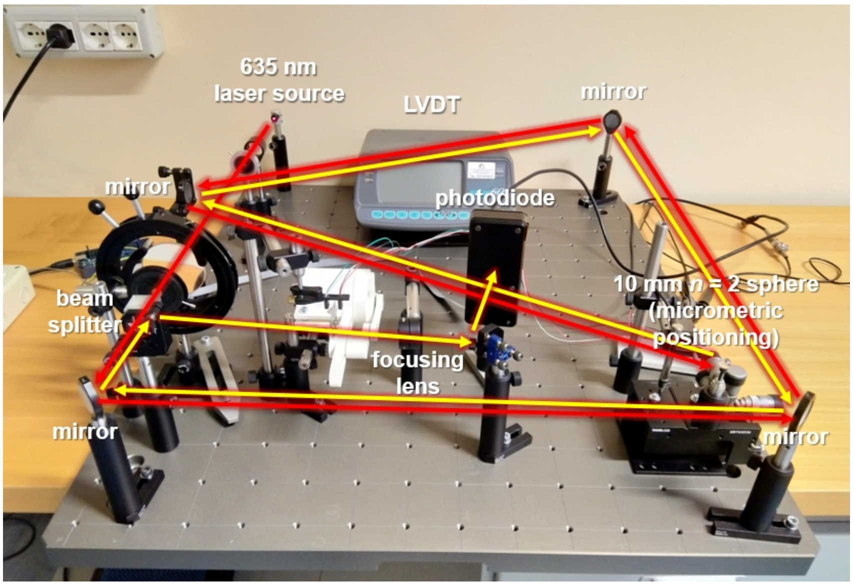
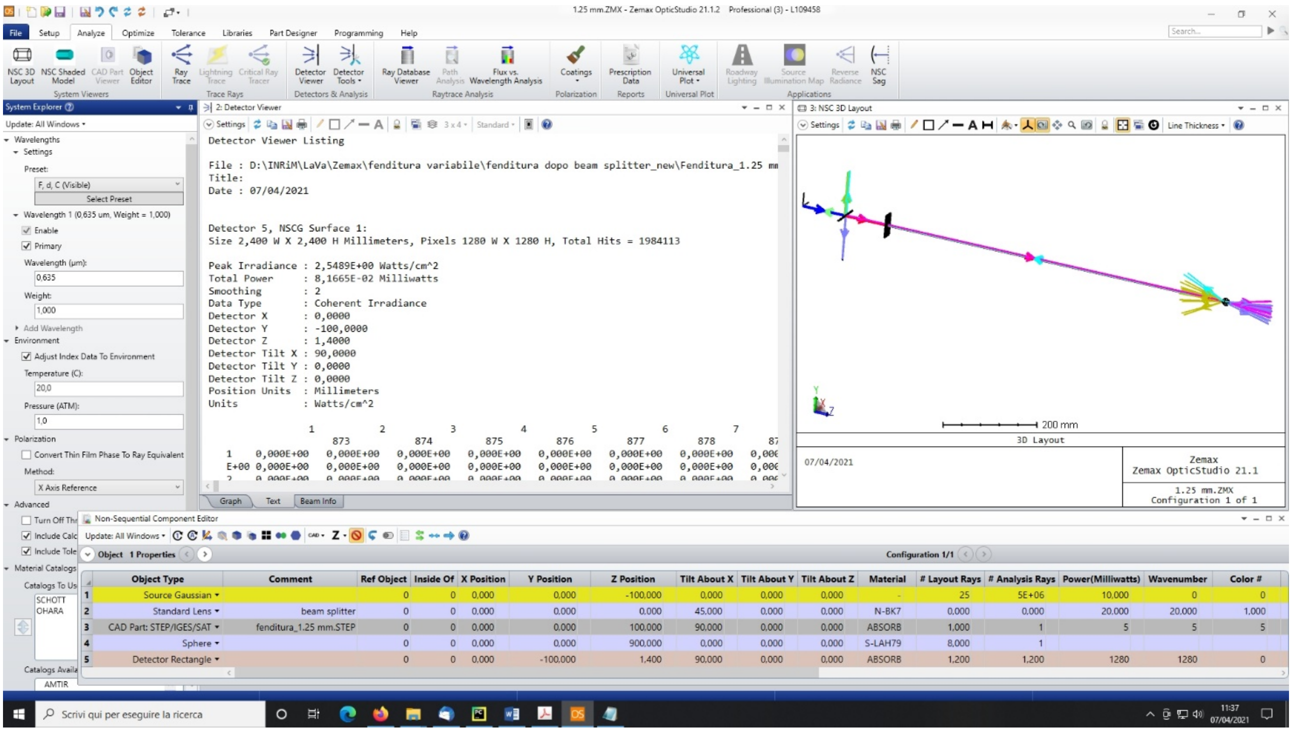


Figure 9: overall view of experimental set up, with the paths of the optical signals (red = forward, yellow = backward) highlighted

References

1. A. Egidi, A. Balsamo and M. Pisani - High-Index Glass Ball Retroreflectors for Measuring Lateral Positions; Sensors 2019, 19(5), 1082; https://doi.org/10.3390/s19051082
2. Large Volume Metrology Applications (“*LaVA*”), EURAMET Project Number: 17IND03
3. Zemax Optic Studio, version 21.1.2
4. T. Takatsuji, M. Goto, S. Osawa, R. Yin and T. Kurosawa - Whole-viewing-angle cat's-eye retroreflector as a target of laser trackers, 1999 Meas. Sci. Technol. 10 N87

Annex A: example of Zemax set up (screenshot)



Annex B: Zemax prescription data

File : D:\INRiM\LaVa\Zemax\fenditura variabile\fenditura dopo beam splitter_new\Fenditura_1.25 mm\1.25 mm.ZMX
Title:
Date : 07/04/2021

GENERAL LENS DATA:

Field Unpolarized : On
J/E Conversion Method : X Axis Reference
Glass Catalogs : SCHOTT OHARA
Temperature (C) : 2,00000E+01
Pressure (ATM) : 1,00000E+00
Adjust Index Data To Environment : On
Primary Wavelength [µm] : 0,635
Lens Units : Millimeters
Source Units : Milliwatts
Analysis Units : Watts/cm^2
Afocal Mode Units : milliradians
MTF Units : cycles/millimeter

NSC SYSTEM DATA:

Maximum Intersections Per Ray : 100
Maximum Segments Per Ray : 500
Maximum Nested/Touching Objects : 10
Maximum Source File Rays In Memory : 1000000
Minimum Relative Ray Intensity : 1,0000E-03
Minimum Absolute Ray Intensity : 0,0000E+00
Glue Distance In Lens Units : 1,0000E-06
Missed Ray Draw Distance In Lens Units : 0,0000E+00

Wavelengths : 1
Units: µm

#	Value	Weight
1	0,635000	1,000000

Wavelengths : 1
Units: µm

#	Value	Weight
1	0,635000	1,000000

OBJECT DATA DETAIL:

There are 5 objects:

Object 1 :

Object Type : Source Gaussian (NSC_SGAU)
Reference Object : 0
Inside Of : 0
XYZ Position : 0 0 -100
Tilt About XYZ : 0 0 0
Pos. Mtrx. R11 R12 R13 X : 1,00000000E+00 0,00000000E+00 0,00000000E+00 0,00000000E+00
Pos. Mtrx. R21 R22 R23 Y : 0,00000000E+00 1,00000000E+00 0,00000000E+00 0,00000000E+00
Pos. Mtrx. R31 R32 R33 Z : 0,00000000E+00 0,00000000E+00 1,00000000E+00 -1,00000000E+02
Source uses system wavelengths
Layout Rays : 25
Analysis Rays : 5000000
Power(Milliwatts) : 10
Wavenumber : 0
Color # : 0
Beam Size : 2
Position : 0

Object 2 : beam splitter
Object Type : Standard Lens (NSC_SLEN)
Face 0 : Side Faces
Face Is : Object Default
Coating : (none)
Scattering : None
Face 1 : Front Face
Face Is : Object Default
Coating : AR_400-700_1L
Scattering : None
Face 2 : Back Face
Face Is : Object Default
Coating : I.50
Scattering : None
Reference Object : 0
Inside Of : 0
XYZ Position : 0 0 0
Tilt About XYZ : 45 0 0
Pos. Mtrx. R11 R12 R13 X : 1,00000000E+00 0,00000000E+00 0,00000000E+00 0,00000000E+00
Pos. Mtrx. R21 R22 R23 Y : 0,00000000E+00 7,07106781E-01 -7,07106781E-01 0,00000000E+00
Pos. Mtrx. R31 R32 R33 Z : 0,00000000E+00 7,07106781E-01 7,07106781E-01 0,00000000E+00
Material : N-BK7
Index at 0,635000 µm = 1,51501420
Radius 1 : 0
Conic 1 : 0
Clear 1 : 20
Edge 1 : 20
Thickness : 1
Radius 2 : 0
Conic 2 : 0

Clear 2 : 20
Edge 2 : 20

Object 3 : fenditura_1.25 mm.STEP
Object Type : CAD Part: STEP/IGES/SAT (NSC_IMPT)
Face 0 : Face 0
Face Is : Object Default
Coating : (none)
Scattering : None
Face 1 : Face 1
Face Is : Object Default
Coating : (none)
Scattering : None
Face 2 : Face 2
Face Is : Object Default
Coating : (none)
Scattering : None
Face 3 : Face 3
Face Is : Object Default
Coating : (none)
Scattering : None
Face 4 : Face 4
Face Is : Object Default
Coating : (none)
Scattering : None
Face 5 : Face 5
Face Is : Object Default
Coating : (none)
Scattering : None
Face 6 : Face 6
Face Is : Object Default
Coating : (none)
Scattering : None
Face 7 : Face 7
Face Is : Object Default
Coating : (none)
Scattering : None
Face 8 : Face 8
Face Is : Object Default
Coating : (none)
Scattering : None
Face 9 : Face 9
Face Is : Object Default
Coating : (none)
Scattering : None
Reference Object : 0
Inside Of : 0
XYZ Position : 0 0 100
Tilt About XYZ : 90 0 0
Pos. Mtrx. R11 R12 R13 X : 1,00000000E+00 0,00000000E+00 0,00000000E+00 0,00000000E+00
Pos. Mtrx. R21 R22 R23 Y : 0,00000000E+00 0,00000000E+00 -1,00000000E+00 0,00000000E+00

Pos. Mtrx. R31 R32 R33 Z : 0,00000000E+00 1,00000000E+00 0,00000000E+00
1,00000000E+02
Material : ABSORB
Scale : 1
Mode : 1
X-Voxels : 5
Y-Voxels : 5
Z-Voxels : 5
Explode? : 0

Object 4 :
Object Type : Sphere (NSC_SPHE)
Face 0 : All Faces
Face Is : Object Default
Coating : (none)
Scattering : None
Reference Object : 0
Inside Of : 0
XYZ Position : 0 0 900
Tilt About XYZ : 0 0 0
Pos. Mtrx. R11 R12 R13 X : 1,00000000E+00 0,00000000E+00 0,00000000E+00
0,00000000E+00
Pos. Mtrx. R21 R22 R23 Y : 0,00000000E+00 1,00000000E+00 0,00000000E+00
0,00000000E+00
Pos. Mtrx. R31 R32 R33 Z : 0,00000000E+00 0,00000000E+00 1,00000000E+00
9,00000000E+02
Material : S-LAH79
Index at 0,635000 µm = 1,99577449
Radius : 8
Is Volume? : 1

Object 5 :
Object Type : Detector Rectangle (NSC_DETE)
Face 0 : All Faces
Face Is : Object Default
Coating : (none)
Scattering : None
Reference Object : 0
Inside Of : 0
XYZ Position : 0 -100 1,4
Tilt About XYZ : 90 0 0
Pos. Mtrx. R11 R12 R13 X : 1,00000000E+00 0,00000000E+00 0,00000000E+00
0,00000000E+00
Pos. Mtrx. R21 R22 R23 Y : 0,00000000E+00 0,00000000E+00 -1,00000000E+00 -
1,00000000E+02
Pos. Mtrx. R31 R32 R33 Z : 0,00000000E+00 1,00000000E+00 0,00000000E+00
1,40000000E+00
Material : ABSORB
X Half Width : 1,2
Y Half Width : 1,2
X Pixels : 1280
Y Pixels : 1280
Data Type : 0

Color : 0
Smoothing : 0
Scale : 0
Plot Scale : 0
Front Only : 0
PSF Wave # : 0
X Angle Min : -90
X Angle Max : 90
Y Angle Min : -90
Y Angle Max : 90
Polarization : 0
Mirroring : 0

Coating Name: I.50 (IDEAL)

Coating AR_400-700_1L, 1 layer(s)

Material	Thickness	Absolute	Loop	Taper
MGF2_EM	0,092030	1	0	

SOLVE AND VARIABLE DATA:

FILES USED:

Zemax File
D:\INRiM\LaVa\Zemax\fenditura variabile\fenditura dopo beam splitter_new\Fenditura_1.25 mm\1.25 mm.ZMX
Session File
D:\INRiM\LaVa\Zemax\fenditura variabile\fenditura dopo beam splitter_new\Fenditura_1.25 mm\1.25 mm.ZDA
Lens Configuration File
D:\INRiM\LaVa\Zemax\fenditura variabile\fenditura dopo beam splitter_new\Fenditura_1.25 mm\1.25 mm.CFG
Glass Catalogs
C:\Users\Geron\OneDrive\Documenti\Zemax\GLASSCAT\SCHOTT.AGF
C:\Users\Geron\OneDrive\Documenti\Zemax\GLASSCAT\OHARA.AGF
Coating Data
C:\Users\Geron\OneDrive\Documenti\Zemax\COATINGS\COATING.DAT
NSC Object Files
C:\Users\Geron\OneDrive\Documenti\Zemax\OBJECTS\CAD Files\fenditura_1.25 mm.STEP
C:\Users\Geron\OneDrive\Documenti\Zemax\OBJECTS\CAD Files\fenditura_1.25 mm.STEP.ZAN
NSC Scatter Profiles
C:\Users\Geron\OneDrive\Documenti\Zemax\PROFILES\SCATTER_PROFILE.DAT
ABg Data
C:\Users\Geron\OneDrive\Documenti\Zemax\ABG_DATA\ABG_DATA.DAT