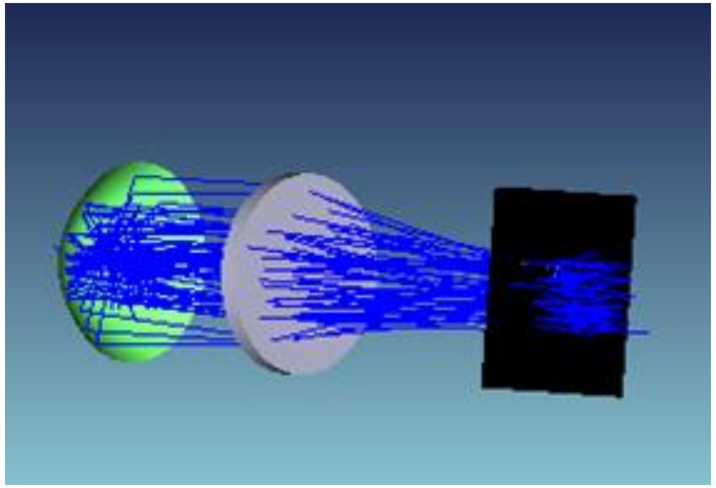
Lecture 21

Introduction to 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

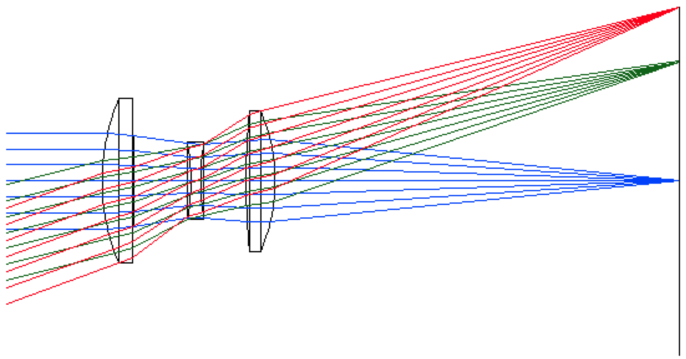
- It is primarily used for non-imaging applications
  such as illumination systems and/or stray-light analysis.

- 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

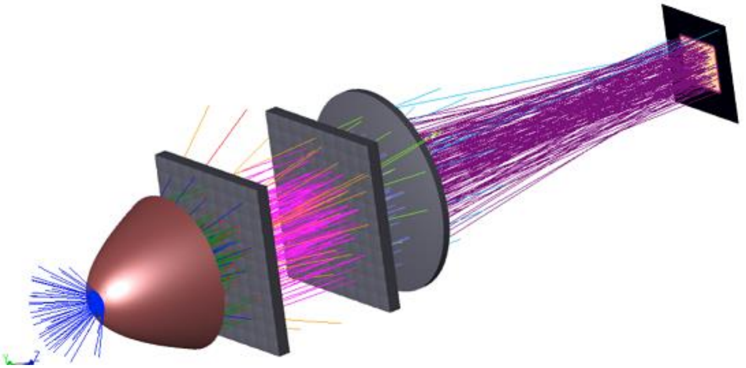
+ Rays must hit
- every surface
- one time
- in the same order



+ Imaging optics
+ Afocal systems

Non-Squentail Mode

+ Rays can hit
- any object
- an number of times (n≥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. $\text{Error} \propto \dfrac{1}{\sqrt{\text{number of rays}}}$

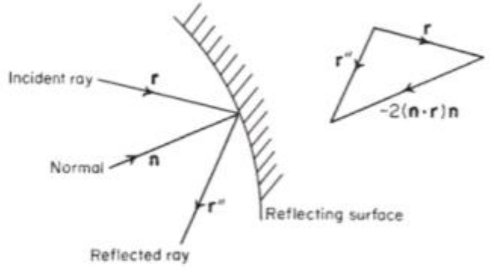
use geometrical optics (vector based calculations for reflection, refraction, polarization)

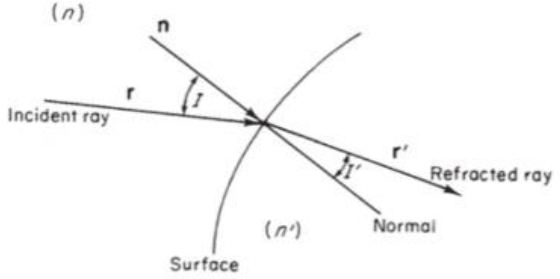
$$n'\sin I' = n\sin I$$

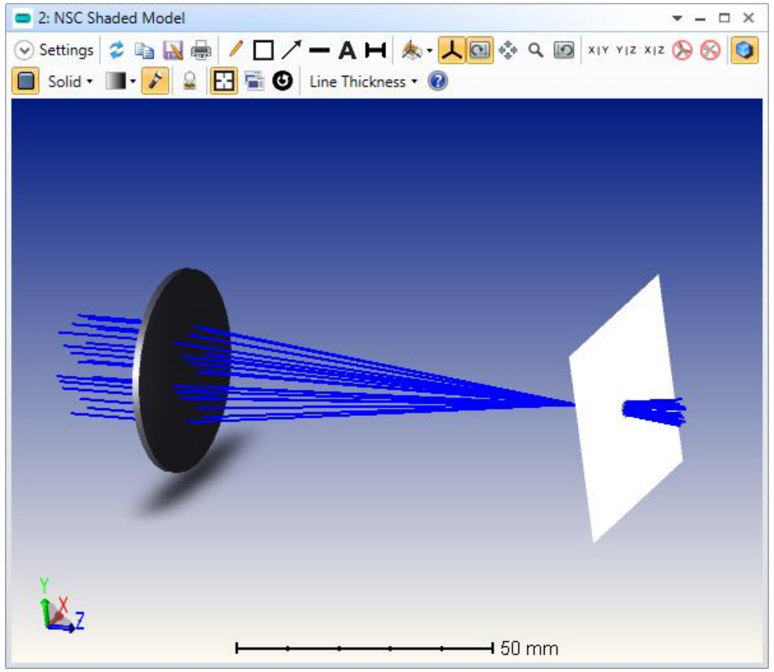
$$n'\mathbf{r}'\times\mathbf{n} = n\mathbf{r}\times\mathbf{n}$$

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

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







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 (or can be ABSORB or MIRROR)

X Half Width 20

Y Half Width 20

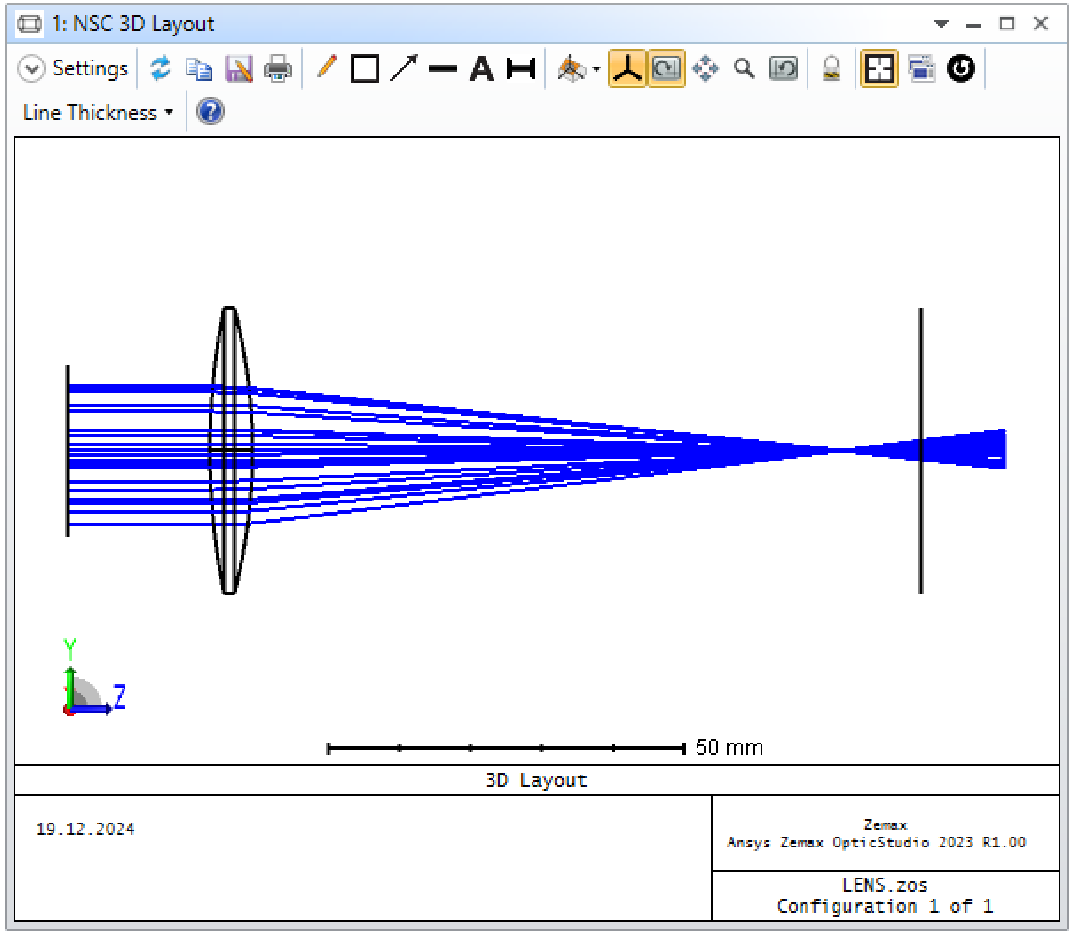
X Pixels 200

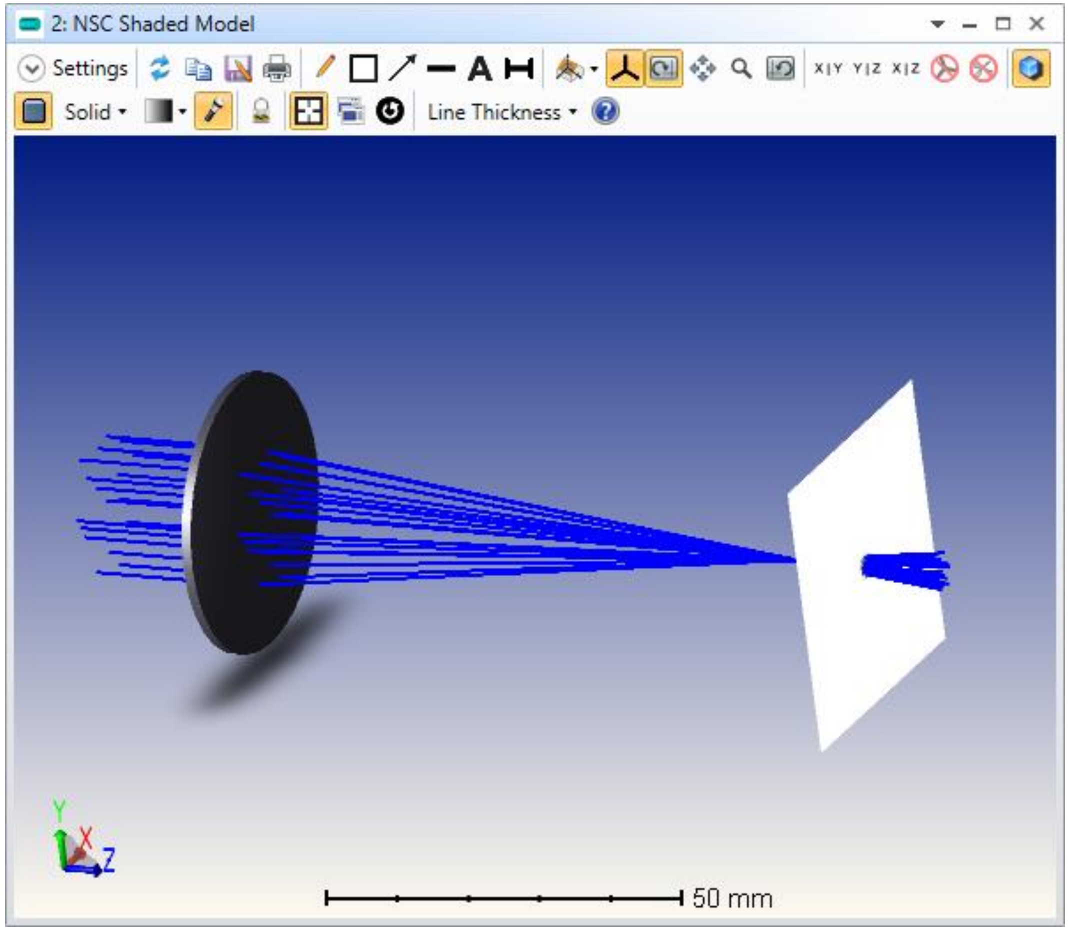
Y Pixels 200

Color 3 (detector displays false color)

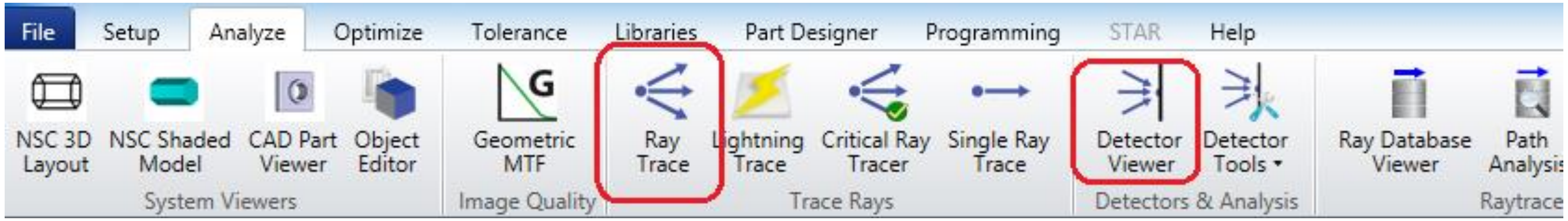
Example 1: Layout

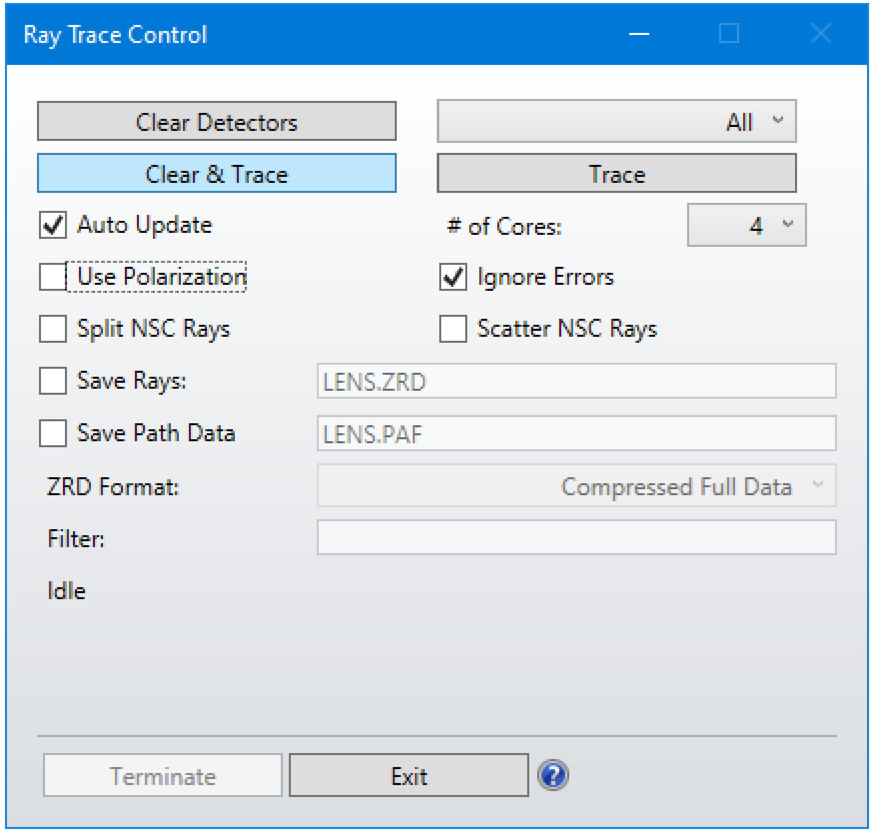
	Object Type	Comment	Ref Object	Inside Of	X Position	Y Position	Z Position	Tilt About X	Tilt About Y	Tilt About Z	Material	X Half Width	Y Half Width	# X Pixels	# Y Pixels	Data Type	Color
1	Source Ellipse ▾		0	0	0.000	0.000	0.000	0.000	0.000	0.000	-	20	1E+05	1.000	0	0	12.000
2	Standard Lens ▾		0	0	0.000	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

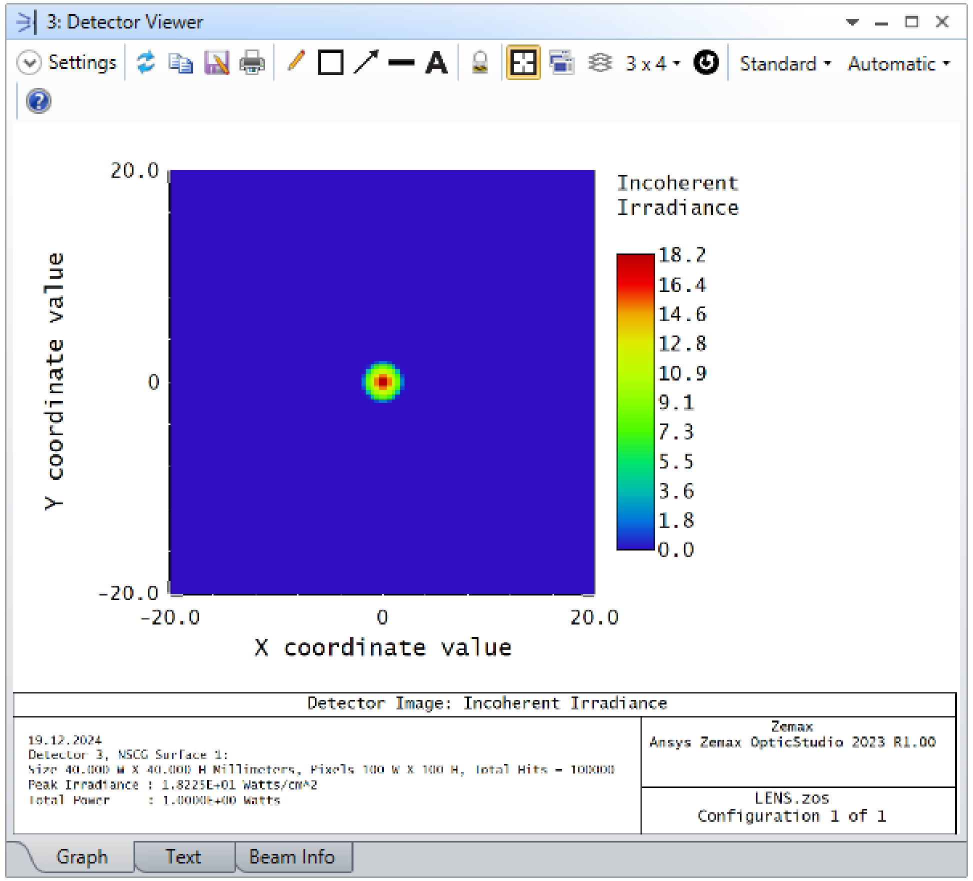




Example 1: Ray Tracing







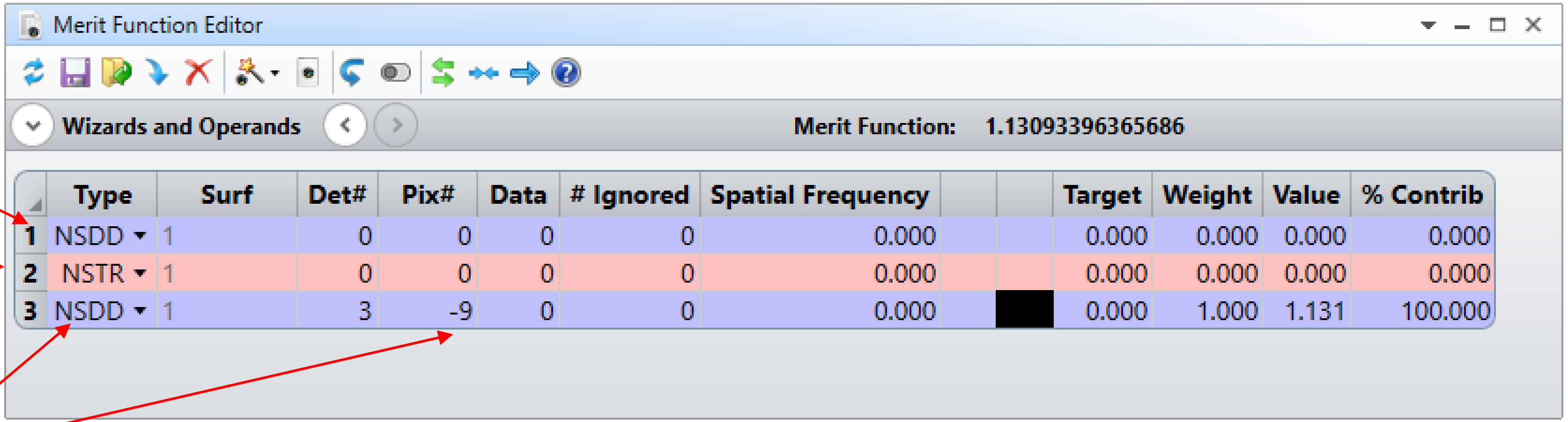
Example 1: Optimization

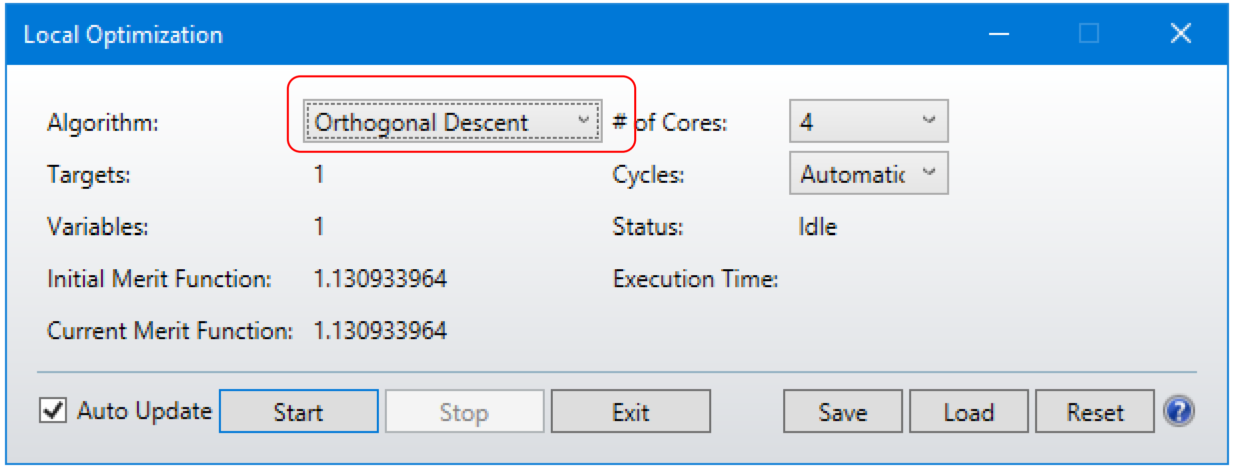
The aim is to put detector at a location where we have minimum rms spot size

Clear detector

Start ray tracing

Obtain minimum spot size

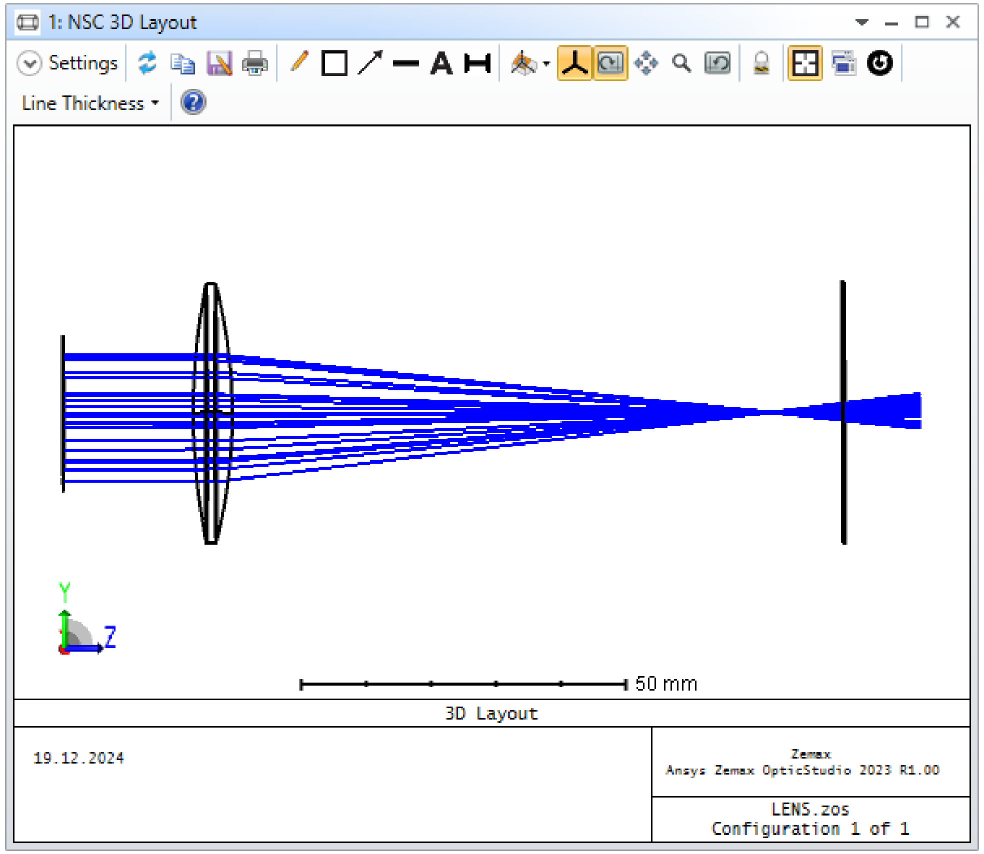




Example 1: Results

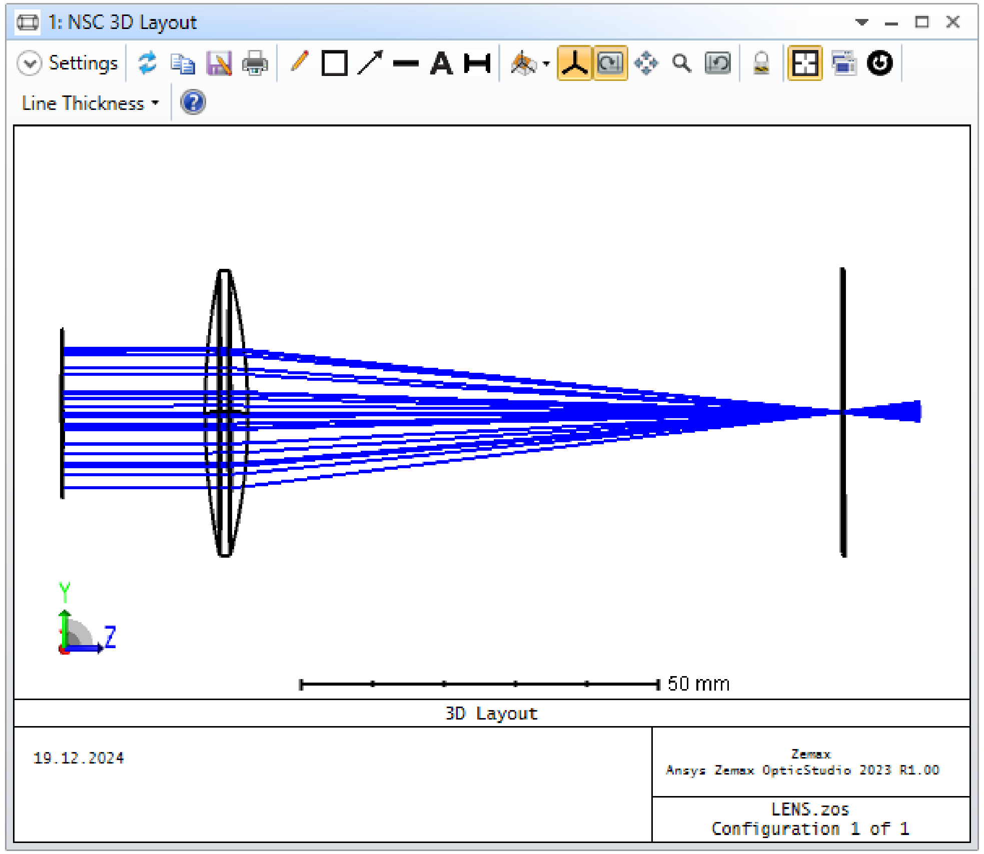
Z Position of detector = 120 mm

Before optimization



Z Position of detector = 108. 7 mm

After optimization

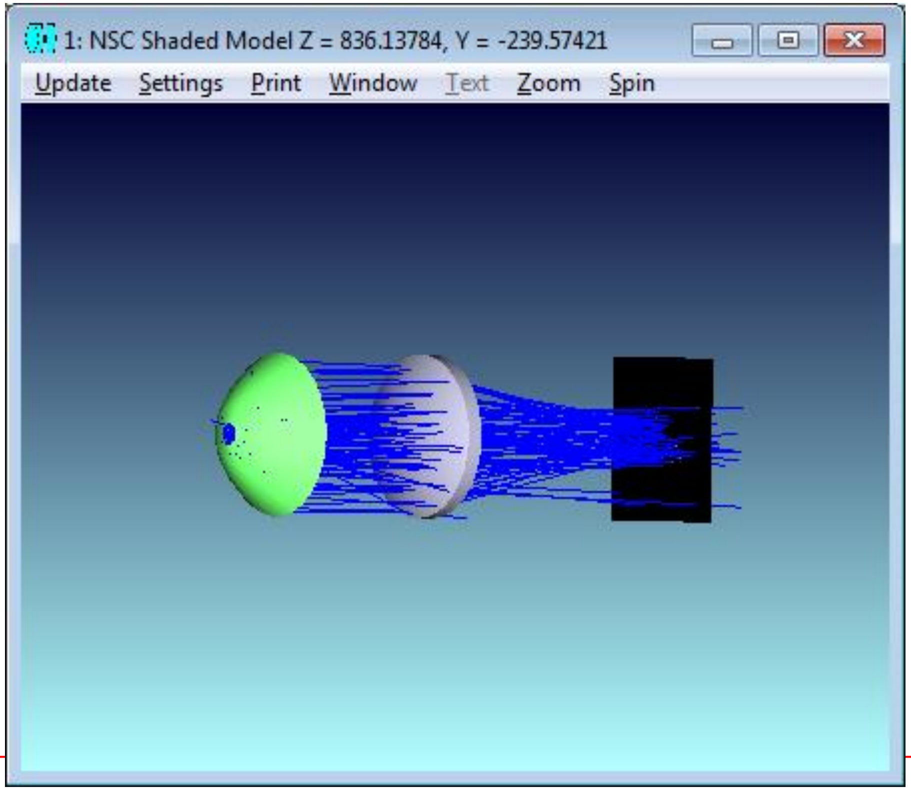


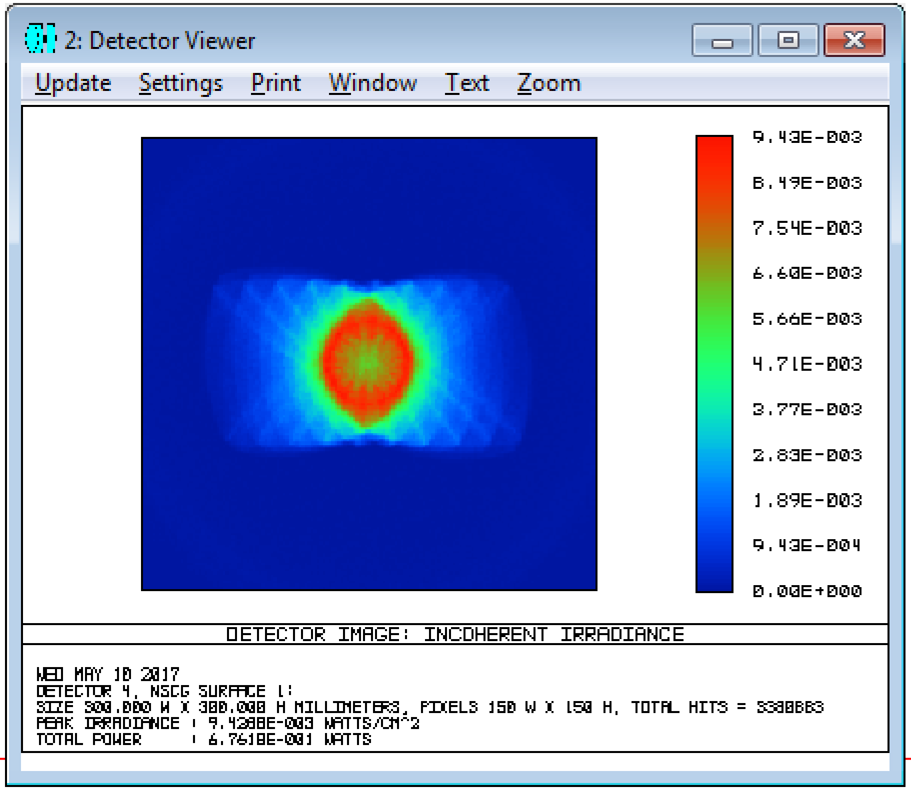
Example 2: Mirror-Lens-Detector

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)

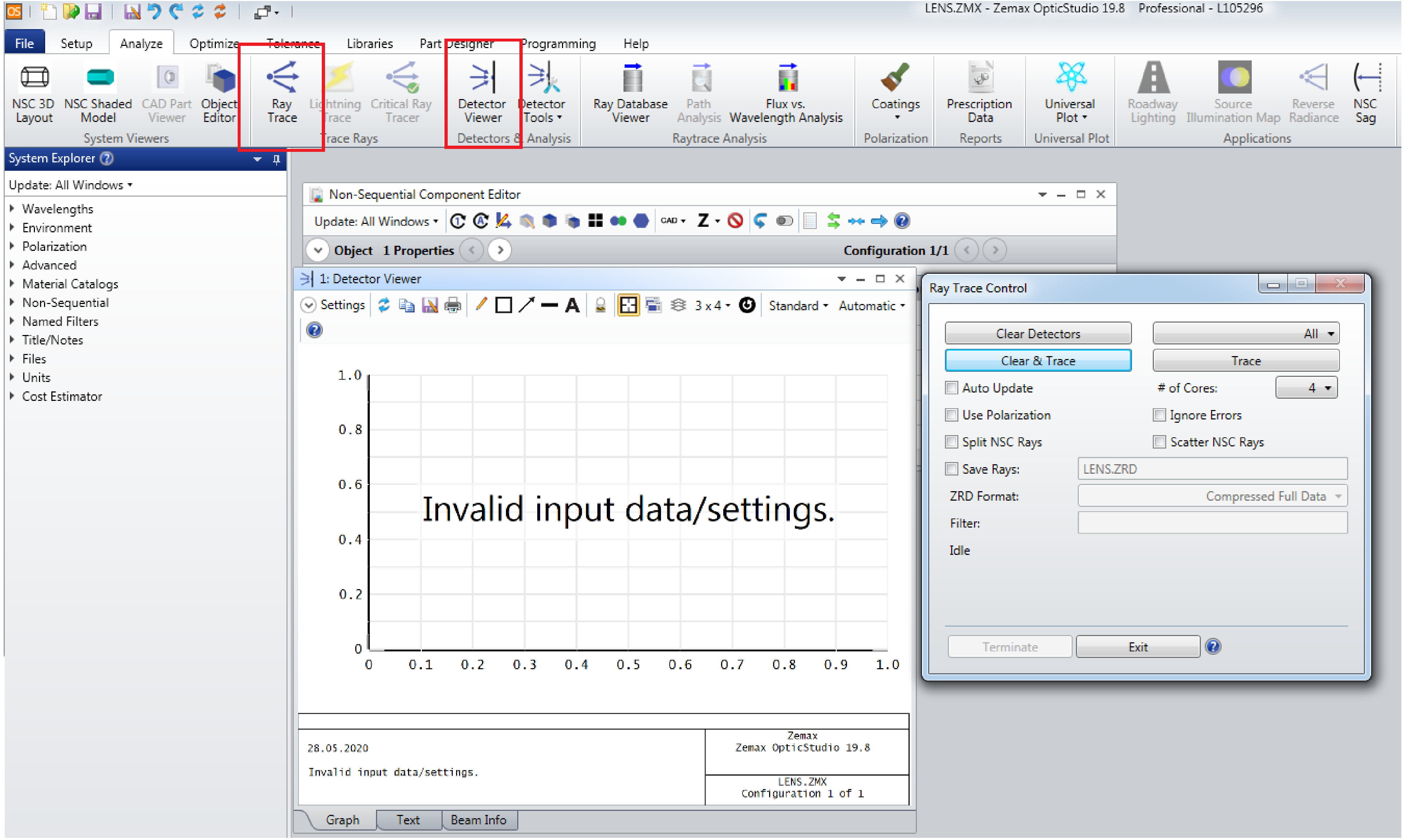
***** Object4**

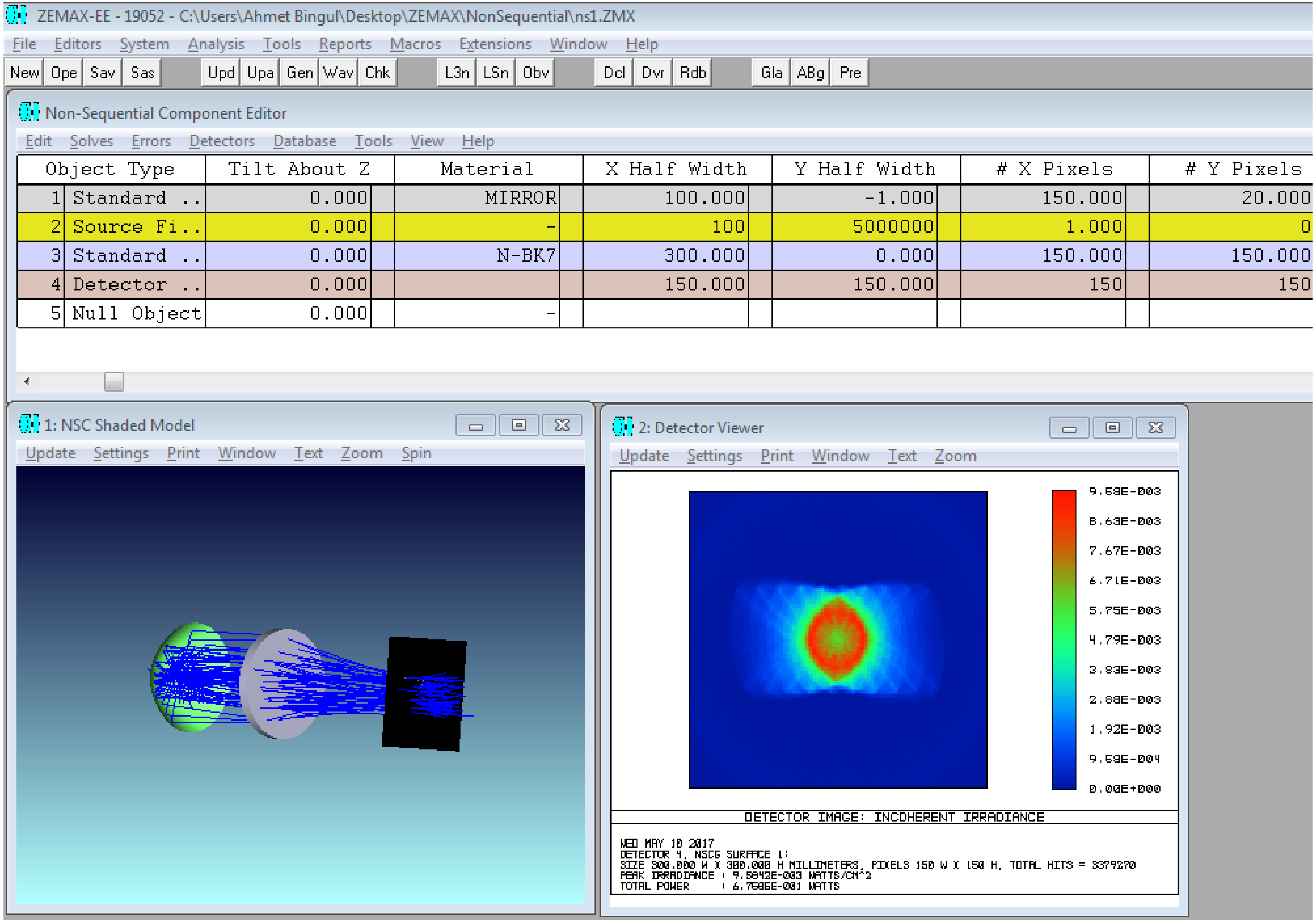
Standard Lens	
Ref Object	3 (before detector)
Z Position	200
Material	N-BK7
Radius 1	300
Clear 1	150
Edge 1	150
Thickness	70
Clear 2	150
Edge 2	150

***** 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

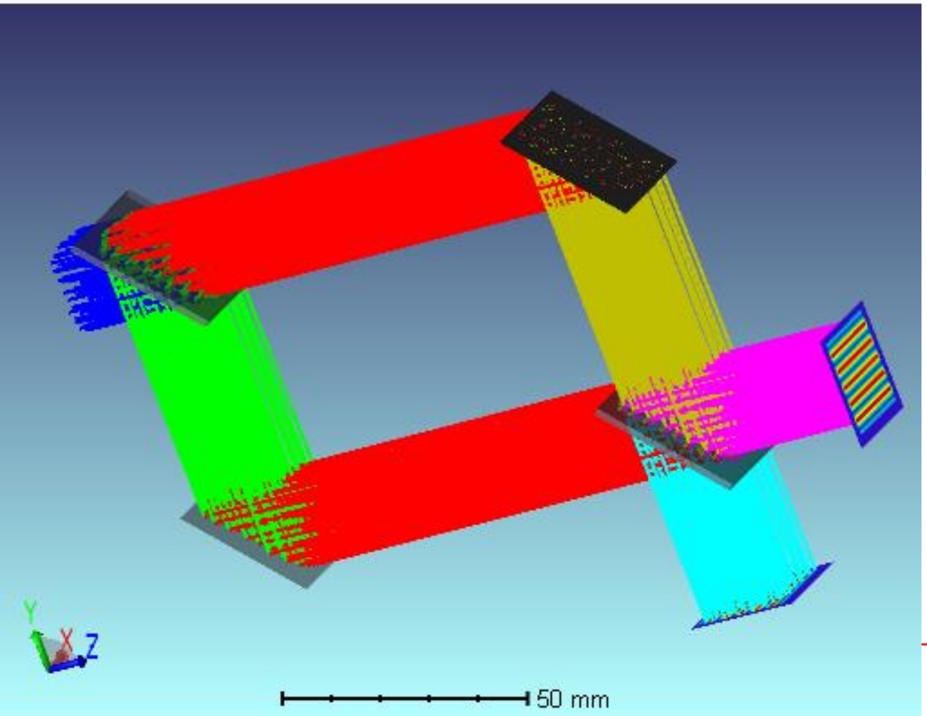
Example 3: Simple Interferometer

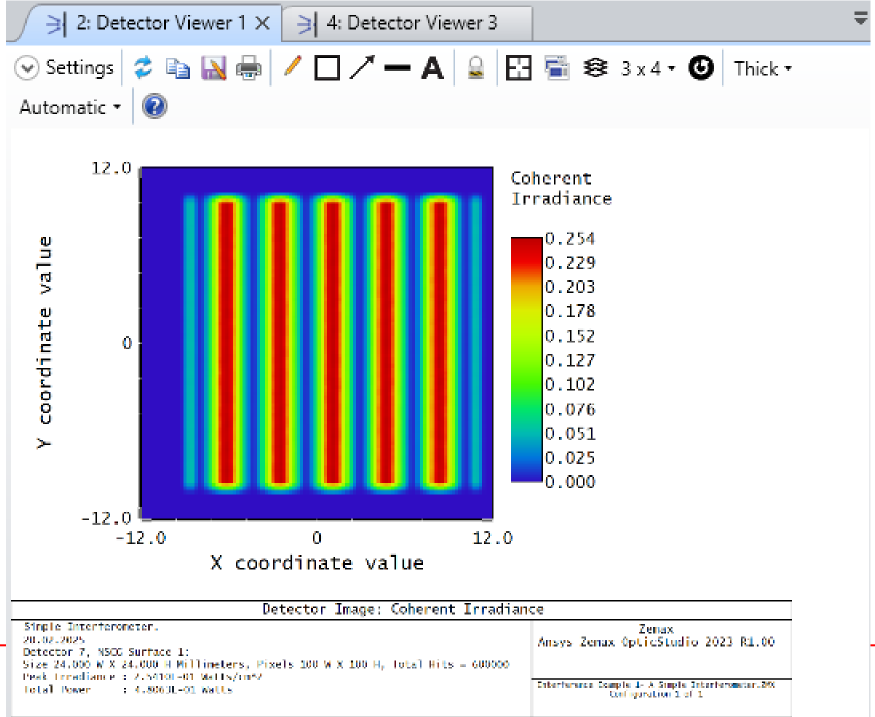
Non-Sequential Component Editor

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



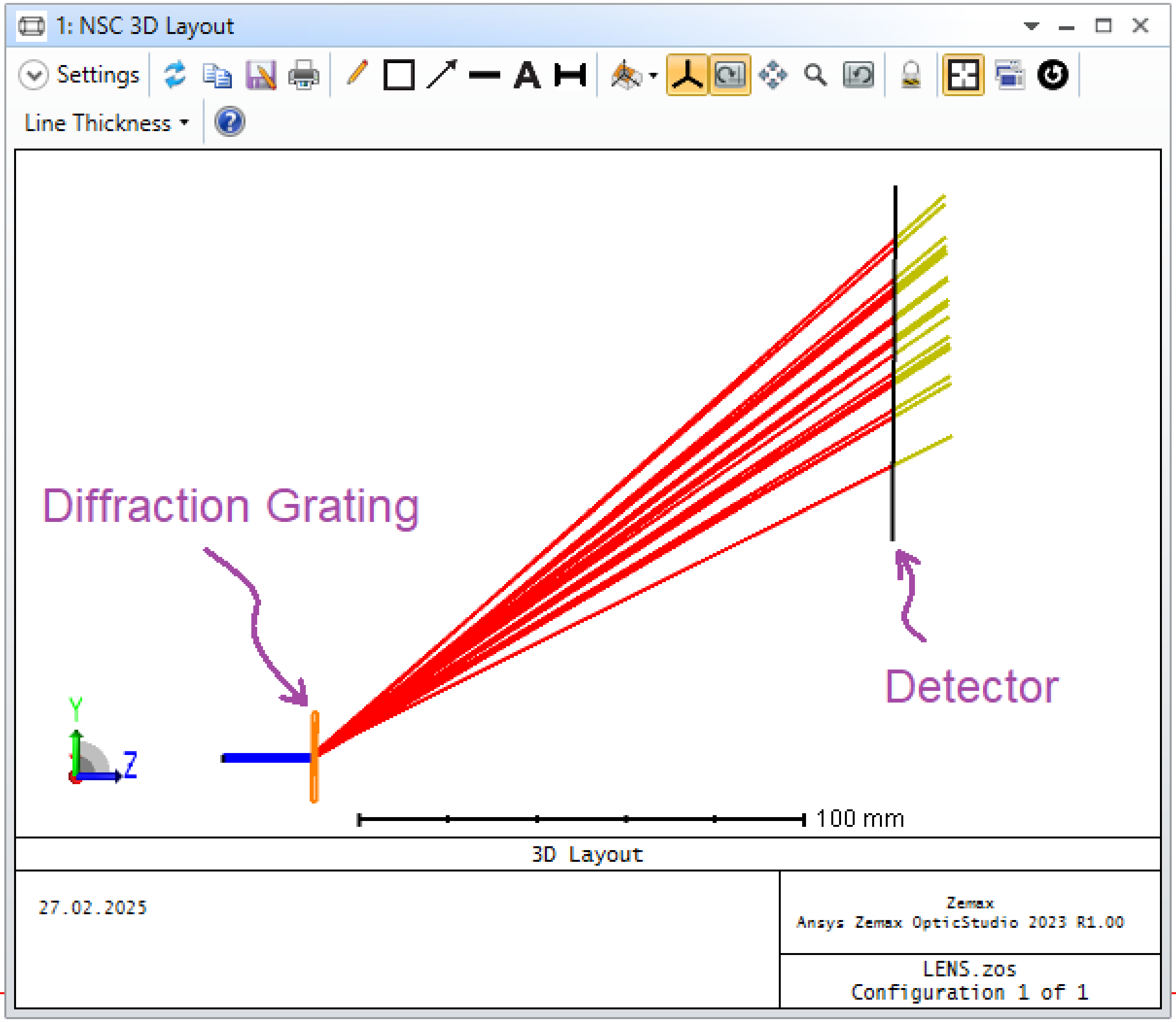


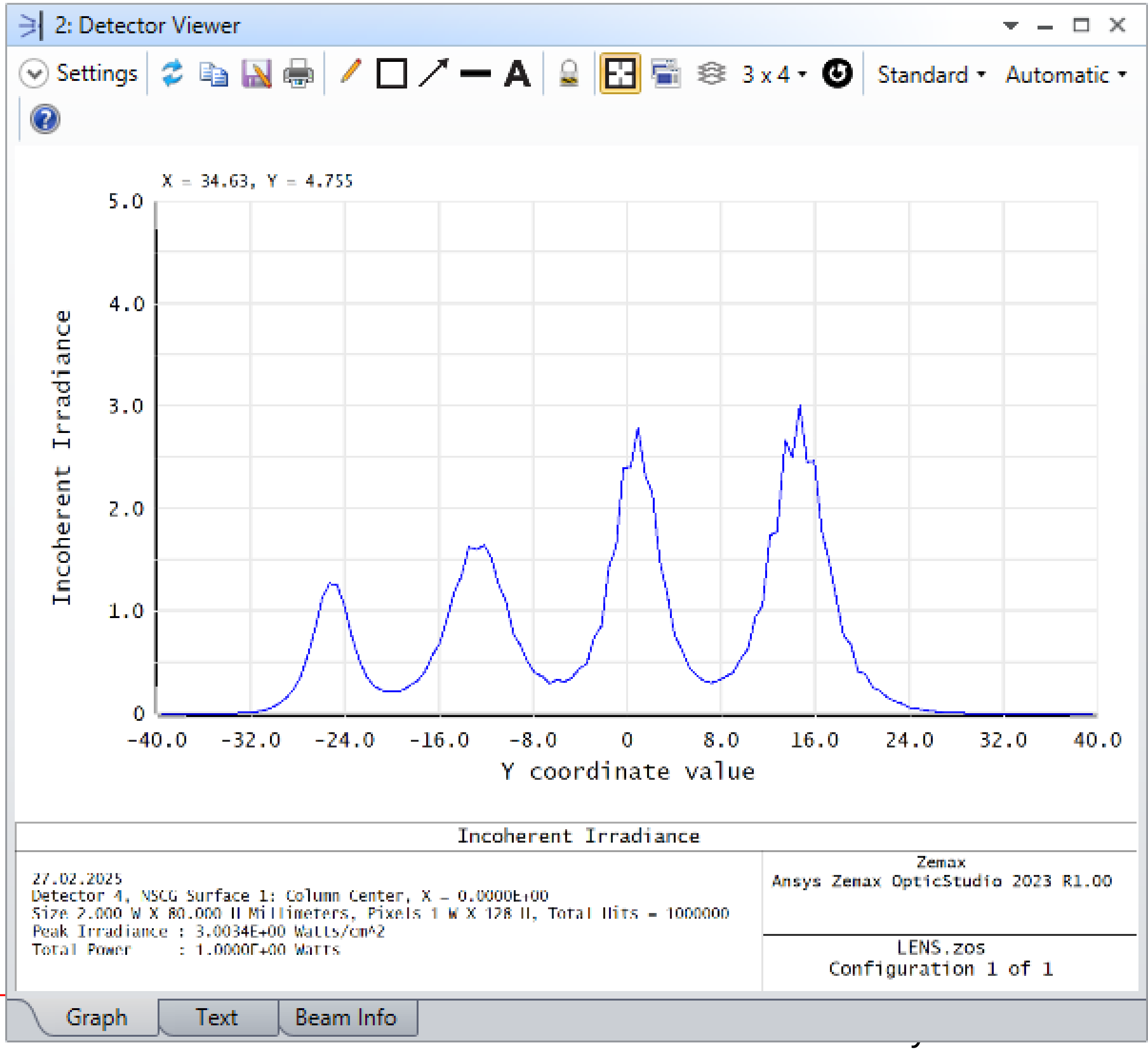
Modify the system

- Elliptic source
- using point source. (first collimate point source using a suitable lens from lens catalog)

Example 4: Simple Spectrometer

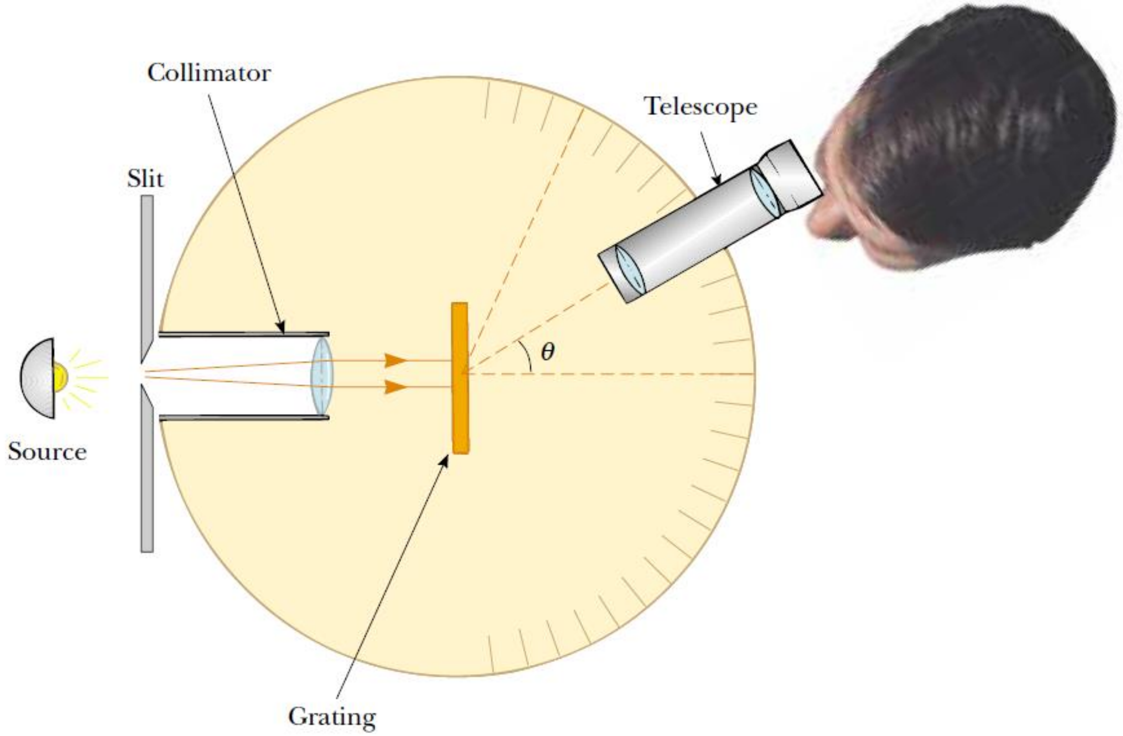
	Object Type	Comment	Ref Object	Inside Of	X Position	Y Position	Z Position	Tilt About X	Tilt About Y	Tilt About Z	Material	Radius 1	Conic 1	Clear 1	Edge 1	Thickness	Radius 2	Conic 2	Clear 2
1	Source Ellipse		0	0	0.000	0.000	0.000	0.000	0.000	0.000	-	10	0	1.000	0	0	1.000	1.000	0.000
2	Source Ellipse		0	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





Diffraction Grating

is a useful device for analyzing light sources, consists of a large number of equally spaced parallel slits. A transmission grating can be made by cutting parallel lines on a glass plate with a precision ruling machine.



Grating equation: $d\sin(\theta) = m\lambda$

d = 1/n

n = number of lines per length (e.g. 1/600 mm)

m = 0, ±1, ±2, . . . (order)

λ = wavelength

Example: Monochromatic light from a helium-neon laser (632.8 nm) is incident normally on a diffraction grating containing 600 lines/mm. Find the angles at which the first, second and third-order maxima are observed.

$d = 1/600 = 1667\,nm$

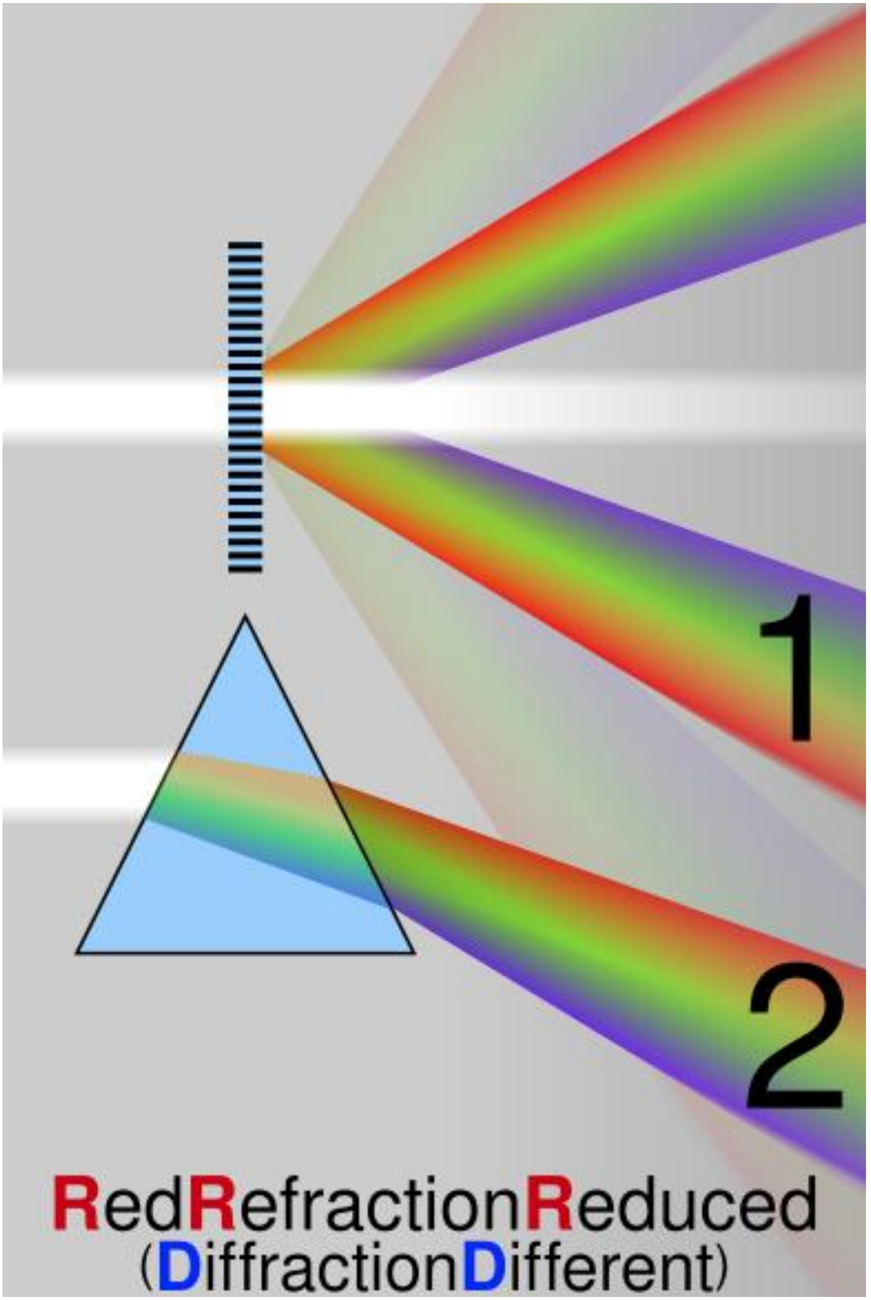
$\sin(\theta_1) = \lambda/d = 0.380 \quad \rightarrow \quad \theta_1 = 22.1°$

$\sin(\theta_2) = 2\lambda/d = 0.759 \quad \rightarrow \quad \theta_2 = 49.4°$

$\sin(\theta_3) = 3\lambda/d = 1.139 \quad \rightarrow \quad \theta_3 = 90° - 29.9°\mathbf{i}$ [not realistic]

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



Resolving power:

For two nearly equal wavelengths λ_1 and λ_2 between which a diffraction grating can just barely distinguish, the resolving power *R* of the grating is defined as: $\boldsymbol{R = \lambda/\Delta\lambda}$

where $\lambda = (\lambda_1 + \lambda_2)/2$ and $\Delta\lambda = \lambda_2 - \lambda_1$.

Thus, a grating that has a high resolving power can distinguish small differences in wavelength.

If N lines of the grating are illuminated, it can be shown that the resolving power in the *m*th-order diffraction is: $\boldsymbol{R = Nm}$

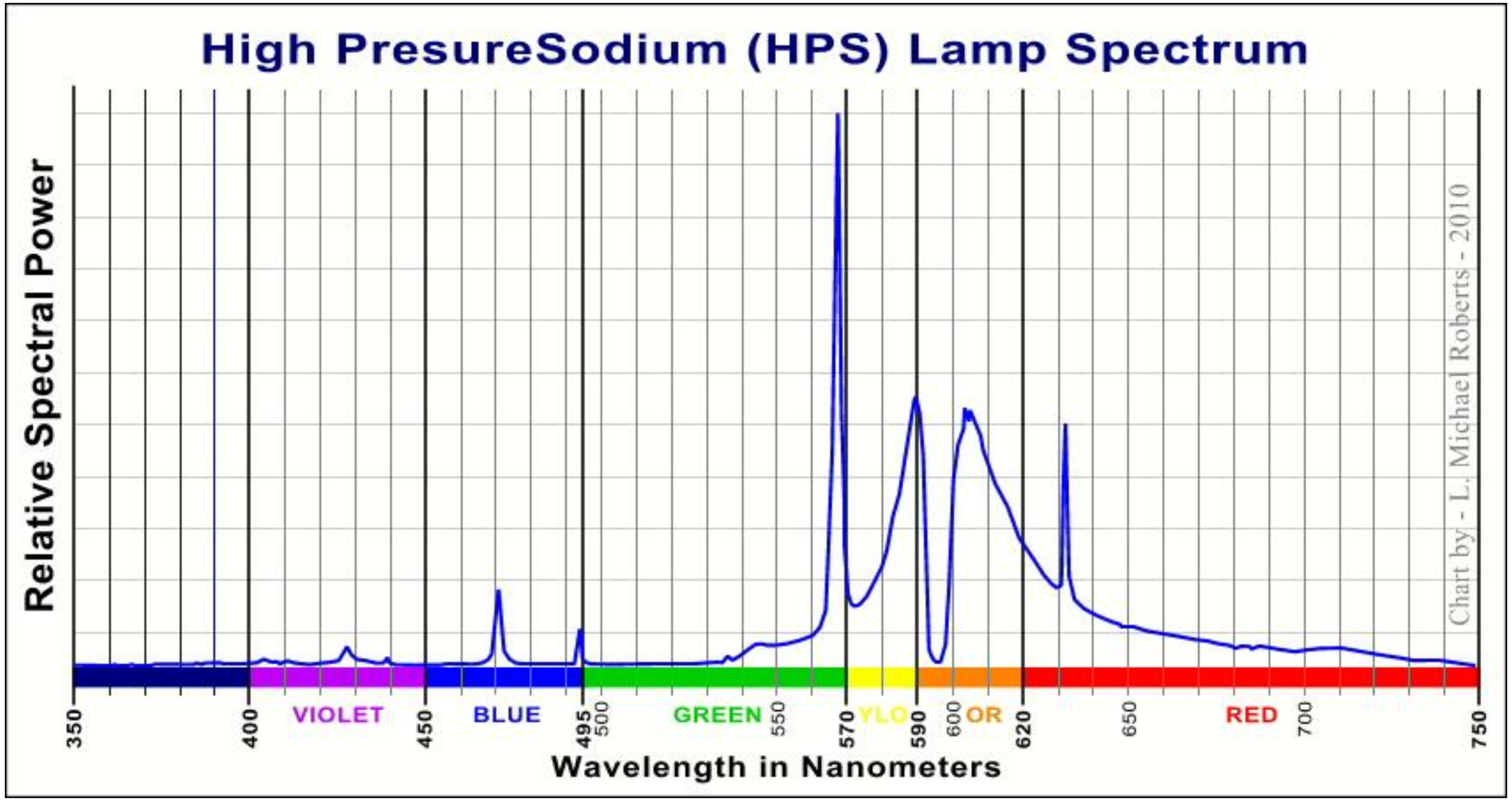
Example: When an element is raised to a very high temperature, the atoms emit radiation having discrete wavelengths. The set of wavelengths for a given element is called its atomic spectrum. Two strong components in the atomic spectrum of sodium have wavelengths of 589.00 nm and 589.59 nm. (See next page)

(a) What must be the resolving power of a grating if these wavelengths are to be distinguished?

$$R = \frac{\lambda}{\Delta\lambda} = 999$$

(b) To resolve these lines in the second-order spectrum, how many lines of the grating must be illuminated?

$$N = \frac{R}{m} = 500 \text{ lines}$$


High PresureSodium (HPS) Lamp Spectrum
Relative Spectral Power
Chart by - L. Michael Roberts - 2010
350
400
VIOLET
450
BLUE
495
500
GREEN
550
570
YLO
590
600
OR
620
650
RED
700
750
Wavelength in Nanometers