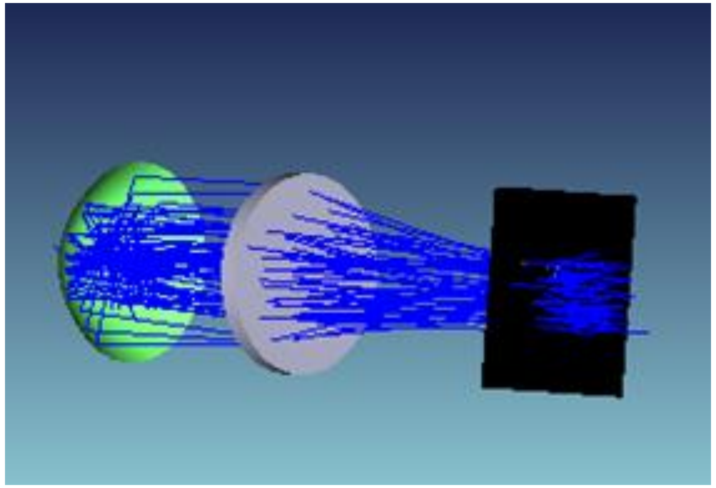
Lecture 17

Non-Sequential Mode in Zemax



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Content

1. **Introduction**

2. **Sequential vs Non-Sequential Modes**

3. **Some NSC Applications**

Introduction

There are 2 distinct ray-tracing modes in Zemax (OpticStudio)

- Sequential
- Non-sequential

In addition, a **hybrid mode** exists in which sequential and non-sequential ray-trace are used in the same system.

In this lecture, we will see some basic applications of Non-squential ray tracing in Zemax.

Sequential Mode

- It is mainly used for designing imaging and afocal systems.
- Surfaces are defined in the Lens Data Editor.
- Ray can only intersect each surface once and has to do it in a specified -sequential- order (i.e. surface #0 then #1 ,#2 …) and hence the name sequential ray tracing.
- Ray can only reflect if the surface material type is MIRROR. *Partial reflections from refractive surfaces (Fresnel reflections) are accounted for to the extent of calculating the correct refracted energy, including the effects on dielectric or metallic mirrors.*
- Each surface has its own local coordinate system. The position of each surface along the optical axis is referenced to the previous surface. In other words, the “Thickness” column in the Lens Data Editor refers to the distance from current surface and not from a global reference point.

Non-sequential Mode

Stray ray example

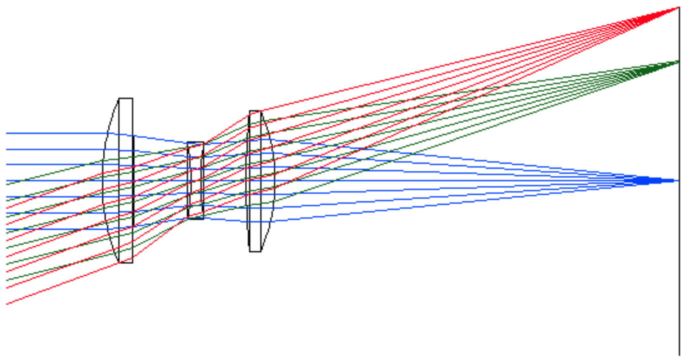
- It is primarily used for non-imaging applications
  such as illumination systems and/or stray-light analysis.

- Surfaces or volume objects are defined in the
  Non-Sequential Component Editor
- Mechanical components may be easily imported from CAD programs,
  so that full Opto-Mechanical analysis may be undertaken.
- A ray can intersect the same object more than once and can intersect multiple objects in any order; hence the name non-sequential.
- Each object is referenced to a global coordinate, unless specified otherwise.
- Imaging-system properties such as stop location, entrance and exit pupil, field, system aperture etc. that exist in sequential systems may not be meaningful in non-sequential systems.
- The main analysis feature in non-sequential mode is the detector ray-trace, which gives spatial and angular data on incoherent or coherent rays.

Comparison / Application

Sequential Mode

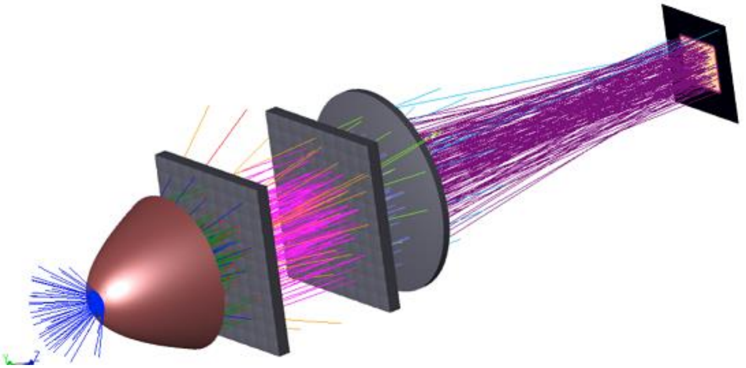
+ Rays must hit
- every surface
- one time
- in the same order



+ Imaging optics
+ Afocal systems

Non-Squentail Mode

+ Rays can hit
- any object
- an number of times ($n \geq 0$)
- in any order



+ Solar Cells
+ Car lamps
+ Monochromator / Spectrometer
+ Illumination Systems

Ray Tracing in Non-Squentail Mode

In Non-squentail mode Zemax uses **Monte Carlo Ray Tracing**.

MC Method

select random rays from any source in the simlation. $\text{Error} \propto \frac{1}{\sqrt{\text{number of rays}}}$

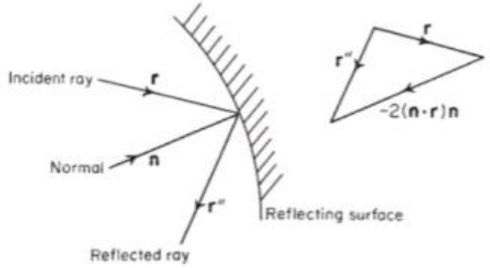
use geometrical optics (vector based calculations for reflection, refraction, polarization)

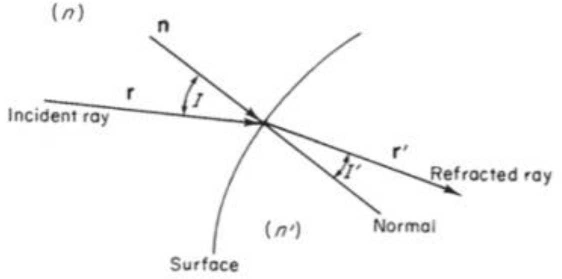
$$n' \sin I' = n \sin I$$

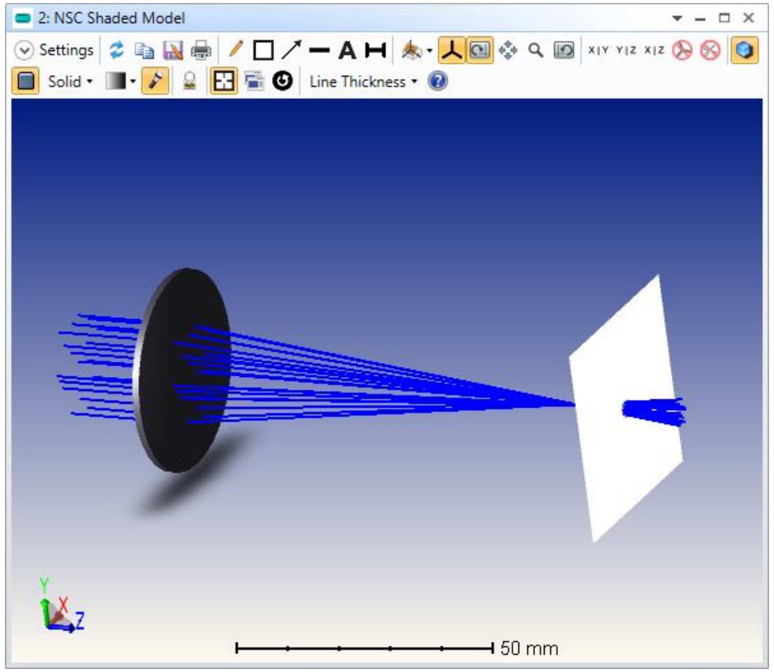
$$n'\mathbf{r}' \times \mathbf{n} = n\mathbf{r} \times \mathbf{n}$$

$$\mathbf{r}'' = \mathbf{r} - 2(\mathbf{n} \cdot \mathbf{r})\mathbf{n}$$

$$n'\mathbf{r}' = n\mathbf{r} + (\overbrace{n'\mathbf{r}' \cdot \mathbf{n} - n\mathbf{r} \cdot \mathbf{n}}^{n' \cos I' - n \cos I})\mathbf{n}$$







Example 1: How to add standart lens

	Object Type	Comment	Ref Object	Inside Of	X Position	Y Position	Z Position	Tilt About X	Tilt About Y	Tilt About Z	Material	X Half Width	Y Half Width	# X Pixels	# Y Pixels	Data Type	Color
1	Source Ellipse ▾		0	0	0.000	0.000	0.000	0.000	0.000	0.000	-	20	1E+05	1.000	0	0	12.000
2	Standard Lens ▾		0	0	0.000	0.000	20.000	0.000	0.000	0.000	BK7	100.000	0.000	20.000	20.000	6.000	-80.000
3	Detector Rectangle ▾		0	0	0.000	0.000	120.000 V	0.000	0.000	0.000		20.000	20.000	100	100	0	3

```
*** Object1
Source Ellipse
# of Layout Rays    20
# of Analysis Rays  1e5
X Half Width        12
Y Half Width        12
*** Object2
Standart Lens
Z position          20
Material            BK7
Radius1             100
Thickness           6
Clear1 = Edge1      20
Radius2            -80
Clear2 = Edge2      20
```

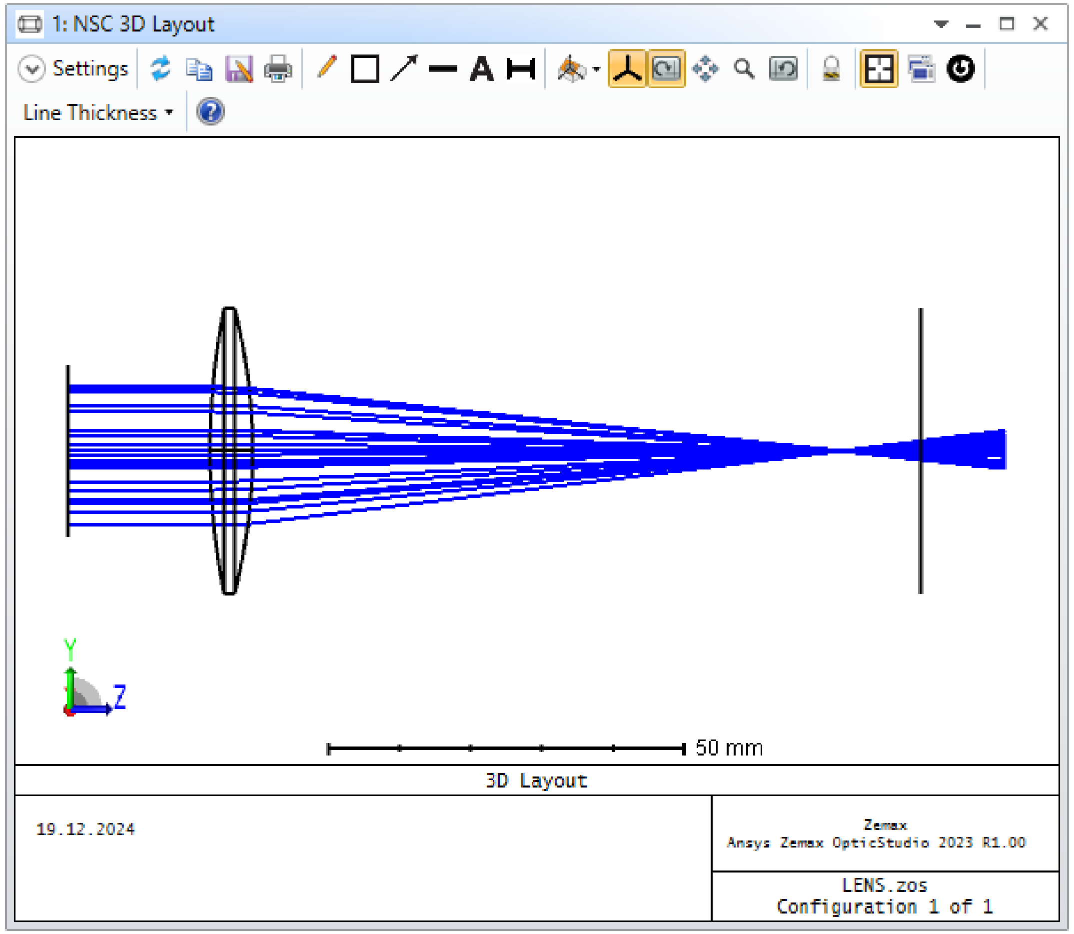
```
*** Object3
Detector        Rect
Z position      120
Material        Blank
X Half Width    20
Y Half Width    20
# X Pixels      200
# Y Pixels      200
Color           3
```

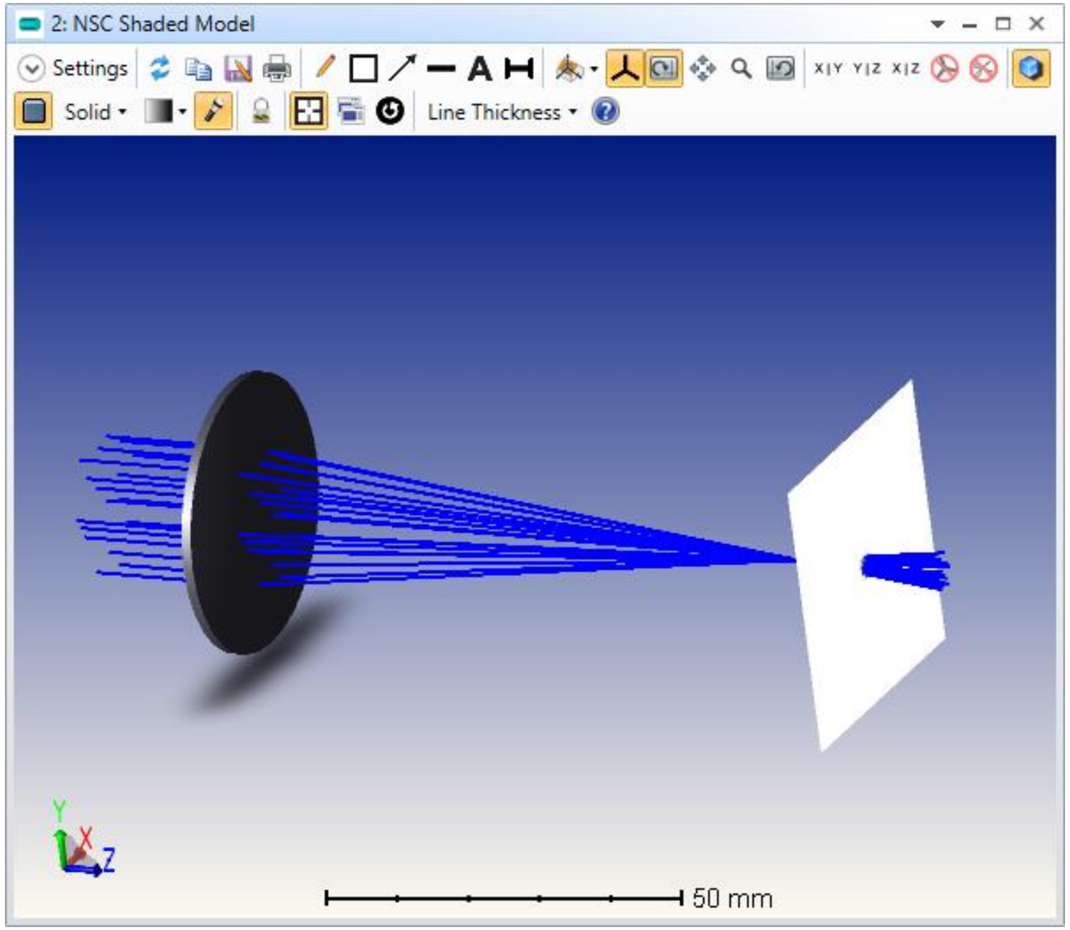
Material Blank (or can be ABSORB or MIRROR)

Color 3 (detector displays false color)

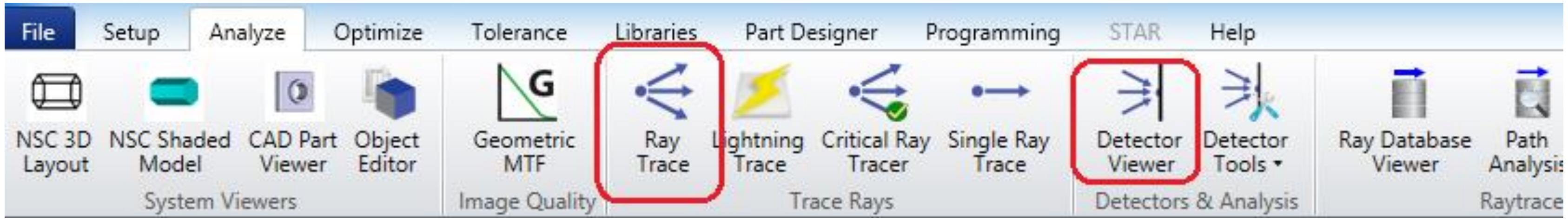
Example 1: Layout

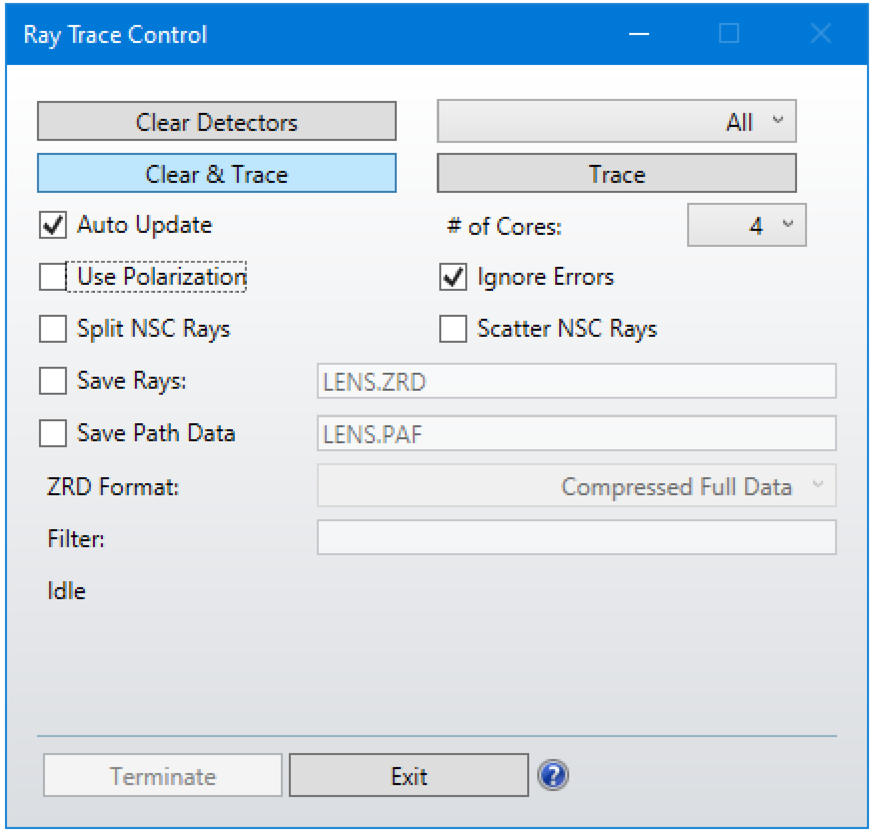
	Object Type	Comment	Ref Object	Inside Of	X Position	Y Position	Z Position	Tilt About X	Tilt About Y	Tilt About Z	Material	X Half Width	Y Half Width	# X Pixels	# Y Pixels	Data Type	Color
1	Source Ellipse ▾		0	0	0.000	0.000	0.000	0.000	0.000	0.000	-	20	1E+05	1.000	0	0	12.000
2	Standard Lens ▾		0	0	0.000	0.000	20.000	0.000	0.000	0.000	BK7	100.000	0.000	20.000	20.000	6.000	-80.000
3	Detector Rectangle ▾		0	0	0.000	0.000	120.000 V	0.000	0.000	0.000		20.000	20.000	100	100	0	3

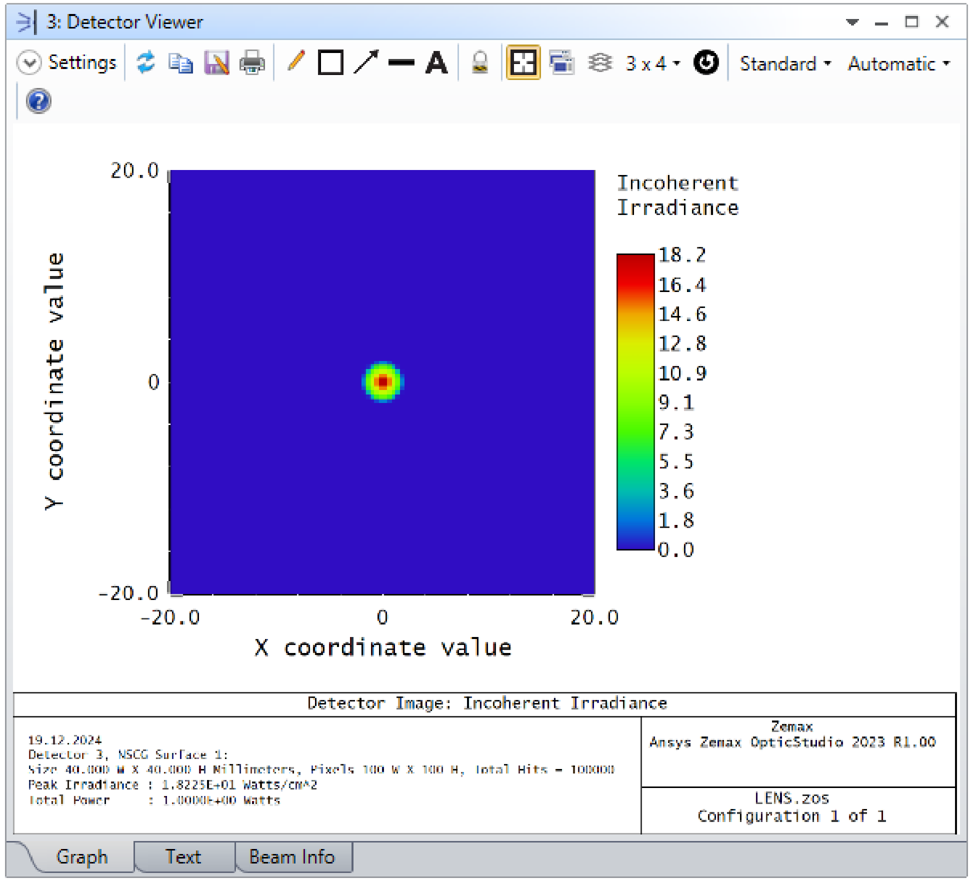




Example 1: Ray Tracing







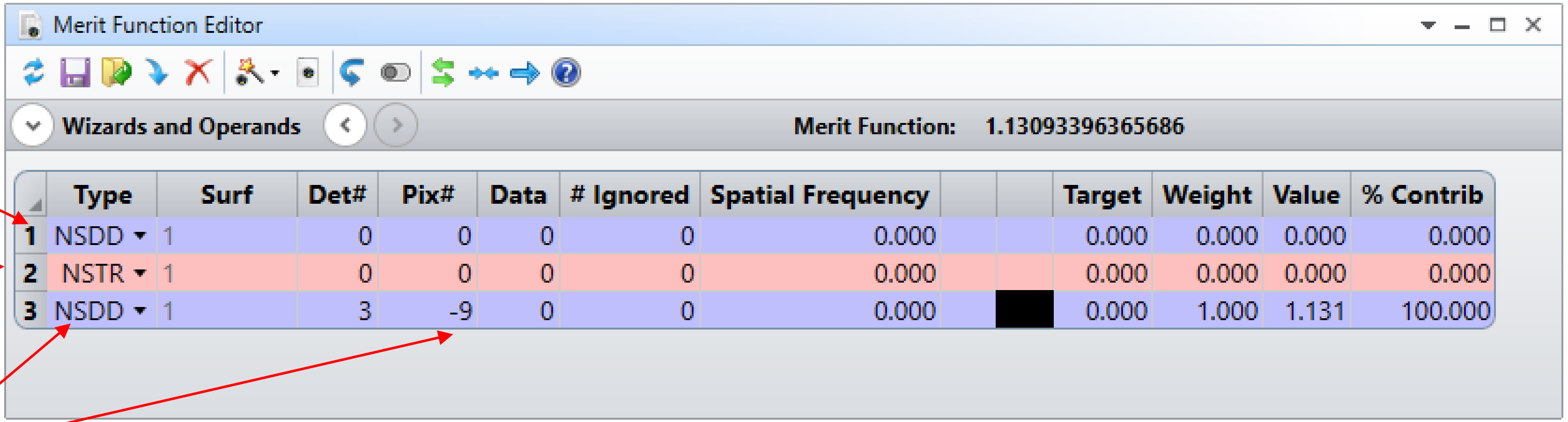
Example 1: Optimization

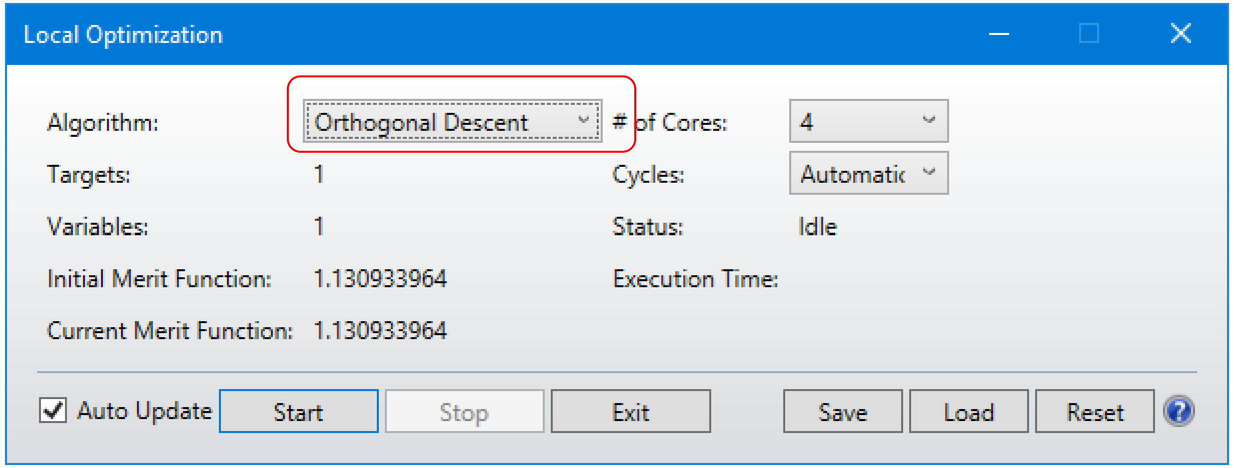
The aim is to put detector at a location where we have minimum rms spot size

Clear detector

Start ray tracing

Obtain minimum spot size

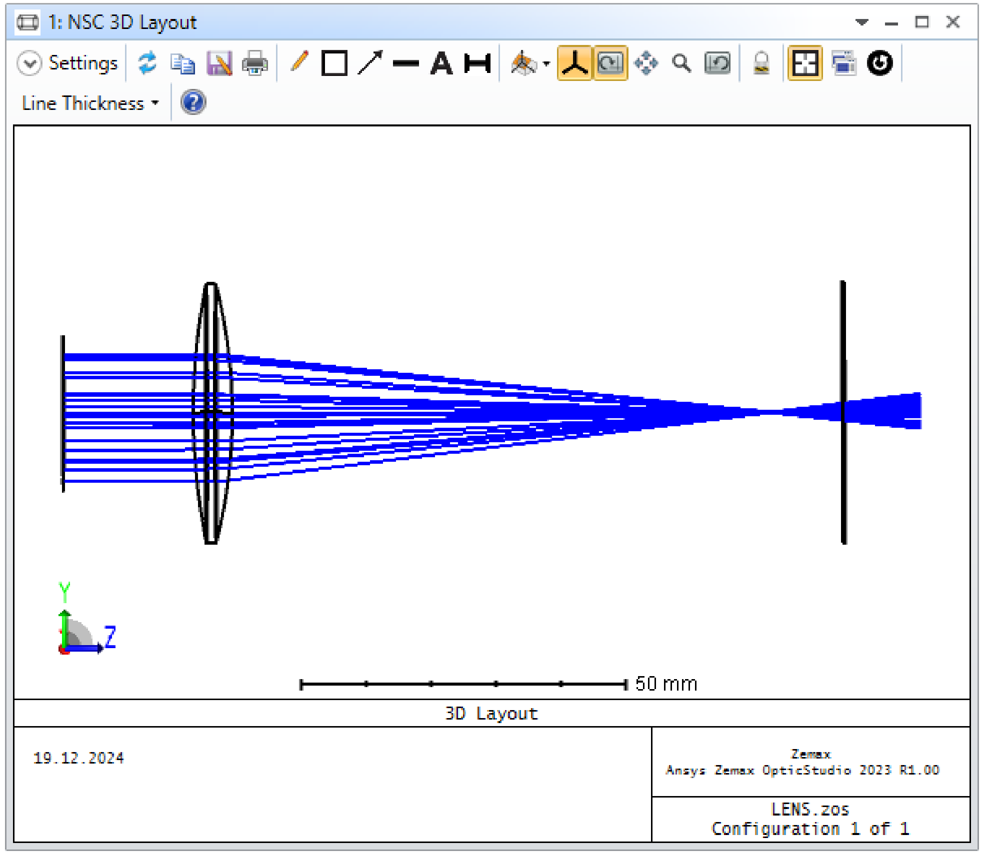




Example 1: Results

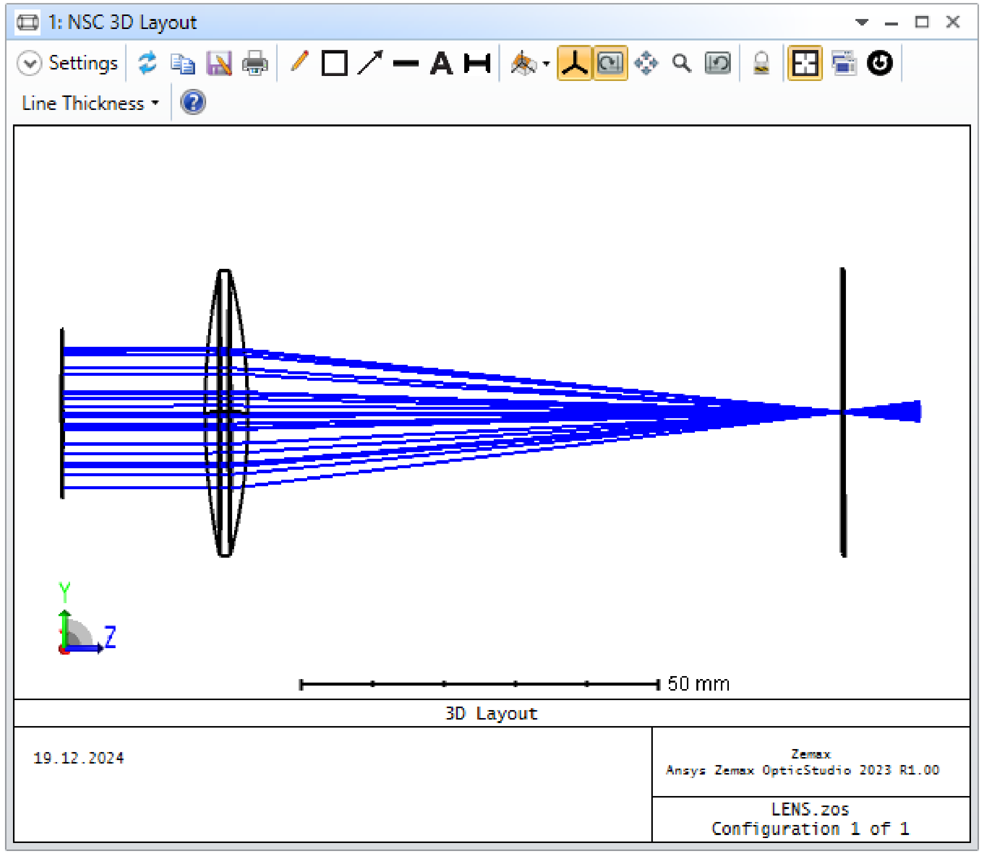
Z Position of detector = 120 mm

Before optimization



Z Position of detector = 108. 7 mm

After optimization

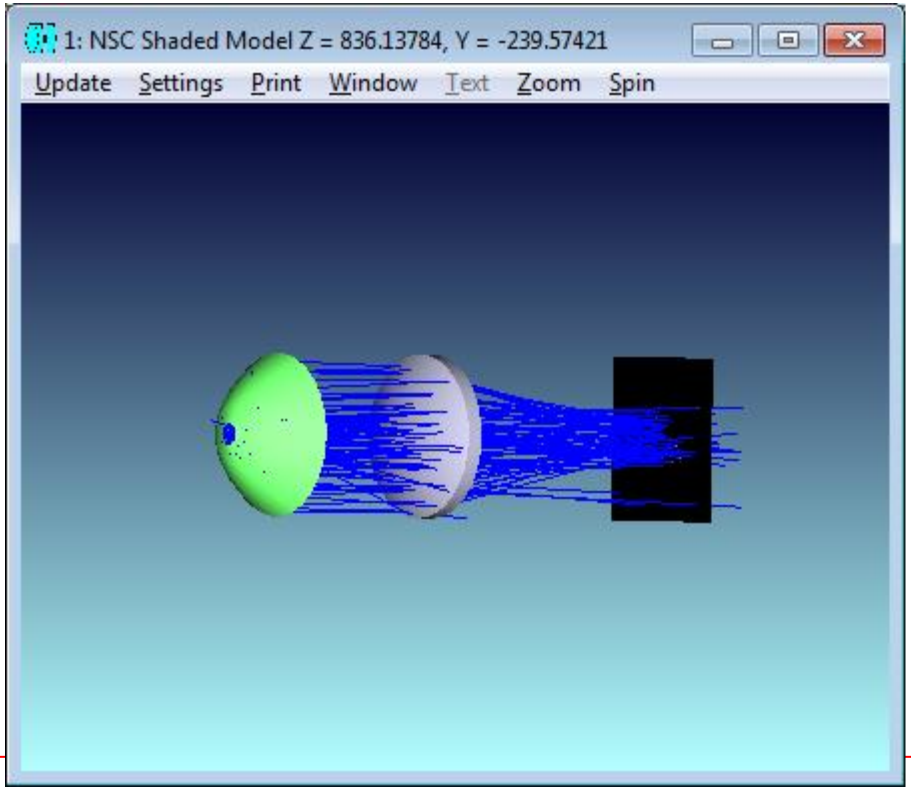


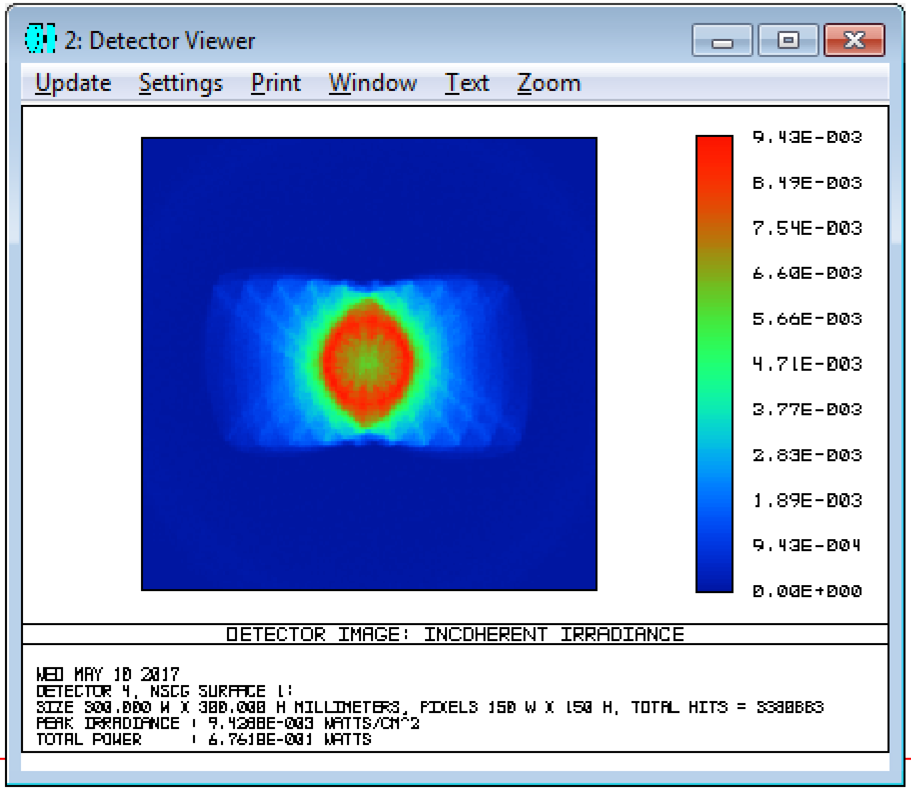
Example 2: Mirror-Lens-Detector

We will make a non-sequential system with

- a filament source
- a parabolic reflector
- a plano-convex lens
- a rectangular detector

as shown in the layout below:





***** Object1**

```
Standart Surface
Material          Mirror
Radius            100
Conic             -1 (parabola)
Max Aper          150
Min Aper          20 (center hole in the reflector)
```

***** Object2**

```
Source Filament
Z position        50 (focus of the parabolic reflector)
# Layout Rays     20
# Analysis Rays   5e6
Length            20
Radius            5
Turns             10
Tilt about Y      90 (deg)
X position       -10 (mm)
```

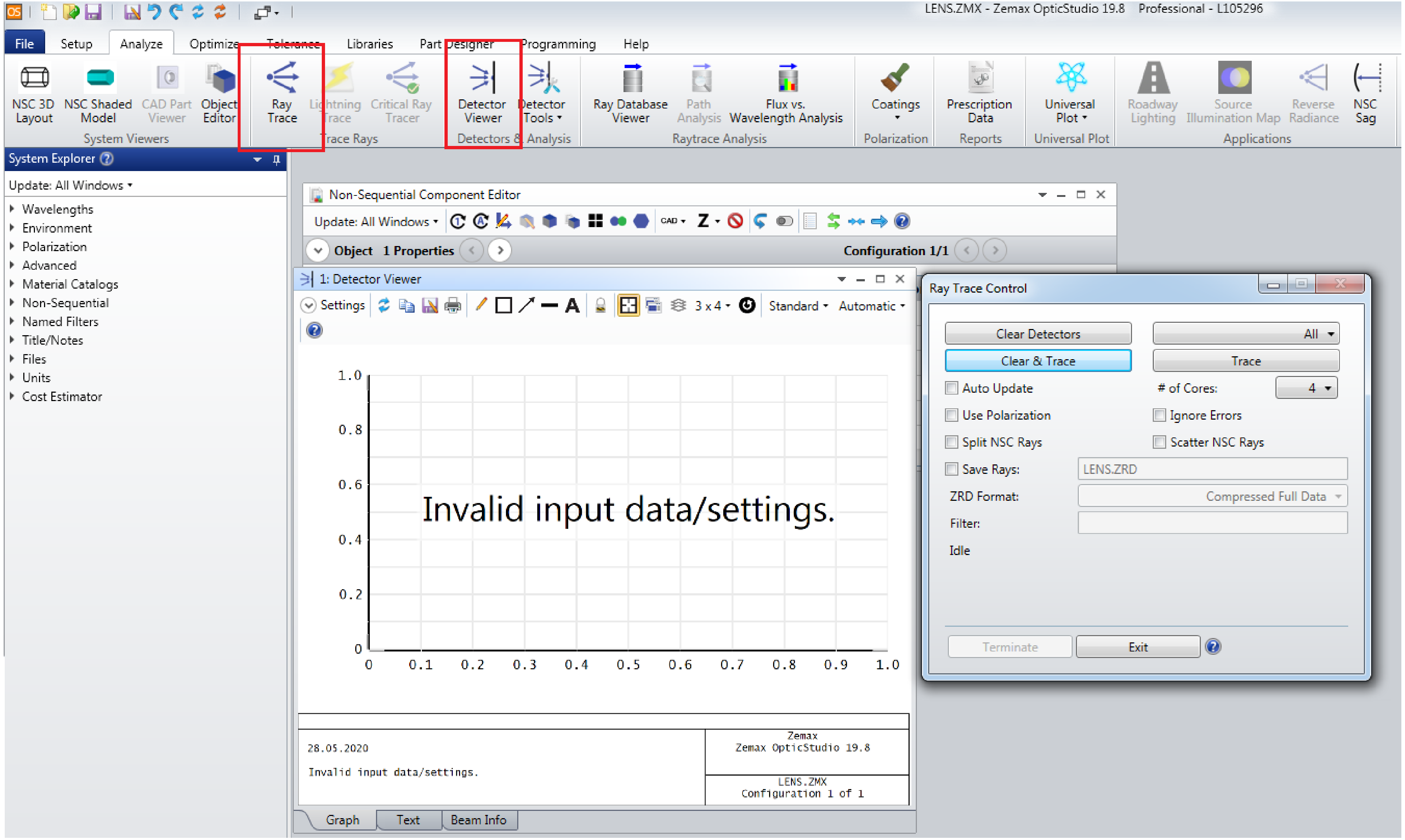
***** Object4**

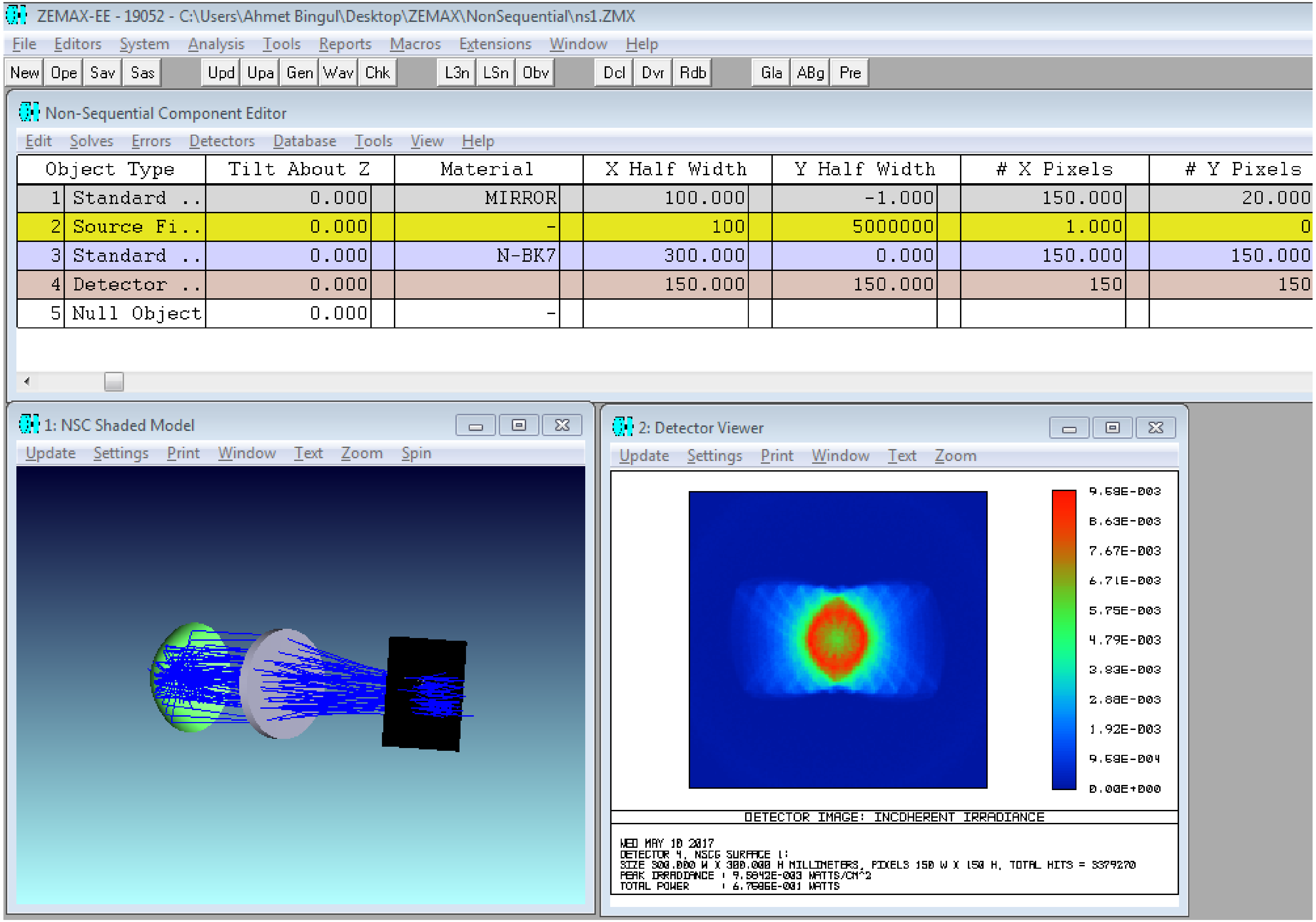
Standard Lens	
Ref Object	3 (before detector)
Z Position	200
Material	N-BK7
Radius 1	300
Clear 1	150
Edge 1	150
Thickness	70
Clear 2	150
Edge 2	150

***** Object5**

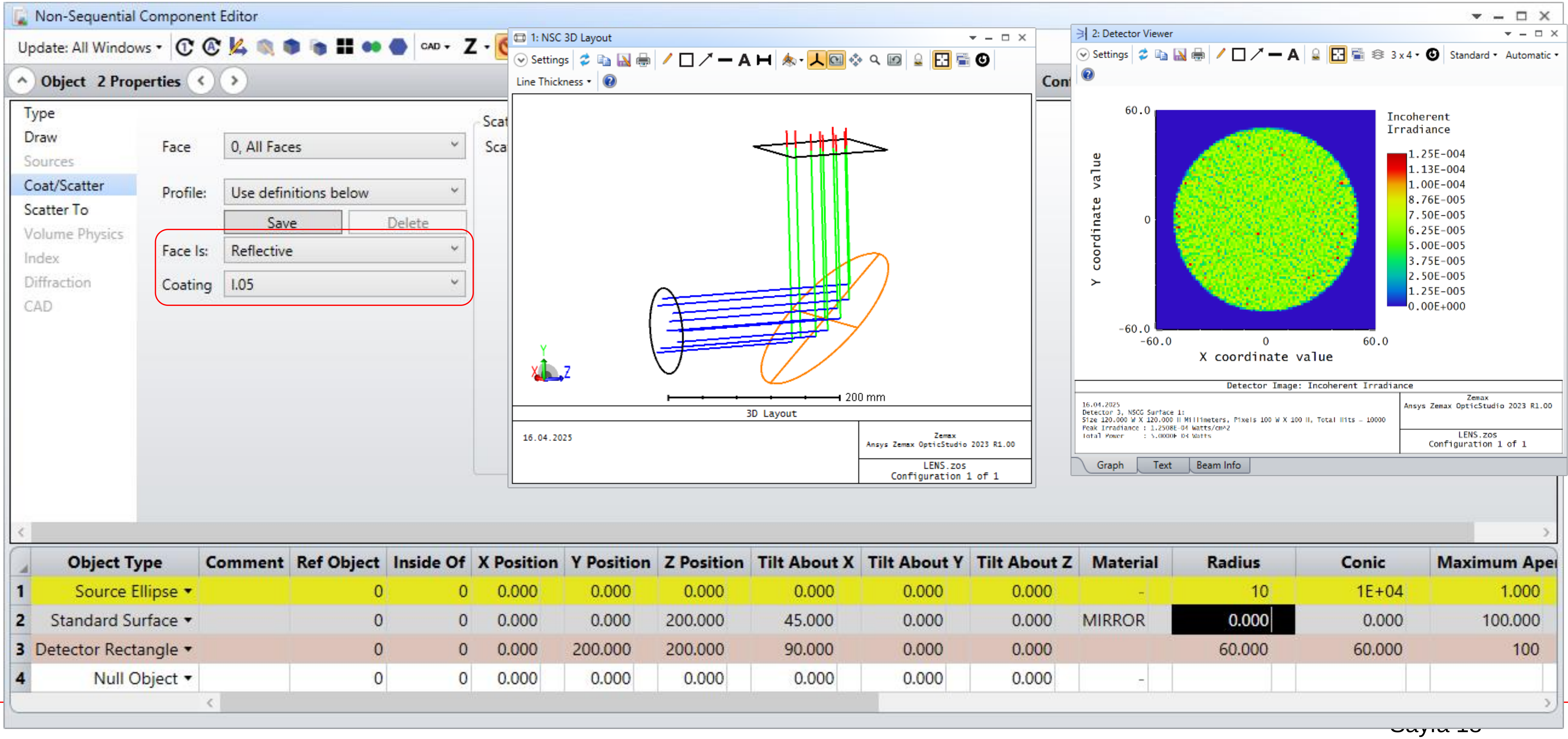
Detector	Rect
Z position	1000
Material	Blank (or can be ABSORB or MIRROR)
X Half Width	150
Y Half Width	150
# X Pixels	150
# Y Pixels	150
Color	1 (detector displays inverse greyscale)

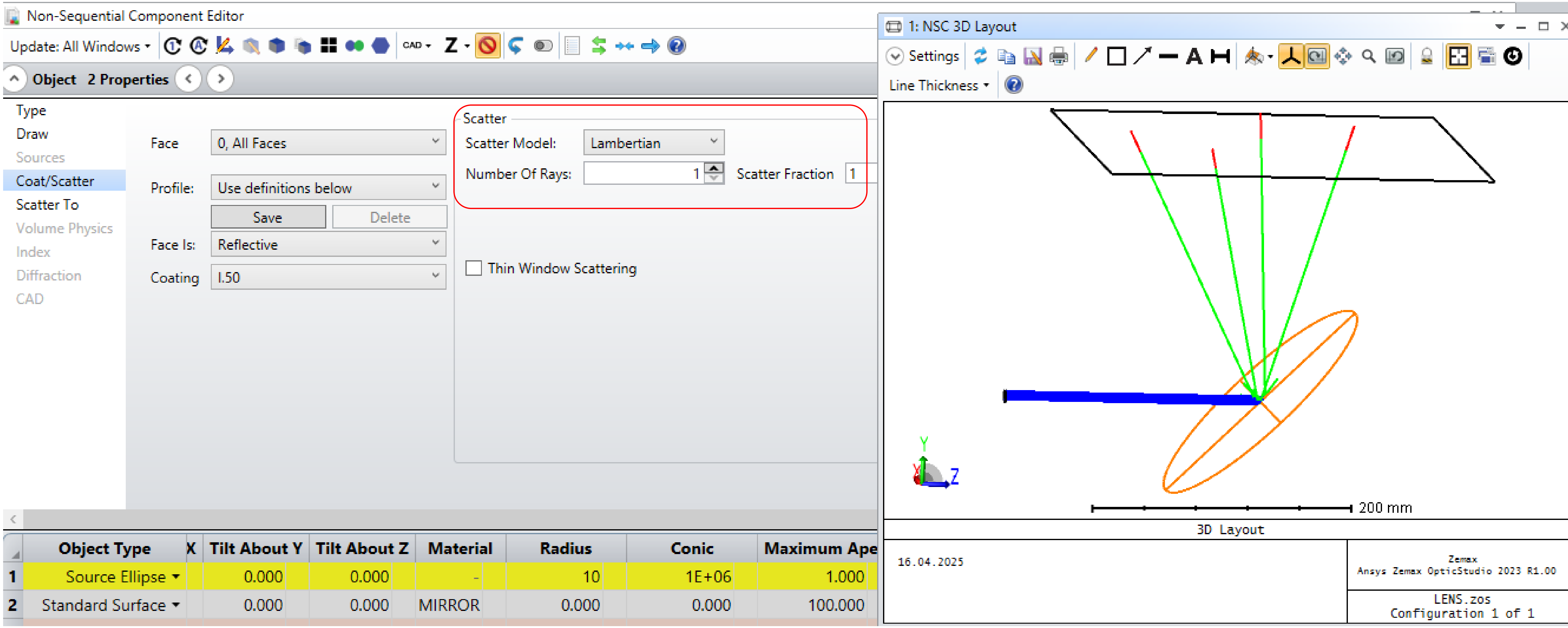
In the analysis you should use **Detector Viewer** and **Ray Trace** buttons.




ZEMAX-EE - 19052 - C:\Users\Ahmet Bingul\Desktop\ZEMAX\NonSequential\ns1.ZMX
File Editors System Analysis Tools Reports Macros Extensions Window Help
New Ope Sav Sas Upd Upa Gen Wav Chk L3n LSn Obv Dcl Dvr Rdb Gla ABg Pre
Non-Sequential Component Editor
Edit Solves Errors Detectors Database Tools View Help
Object Type | Tilt About Z | Material | X Half Width | Y Half Width | # X Pixels | # Y Pixels
1 Standard .. | 0.000 | MIRROR | 100.000 | -1.000 | 150.000 | 20.000
2 Source Fi.. | 0.000 | - | 100 | 5000000 | 1.000 | 0
3 Standard .. | 0.000 | N-BK7 | 300.000 | 0.000 | 150.000 | 150.000
4 Detector .. | 0.000 | | 150.000 | 150.000 | 150 | 150
5 Null Object | 0.000 | - | | | |
1: NSC Shaded Model
Update Settings Print Window Text Zoom Spin
2: Detector Viewer
Update Settings Print Window Text Zoom
9.59E-003
8.63E-003
7.67E-003
6.71E-003
5.75E-003
4.79E-003
3.83E-003
2.88E-003
1.92E-003
9.59E-004
0.00E+000
DETECTOR IMAGE: INCOHERENT IRRADIANCE
WED MAY 10 2017
DETECTOR 4, NSCG SURFACE 1:
SIZE 300.000 W X 300.000 H MILLIMETERS, PIXELS 150 W X 150 H, TOTAL HITS = 5379270
PEAK IRRADIANCE : 9.5842E-003 WATTS/CM^2
TOTAL POWER : 6.7986E-001 WATTS

Example 3: Effect of Coating/Scatering on Mirror Surface




Non-Sequential Component Editor
Update: All Windows
Object 2 Properties
Type
Draw
Sources
Coat/Scatter
Scatter To
Volume Physics
Index
Diffraction
CAD
Face
0, All Faces
Profile:
Use definitions below
Save
Delete
Face Is:
Reflective
Coating
I.50
Scatter
Scatter Model:
Lambertian
Number Of Rays:
1
Scatter Fraction
1
Thin Window Scattering
Object Type
X
Tilt About Y
Tilt About Z
Material
Radius
Conic
Maximum Ape
1 Source Ellipse 0.000 0.000 - 10 1E+06 1.000
2 Standard Surface 0.000 0.000 MIRROR 0.000 0.000 100.000
1: NSC 3D Layout
Settings
Line Thickness
Y
Z
200 mm
3D Layout
16.04.2025
Zemax
Ansys Zemax OpticStudio 2023 R1.00
LENS.zos
Configuration 1 of 1

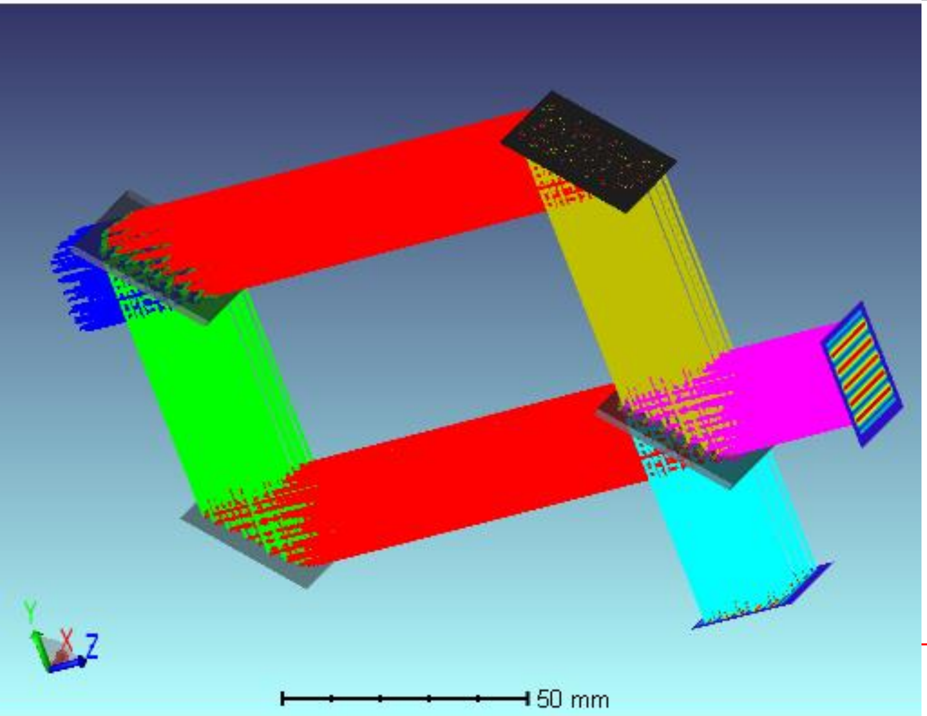
Example 4: Interferometer (See Zemax Sample Folder)

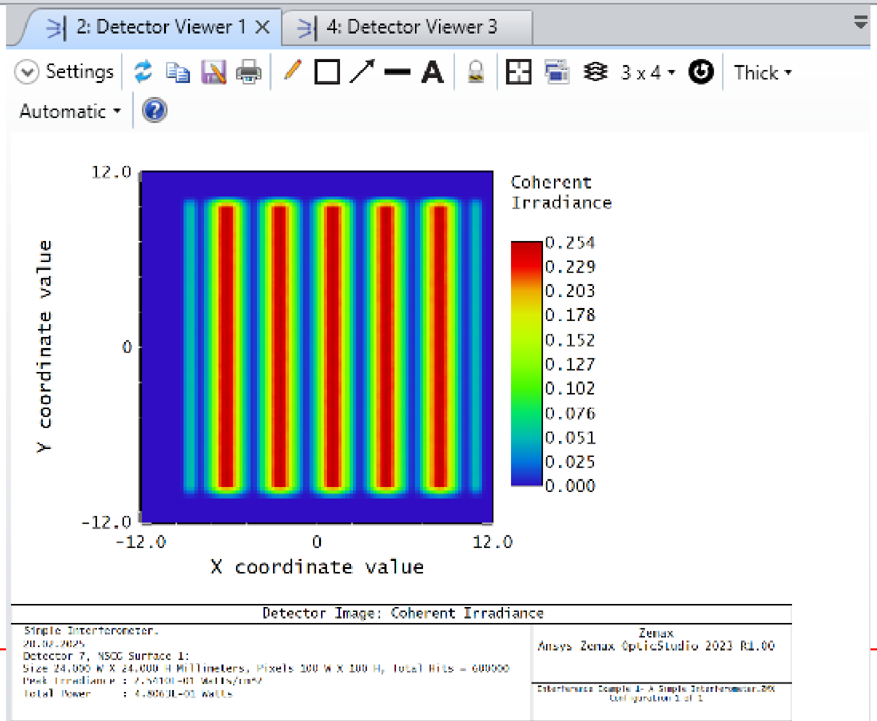
Non-Sequential Component Editor

Update: All Windows

Object 7 Properties | Configuration 1/1

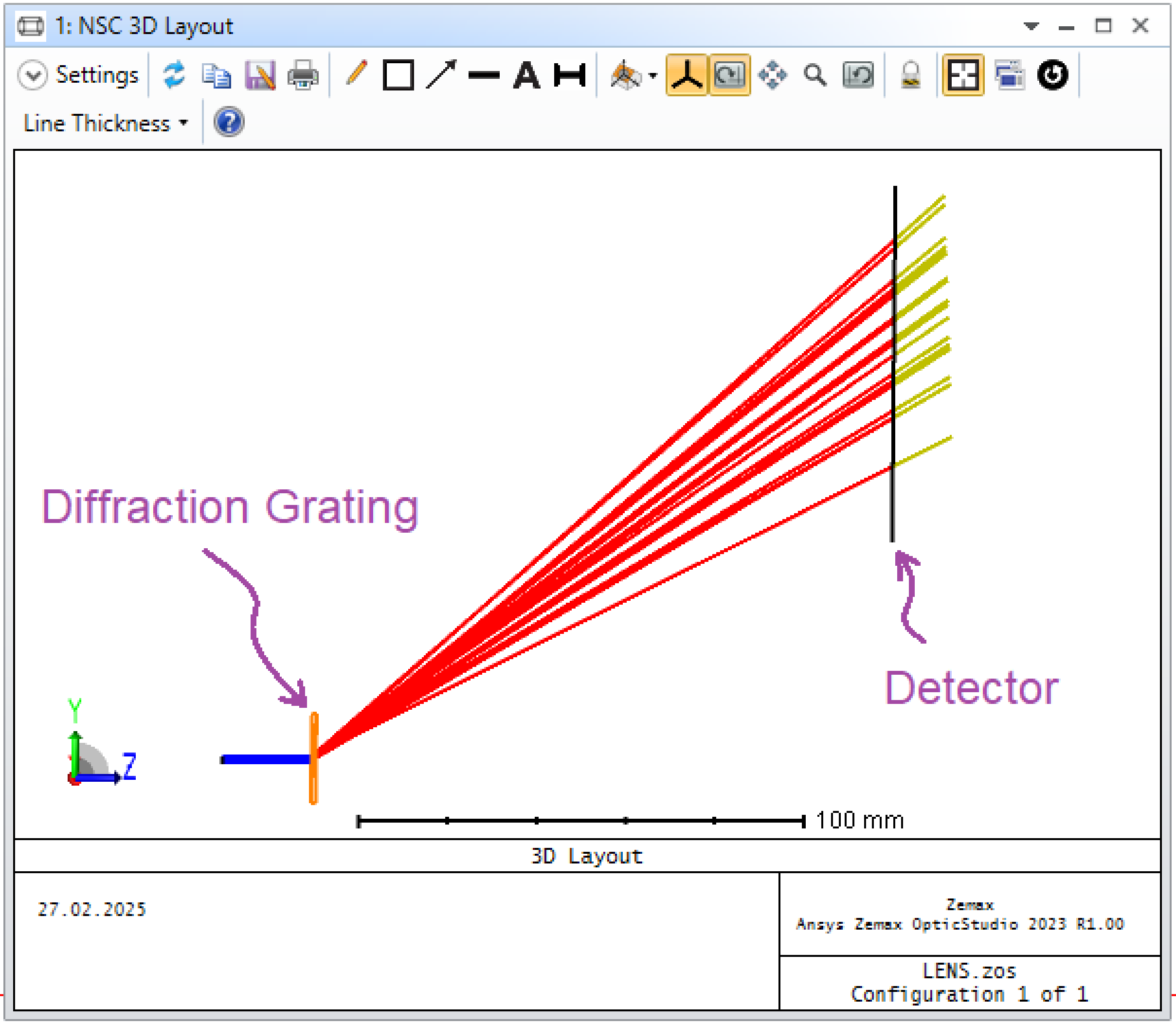
	Object Type	Comment	Ref	Ins	X Position	Y Position	Z Position	Tilt About X	Tilt About Y	Tilt About Z	Material	X Half Width	Y Half Width	# X Pixels	# Y Pixels
1	Source Rectangle		0	0	0.000	0.000	0.000	0.000	0.000	0.000	-	100	3E+05	1.000	0
2	Polygon Object	SPLITTER.POB	0	0	0.000	0.000	20.000	-45.000	0.000	0.000	BK7	16.000	1		
3	Rectangle		0	0	0.000	-60.000	20.000	-45.005	0.000	0.000	MIRROR	15.000	15.000		
4	Rectangle		0	0	0.000	0.000	120.000	-45.000	0.000	0.000	MIRROR	15.000	15.000		
5	Polygon Object	SPLITTER.POB	0	0	0.000	-60.000	120.000	-225.000	0.000	0.000	BK7	16.000	1		
6	Detector Rectangle		0	0	0.000	-60.000	160.000	0.000	0.000	-90.000	ABSORB	12.000	12.000	100	100
7	Detector Rectangle		0	0	0.000	-100.000	120.000	90.000	0.000	-90.000	ABSORB	12.000	12.000	100	100

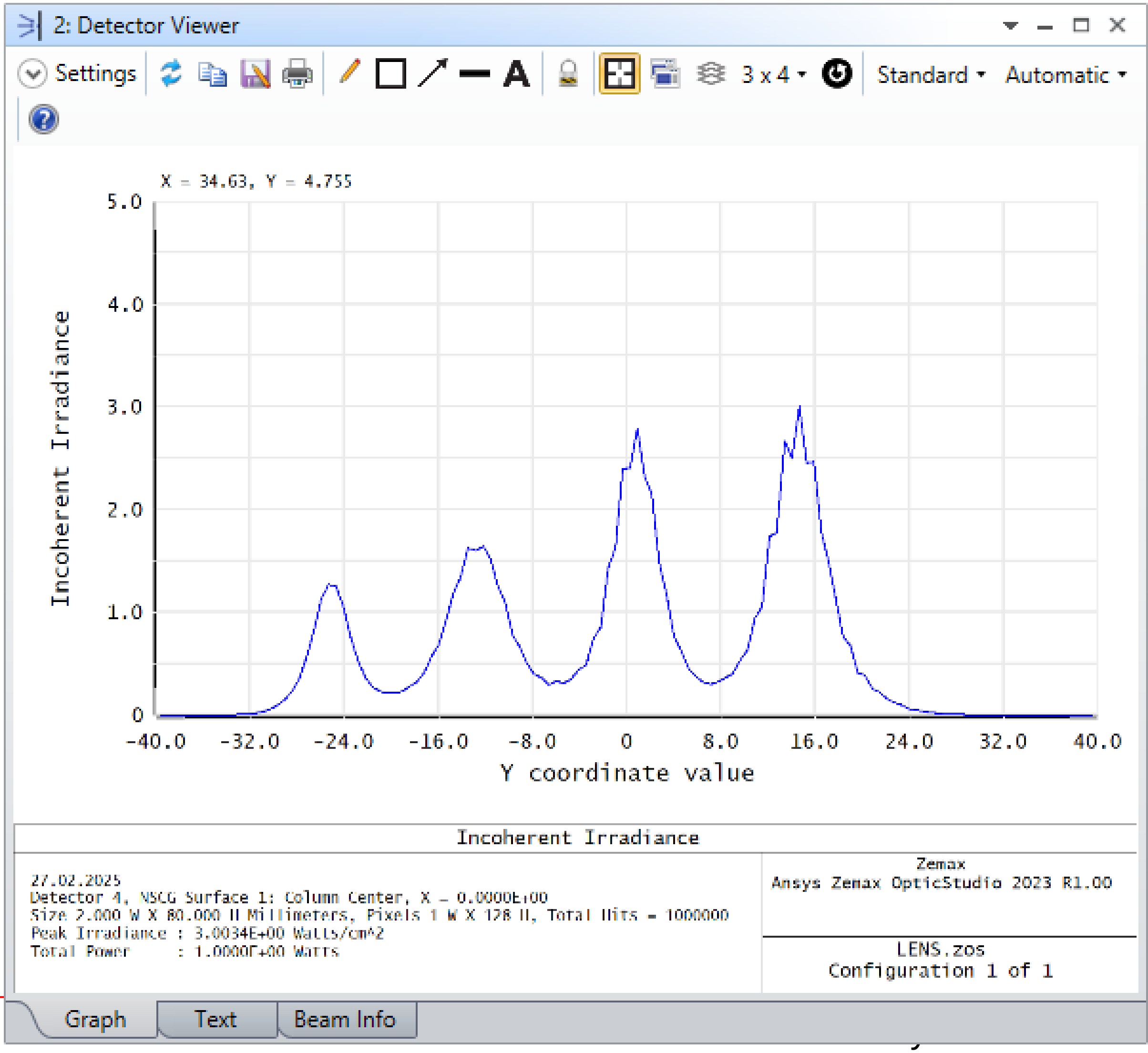




Example 5: Simple Spectrometer

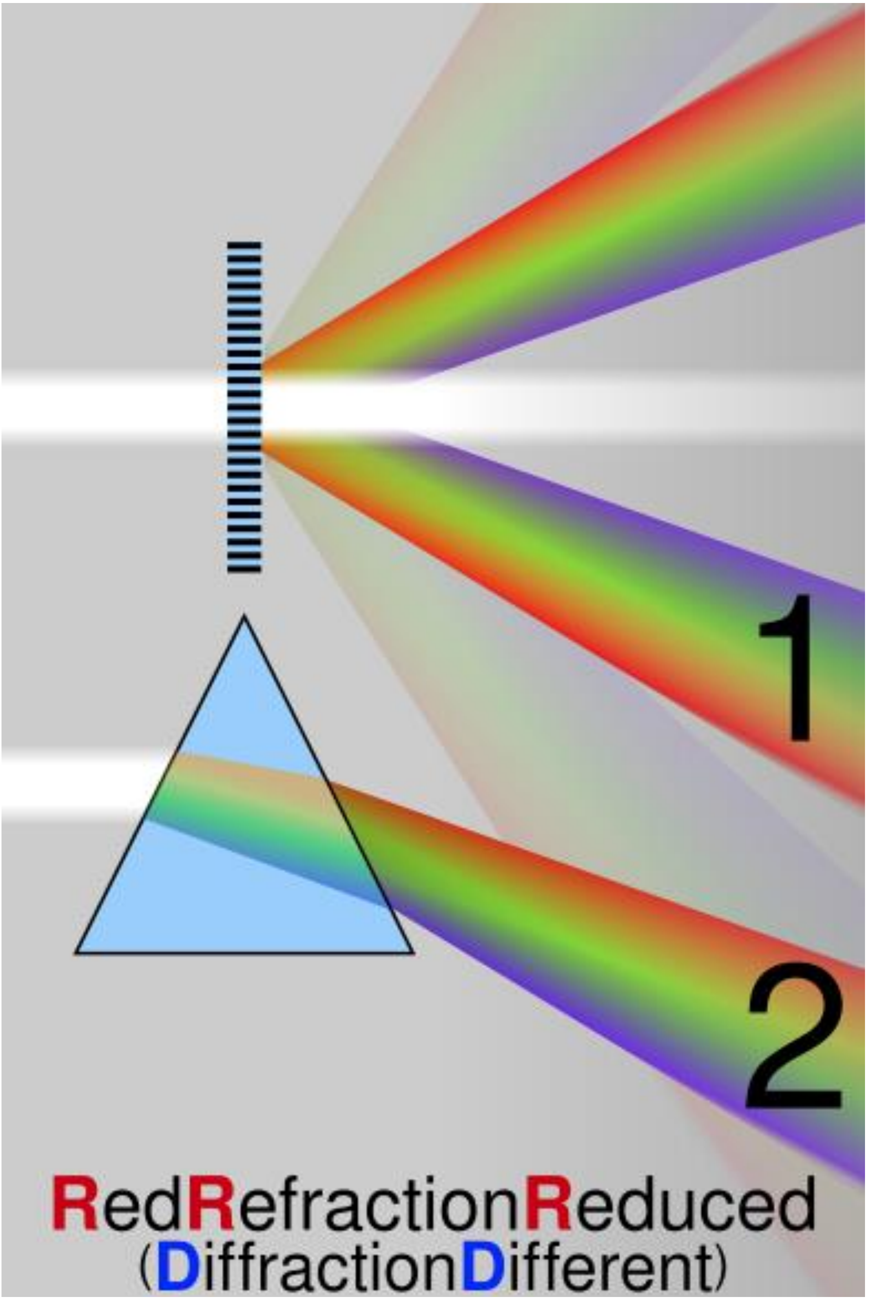
	Object Type	Comment	Ref Object	Inside Of	X Position	Y Position	Z Position	Tilt About X	Tilt About Y	Tilt About Z	Material	Radius 1	Conic 1	Clear 1	Edge 1	Thickness	Radius 2	Conic 2	Clear 2
1	Source Ellipse		0	0	0.000	0.000	0.000	0.000	0.000	0.000	-	10	0	1.000	0	0	1.000	1.000	0.000
2	Source Ellipse		0	0	0.000	0.000	0.000	0.000	0.000	0.000	-	10	1E+06	1.000	0	0	1.000	1.000	0.000
3	Diffraction Grating		0	0	0.000	0.000	20.000	0.000	0.000	0.000	[redacted]	0.000	0.000	10.000	10.000	1.000	0.000	0.000	10.000
4	Detector Rectangle		0	0	0.000	90.000	150.000	0.000	0.000	0.000		1.000	40.000	1	128	0	0	0	0





Comparison of the spectra obtained from a diffraction grating by diffraction (1), and a prism by refraction (2). Longer wavelengths (red) are diffracted more, but refracted less than shorter wavelengths (violet).

https://en.wikipedia.org/wiki/Diffraction_grating



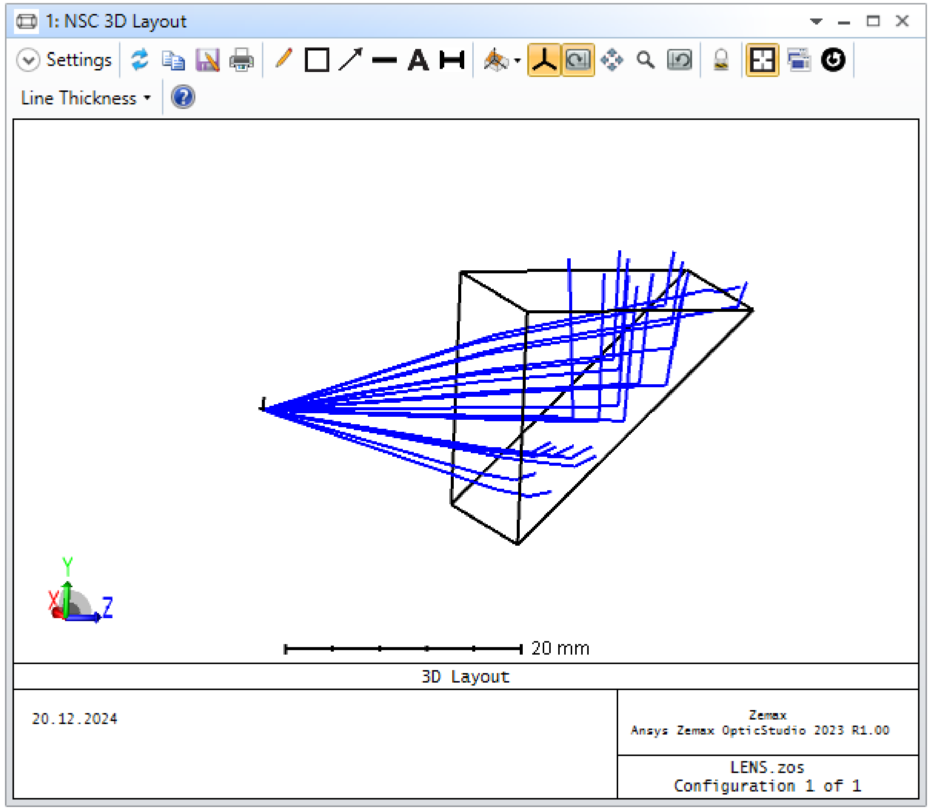
Example 6: Source Point

Non-Sequential Component Editor

Update: All Windows

Object 1 Properties — Configuration 1/1

	Object Type	Comment	Ref Object	Inside Of	X Position	Y Position	Z Position	Tilt About X	Tilt About Y	Tilt About Z	Material	# Layout Rays	# Analysis Rays	Power(Watts)	Wavenumber	Color #	Cone Angle
1	Source Point		0	0	0.000	0.000	0.000	0.000	0.000	0.000	-	20	1E+05	1.000	0	0	20.000
2	Polygon Object	Prism45.POB	0	0	0.000	0.000	20.000	0.000	0.000	0.000	BK7	10.000	1				
3	Null Object		0	0	0.000	0.000	0.000	0.000	0.000	0.000	-						

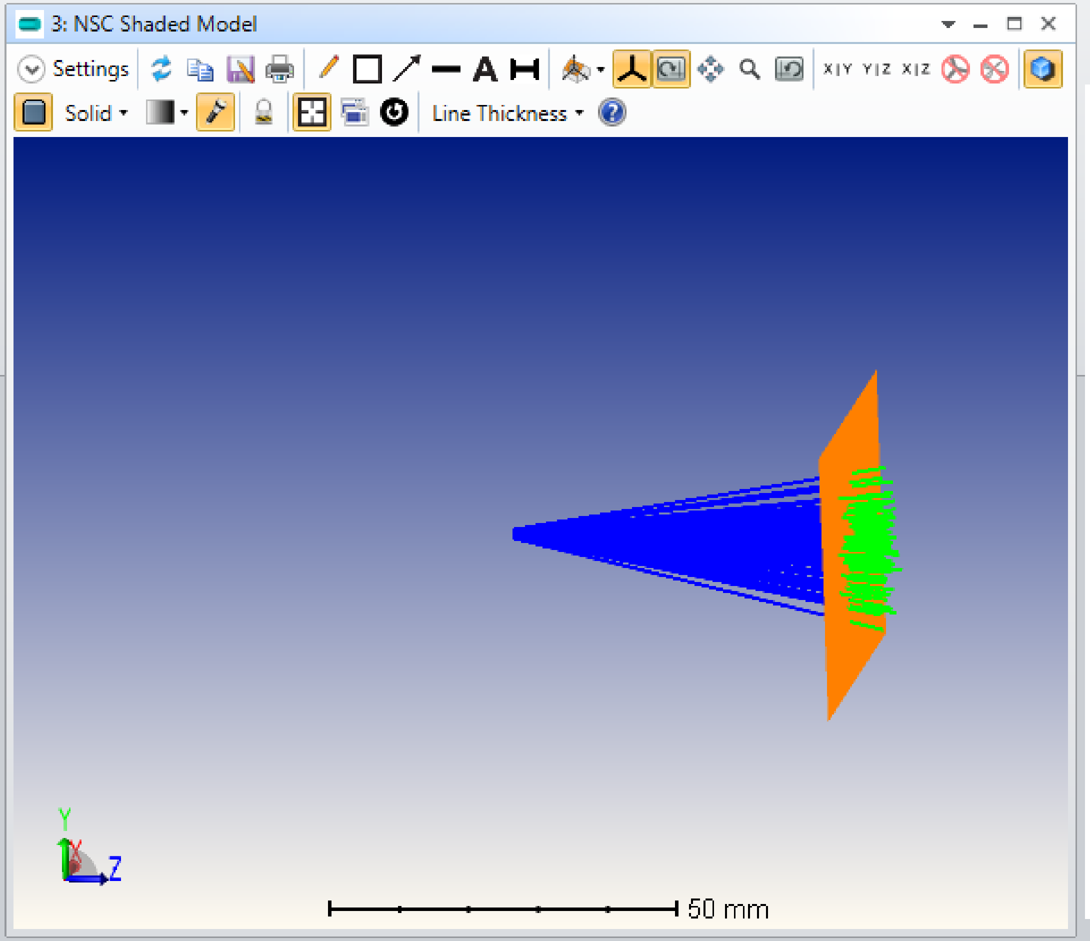


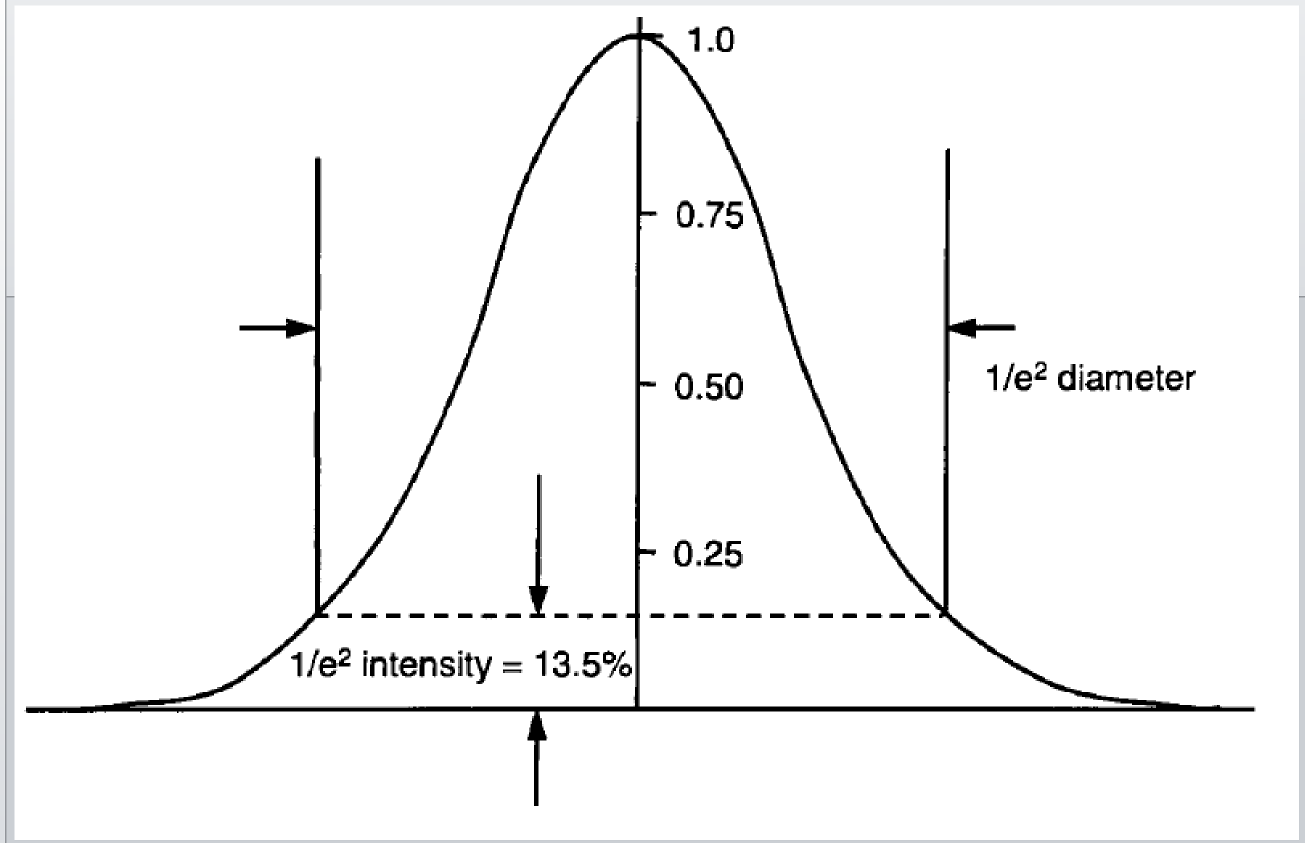
Example 7: Source Gaussian

Non-Sequential Component Editor

Object 2 Properties — Configuration 1/1

	Object Type	Comme	Ref Object	Inside Of	X Position	Y Position	Z Position	Tilt About X	Tilt About Y	Tilt About Z	Material	X Half Width	Y Half Width	# X Pixels	# Y Pixels
1	Source Gaussian		0	0	0.000	0.000	0.000	0.000	0.000	0.000	-	100	1E+05	1.000	0
2	Detector Rectangle		0	0	0.000	0.000	50.000	0.000	0.000	0.000		20.000	20.000	100	100





Source File

- The Source File is a source whose **ray coordinates**, **cosines**, and **intensity** are defined in a user supplied file.
- The file extension may be either DAT or SDF and the file must be placed in the **`<data>\Objects\Sources\Source Files`** folder (see “Folders”).
- The file format may be either **text** or **binary**, both formats are in Help File.

We will see both formats.

Example 8: How to use LED (a binary source file)

LED manufacturers (such as Osram Opto Semiconductors) distribute comprehensive ray-tracing data files to be used in optical simulations such as

eulumdat file,
ray file and
spectrum file.

- In principle, LED is considered as a point source in **eulumdat file** which is used for a quick analysis.
- **The ray file** represents actual spatial and angular distribution of rays originating from the outer surface of LED. Therefore, ray files can be used in more realistic simulations.
- The spectral distribution of LED (wavelengths emitted and corresponding weights) are stored in **spectrum files**.

Two types (White and IR) of LED provided by Osram Company will be presented.

[If possible, show ray files and eulumdat files]

Examples:

- **LUW H9GP** a white LED having color temperature of 6500 K.
- **SFH 4718A** which is an IR LED whose peak irradiance is at 850 nm

After downloading LED’s simulation files, you should copy and paste files to the related folders:

Put Geometry files (igs or step) in

```
C:\<ZEMAX>\Objects\CAD Files
```

Put Spectrum files must be in

```
C:\<ZEMAX>\Objects\Sources\Spectrum Files
```

Put Ray files in

```
C:\<ZEMAX>\Objects\Sources\Source Files
```

Example 9: Simple LED Collimator

We will use the LED (SFH4718A) placed at (0,0,0), a collimating plano-convex lens and a detector. In the lecture, I will show you both rectangular and polar detectors.

<u>Standard Lens</u>
Z pos = 4 mm (can be variable)
Clear1=Edge1=Clear2=Edge2 = 6 mm
Thickness = 6 mm
Radius2 = -6 mm
Conic2 = 0 mm

<u>Detector</u>
Z pos = 100 mm
X-Y Half Width = 100 mm
X-Y Pixel # = 100

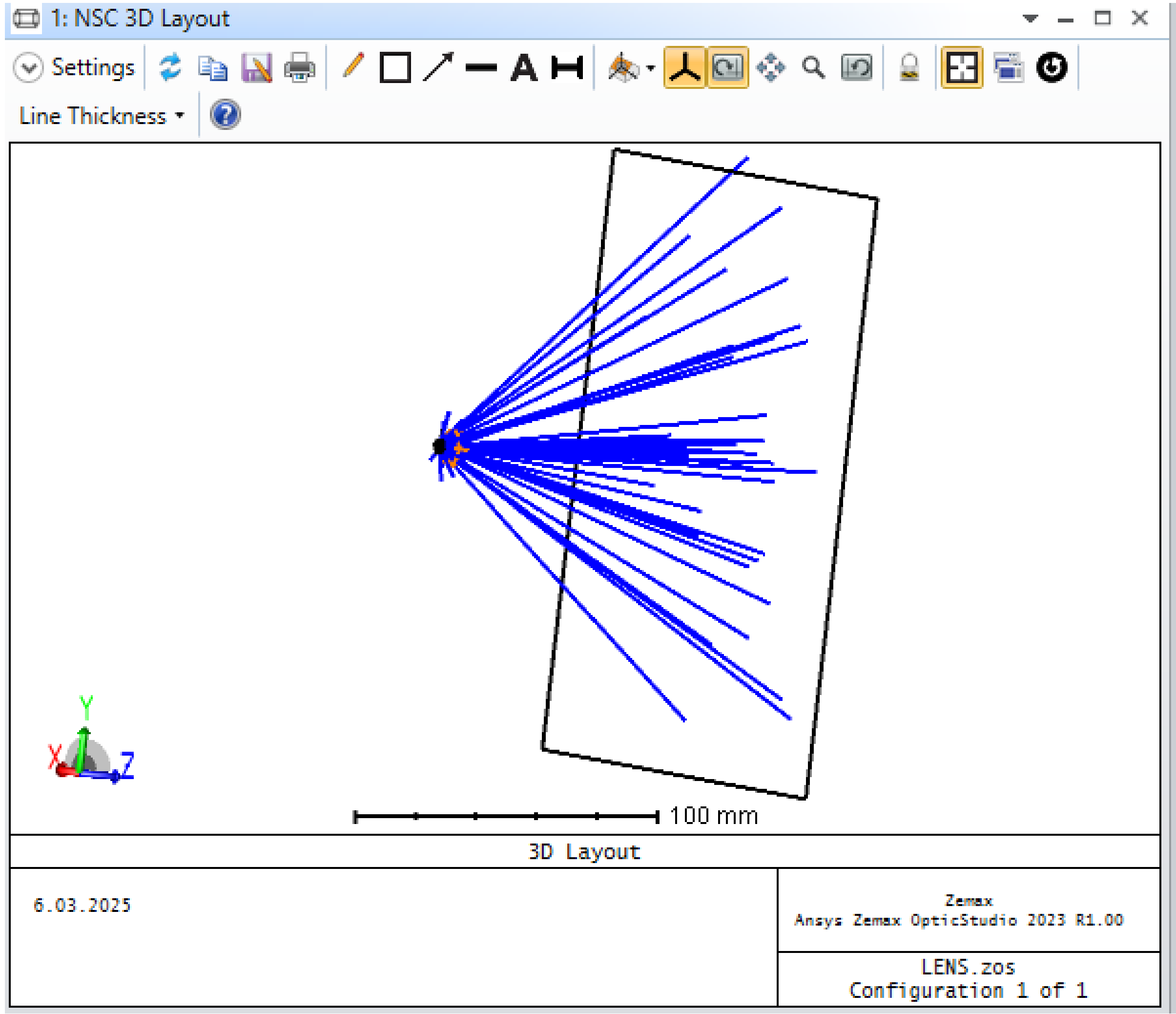
	Object Type	Comment	Ref	Insi	X Position	Y Position	Z Position	Tilt About X	Tilt About Y	Tilt About Z	Material	Radius 1	Conic 1	Clear 1	Edge 1
1	CAD Part: STEP/IGES/SAT	SFH_4718A_20220909_geometry.STEP	0	0	0.000	0.000	0.000	0.000	0.000	0.000		1.000	1	5	5
2	Source File	rayfile_SFH_4718A_100k_20220909_Zemax.DAT	0	0	0.000	0.000	0.000	0.000	0.000	0.000	-	50	1E+05	1.000	0
3	Standard Lens		0	0	0.000	0.000	4.000	0.000	0.000	0.000	PMMA	0.000	0.000	6.000	6.000
4	Detector Rectangle		0	0	0.000	0.000	100.000	0.000	0.000	0.000		100.000	100.000	100	100

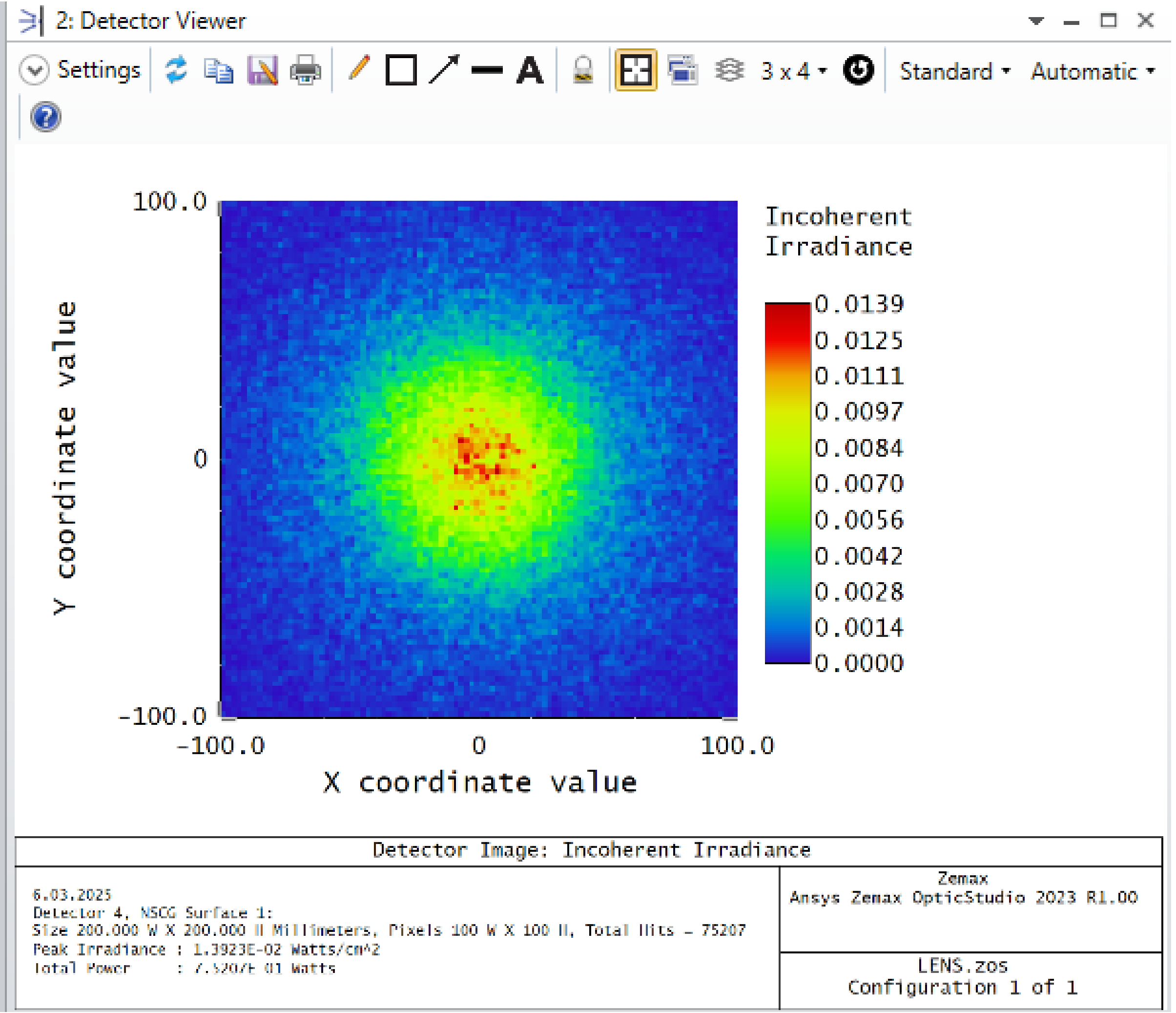
Merit Function Editor

Wizards and Operands Merit Function: 14.3097833683746

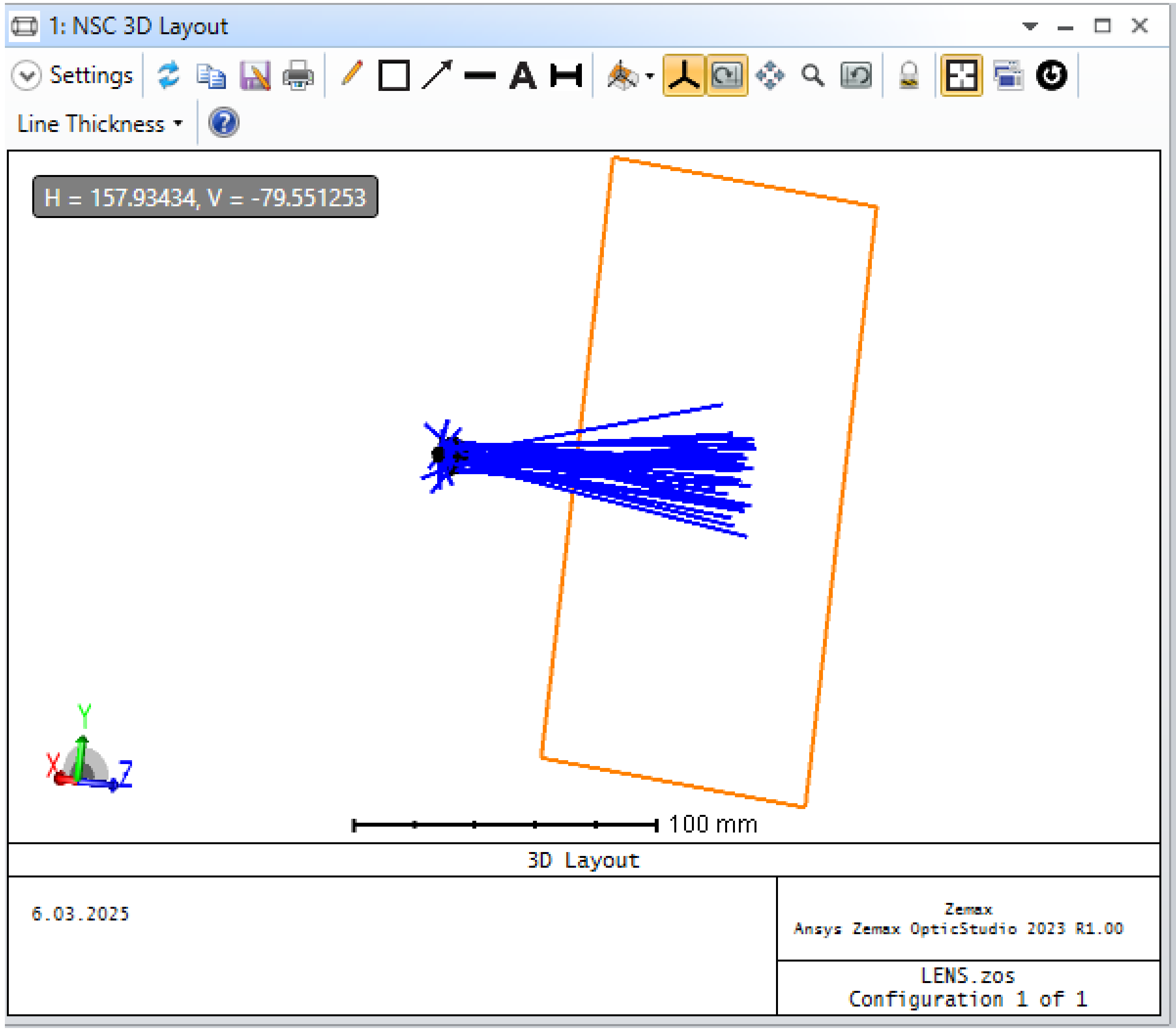
	Type	Surf	Det#	Pix#	Data	# Ignored	Spatial Frequency		Target	Weight	Value	% Contrib
1	NSDD	1	0	0	0	0	0.000		0.000	0.000	0.000	0.000
2	NSTR	1	0	0	0	0	1.000		0.000	0.000	0.000	0.000
3	NSDD	1	4	-9	0	1	0.000		0.000	1.000	14.310	100.000

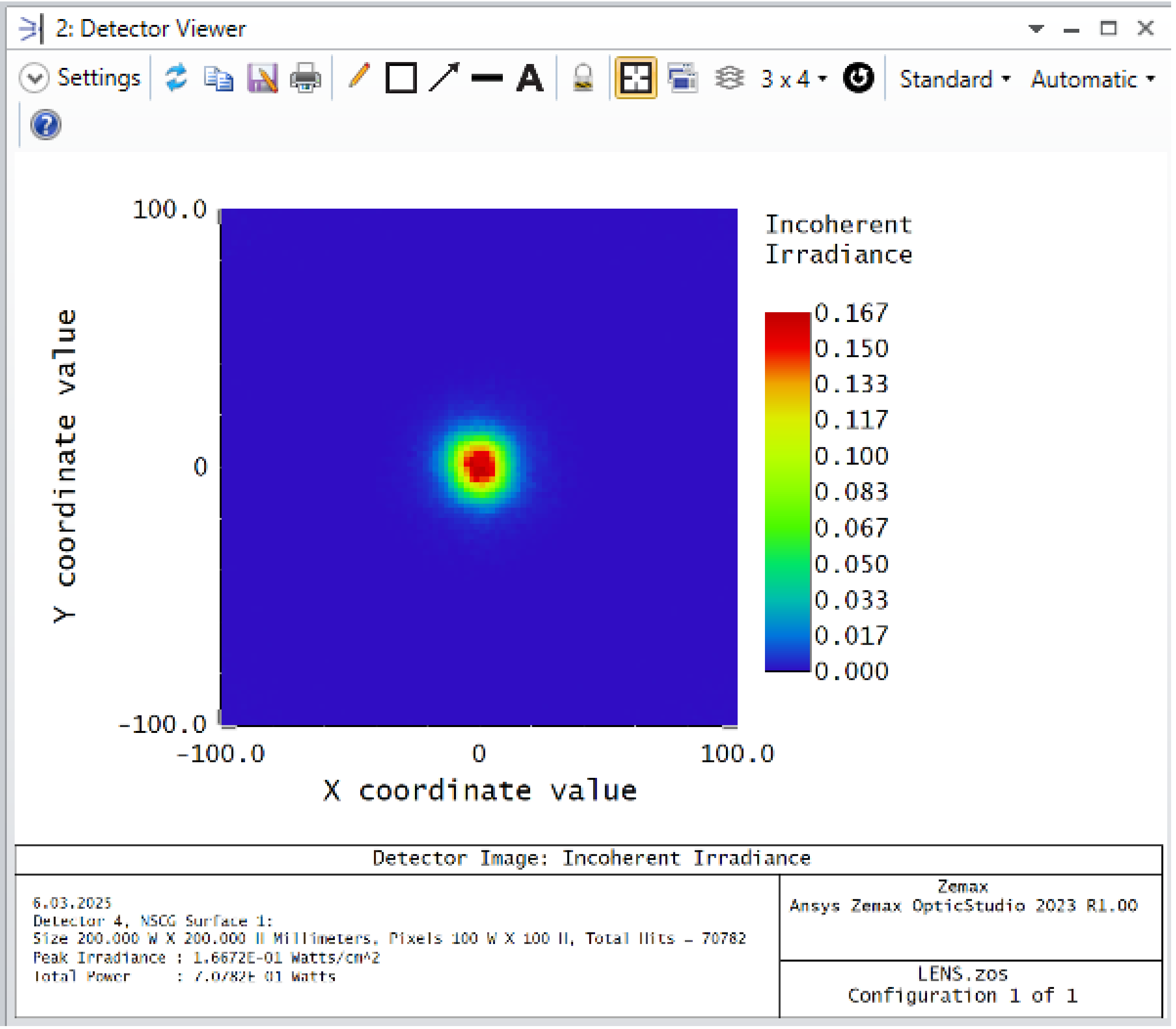
Without collimating lens



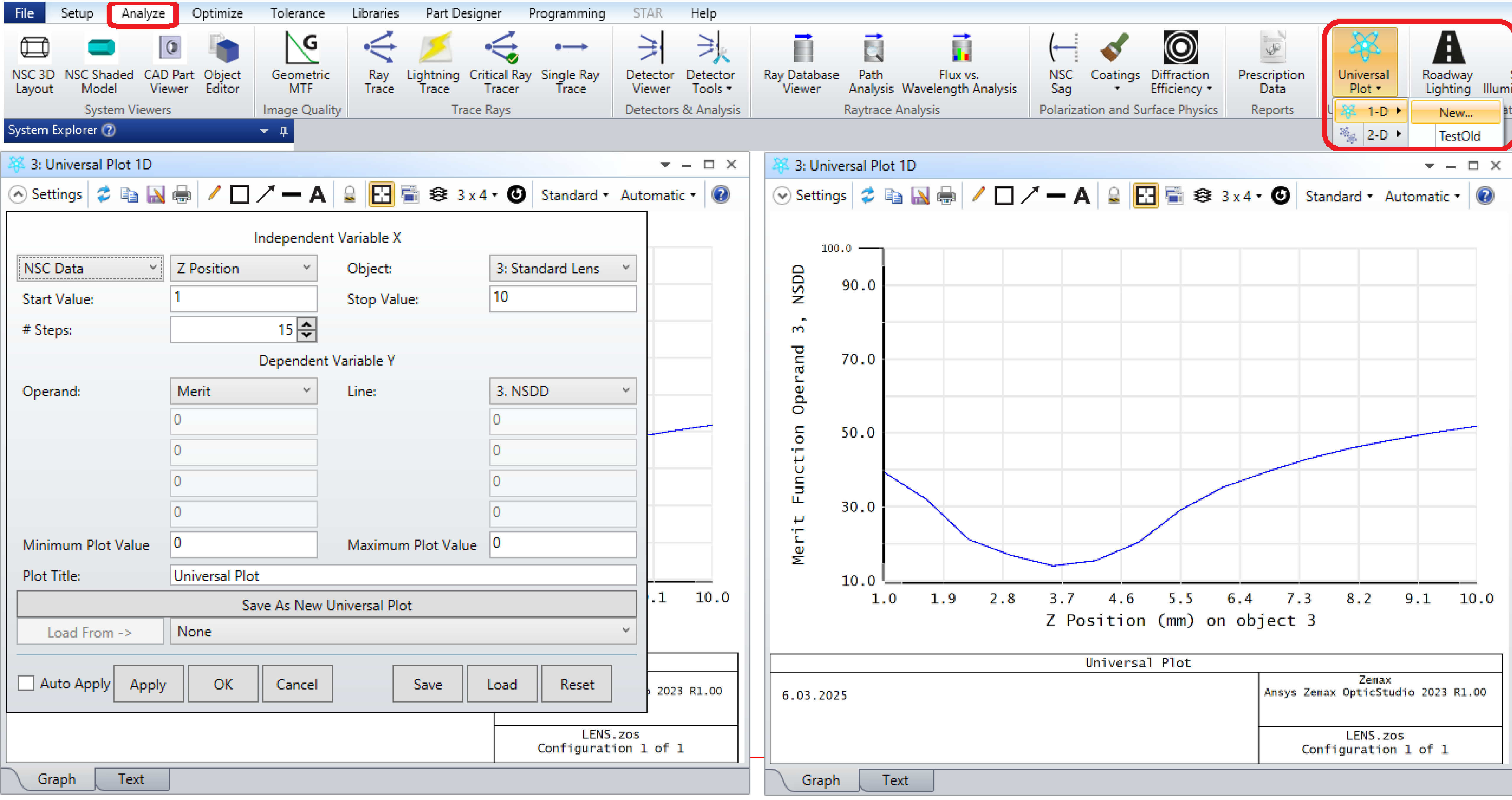


With collimating lens

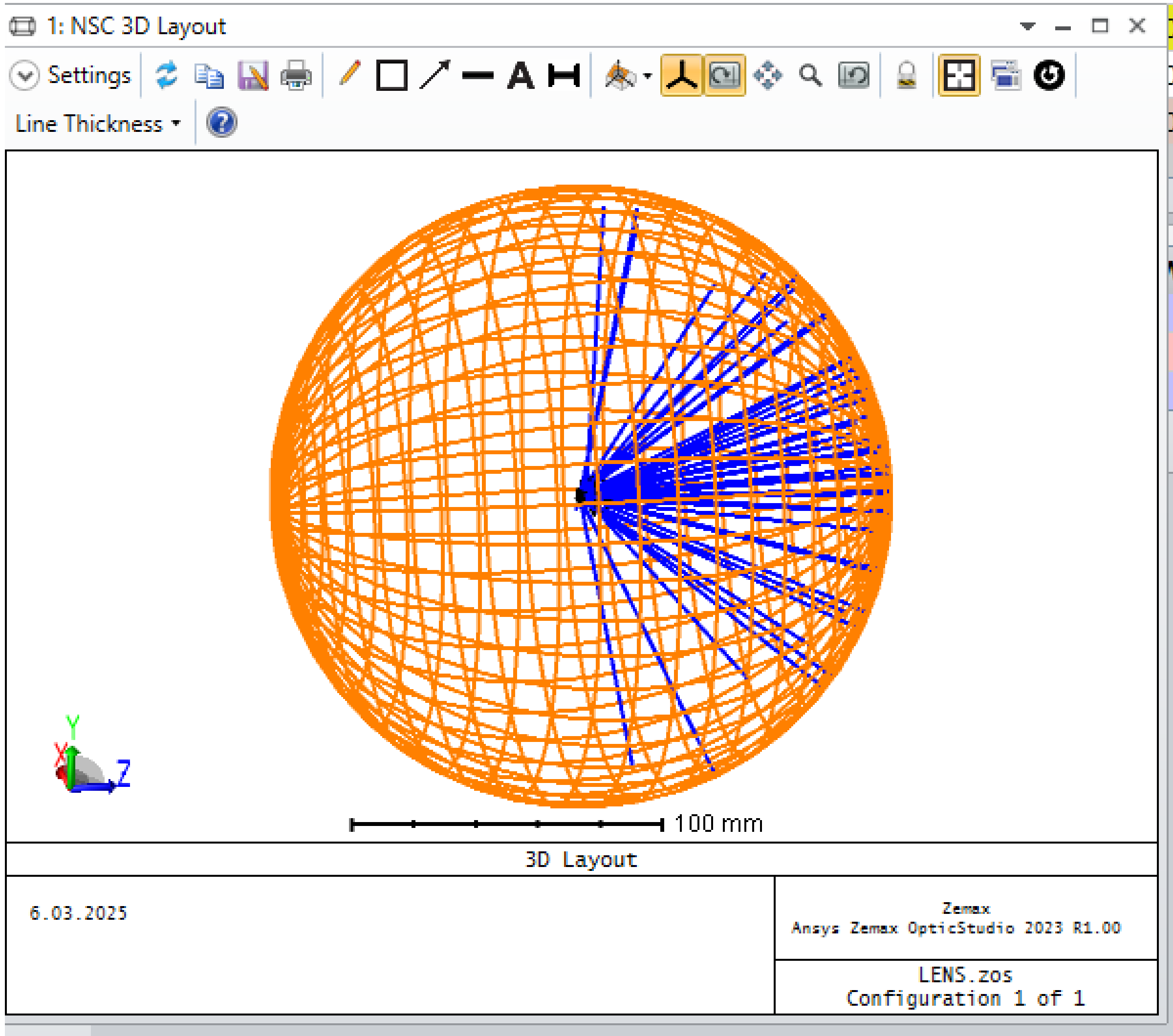


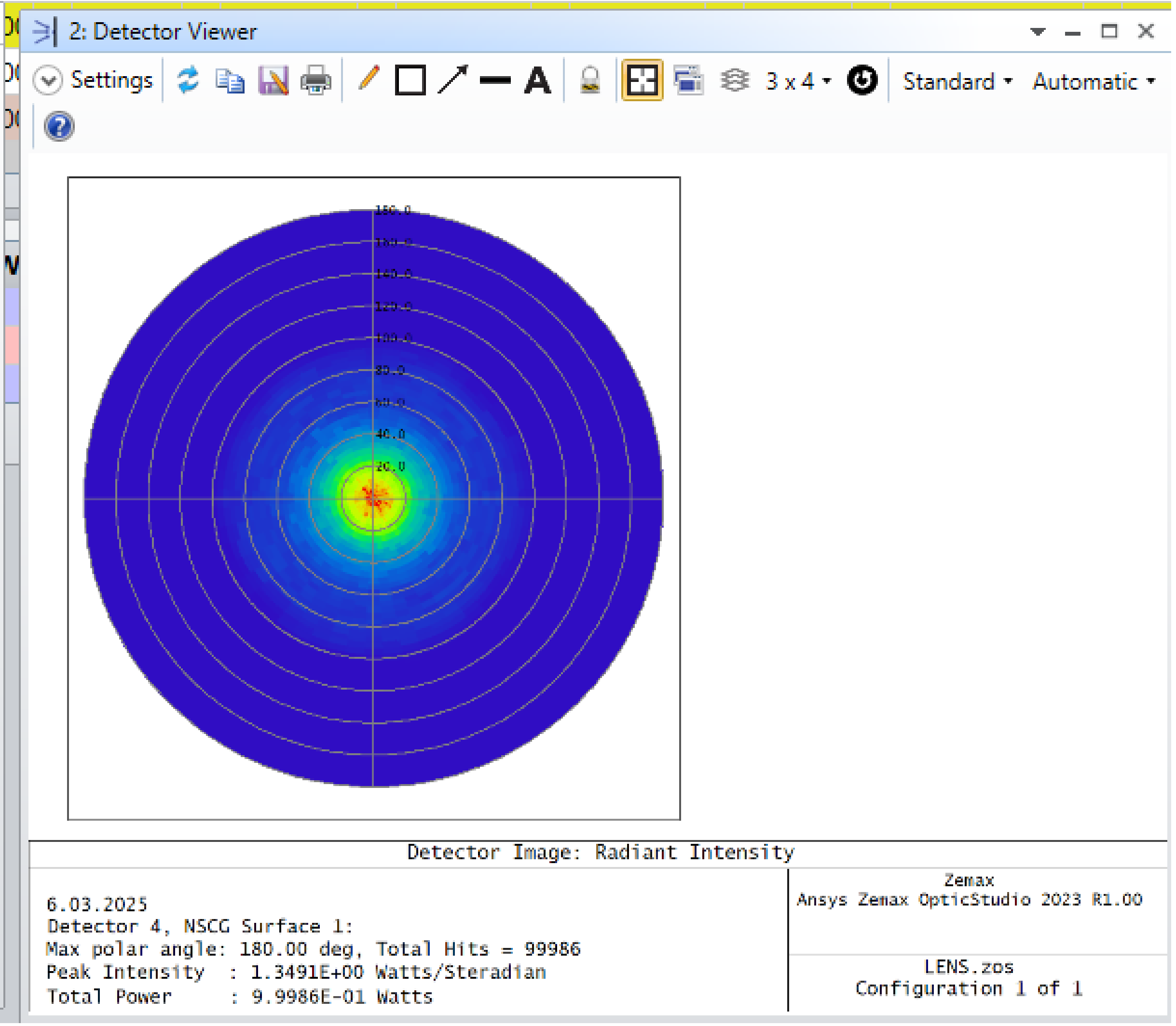


Universal Plot



Polar detector





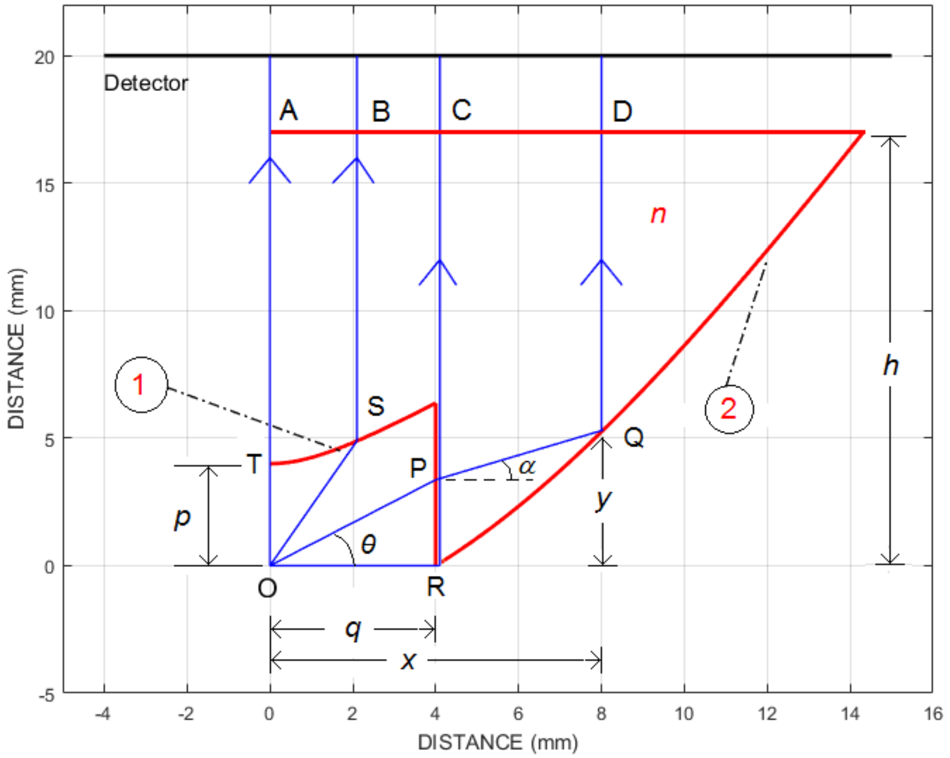
Example 10: How to use Pre-designed Freeform Lens

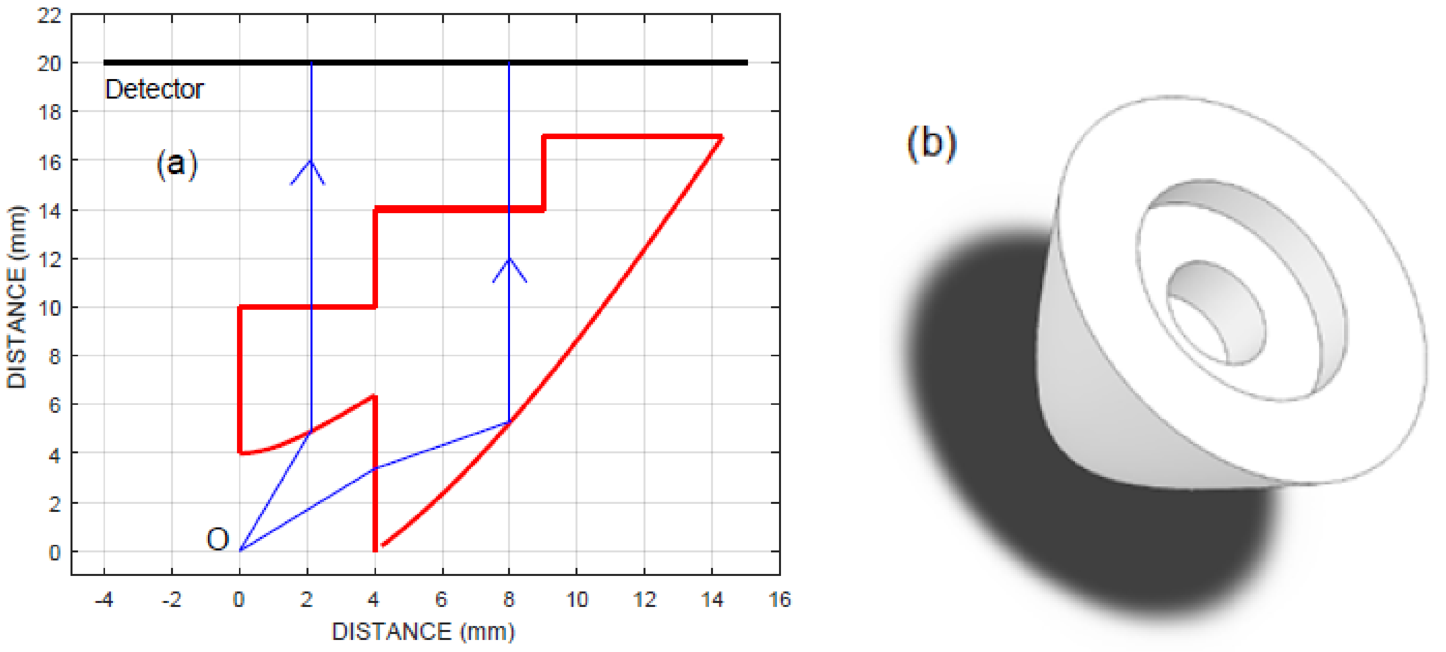
In this example, you will see adding a specific lens designed first in **Matlab**.

Solid model of the lens is then produced via **SolidWorks** program.

Osram SFH 4718A IR LED used to test.

This was a TUBITAK 1005 Project (118M568).

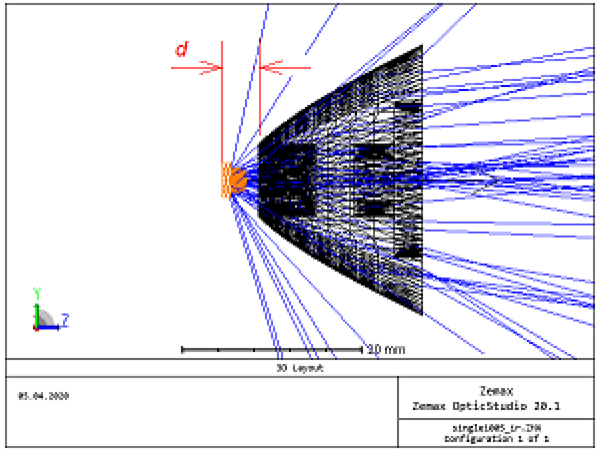


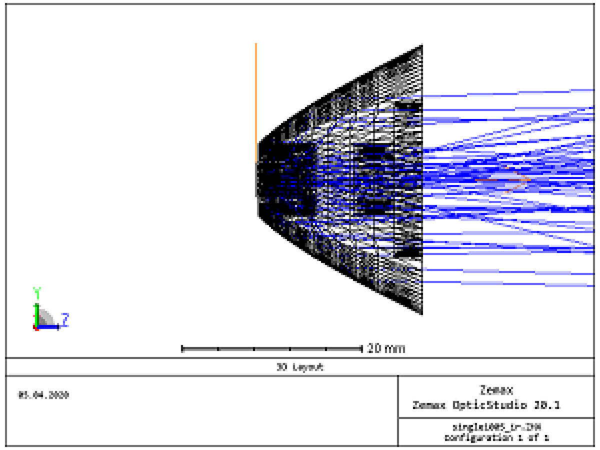


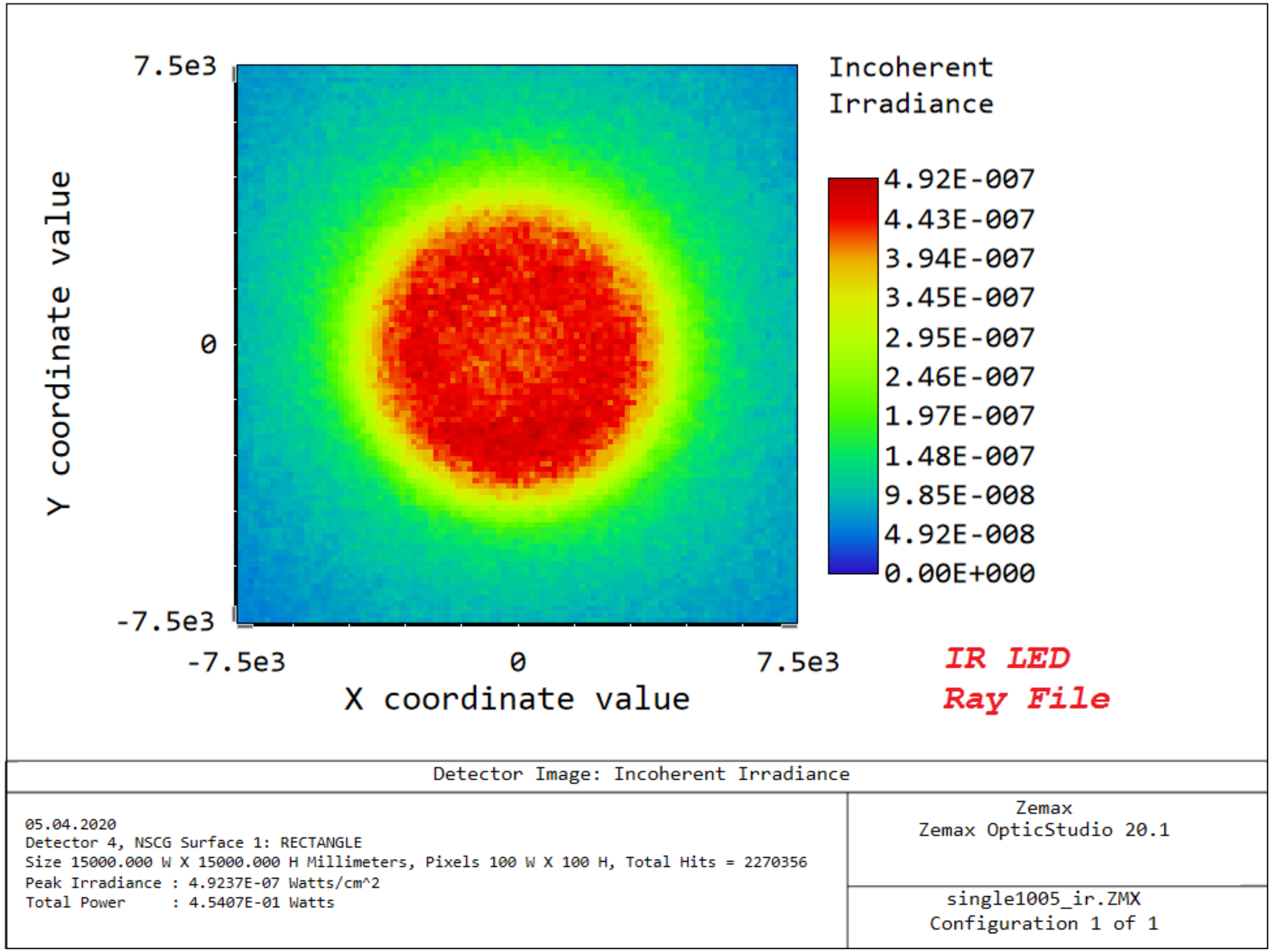
You can download **pmmaLEDcollimator-small.stp** the file from the course web page.

The lens file must be placed under:

`C:\<ZEMAX>\Objects\CAD Files`

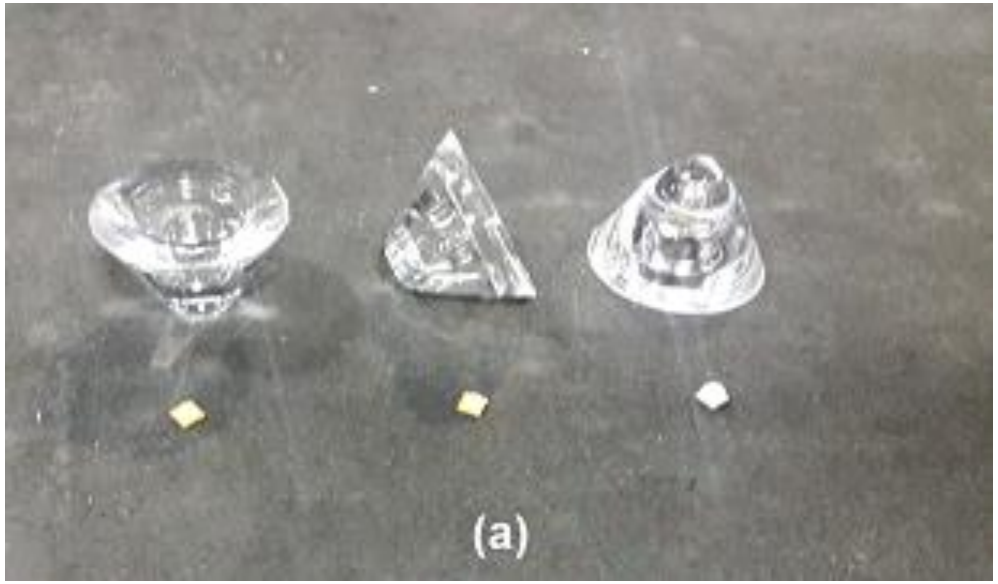


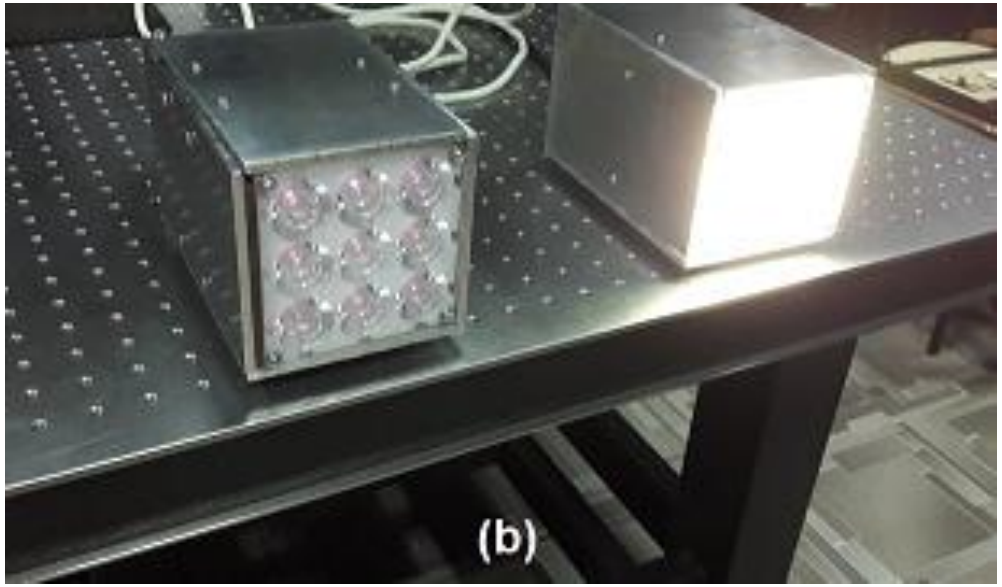




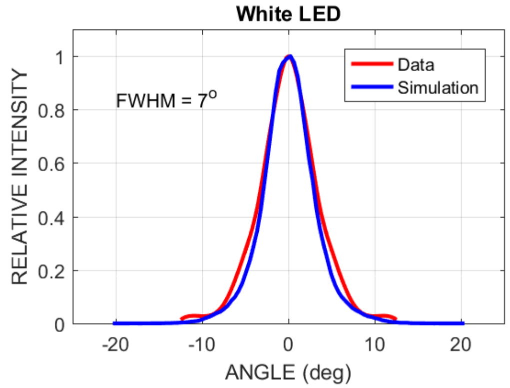
Manufacturing the lens

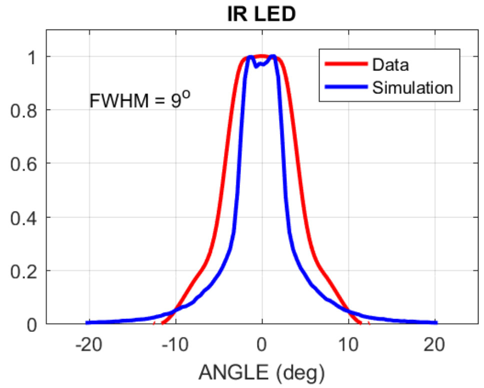
A prototype of a solid free-form lens is manufactured by using PMMA via plastic injection molding method.

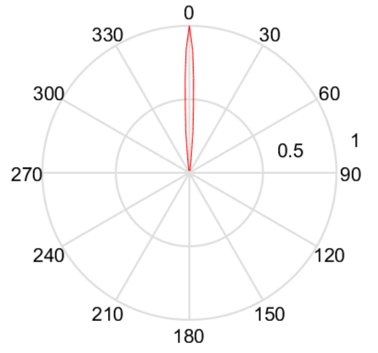


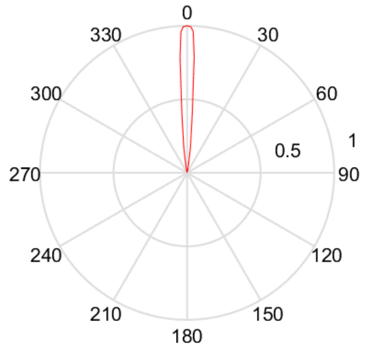


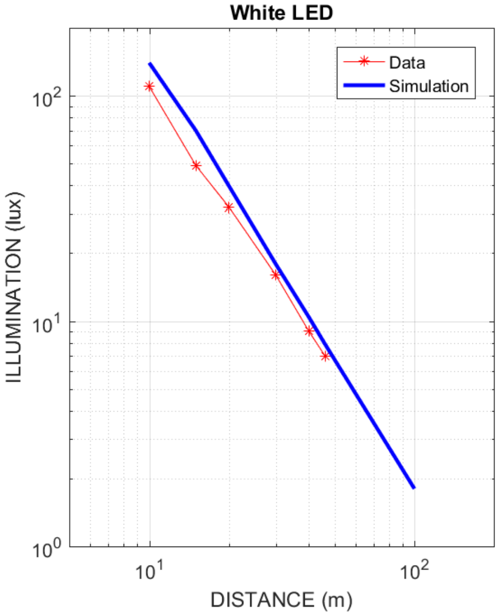
Optical Performance

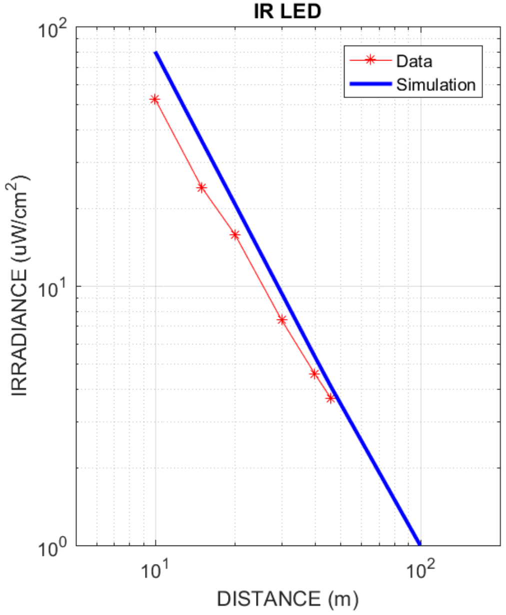








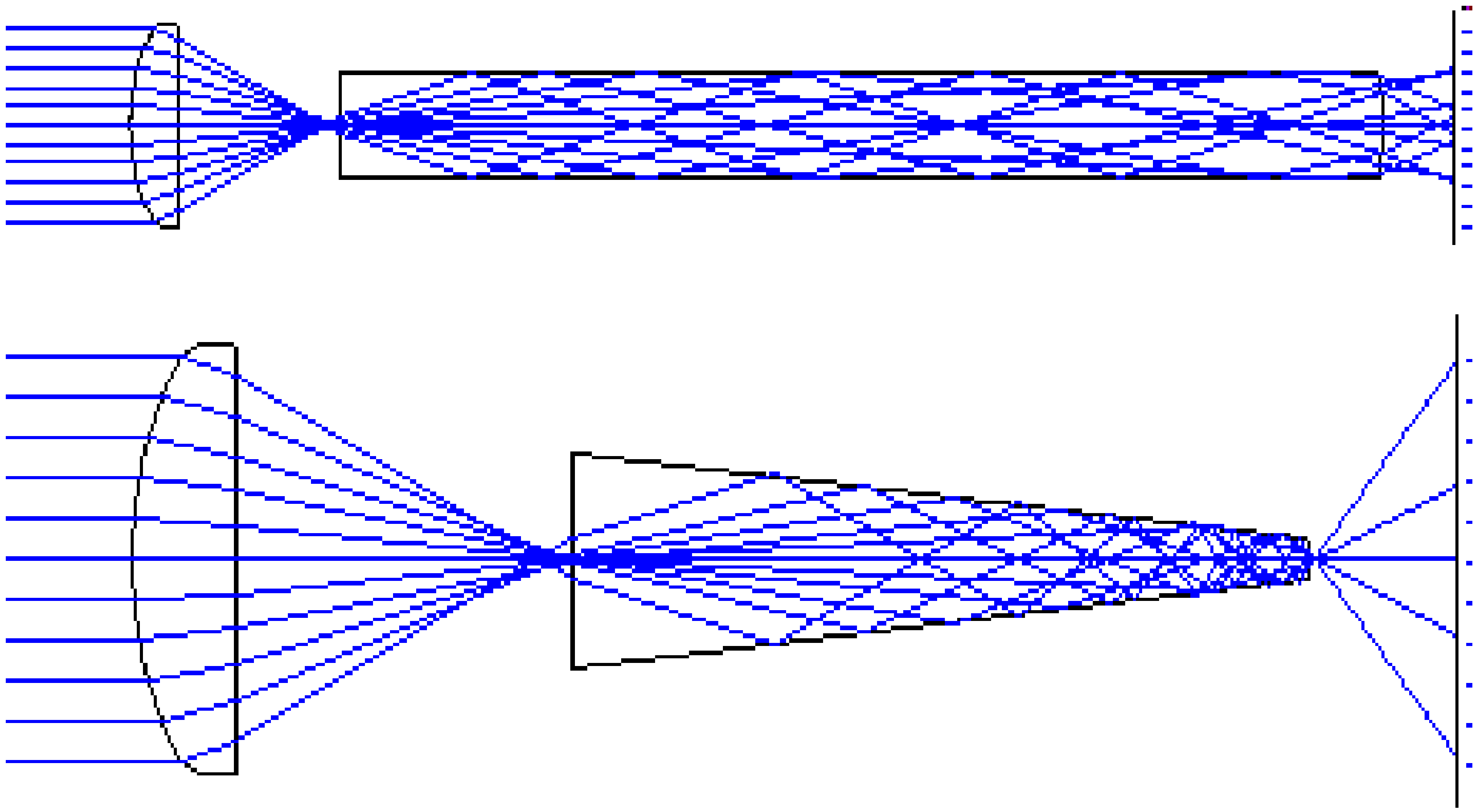




50 m uzunluğundaki karanlık bir koridorun aydınlatılması.
Solda görünür bölge ve sağda sadece kızılötesi aydınlatma yapılmıştır.

Ayrıca bkz: http://www1.gantep.edu.tr/~bingul/irwalk.gif

Example 11: Light Pipes



Example 12: Hybrid Mode in Zemax

	Surface Type	Comm	Radius	Thickness	Material	Coating	Clear Semi-Di	Chip Zone	Mech Sem	Conic
0	Standard		Infinity	10.000			0.000	0.000	0.000	0.000
1	Standard		5.185	5.000	BK7		5.000 U	0.000	5.000	-2.306
2	Standard		Infinity	10.000			5.000 U	0.000	5.000	0.000
3	Non-Sequential Component		Infinity	-			5.000 U	-	-	0.000
4	Standard		Infinity	1.000			5.000 U	0.000	5.000	0.000
5	Standard		Infinity	5.000	BK7		5.000 U	0.000	5.000	0.000
6	Standard		-10.000	18.000			5.000 U	0.000	5.000	0.000
7	Standard		Infinity	-			1.817 U	0.000	1.817	0.000

	Object Type	Comment	Ref Object	Inside Of	X Position	Y Position	Z Position	Tilt About X	Tilt About Y	Tilt About Z	Material	Scale
1	Polygon Object	Prism45.POB	0	0	0.000	0.000	0.000	0.000	0.000	0.000	BK7	4.000
2	Polygon Object	Prism45.POB	0	0	0.000	10.000	8.000	180.000	0.000	0.000	BK7	4.000