How to Create a Simple Non-Sequential System

http://www.zemax.com/kb/articles/33/1/How-to-Create-a-Simple-Non-Sequential-System/Page1.html
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This article explains:

- *How to enter and edit non-sequential objects in the non-sequential editor*
- *How to draw rays on the layout plots to get a qualitative feel for the optical system performance*
- *How to trace large numbers of rays to get quantitative data on system performance*

The lens file representing the final system is included as zipped file, which can be downloaded from the last page of this article.

Introduction to Non-Sequential Ray Tracing.

There are 2 distinct ray-tracing modes in ZEMAX; sequential and non-sequential. The key differences between sequential and non-sequential modes are:

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

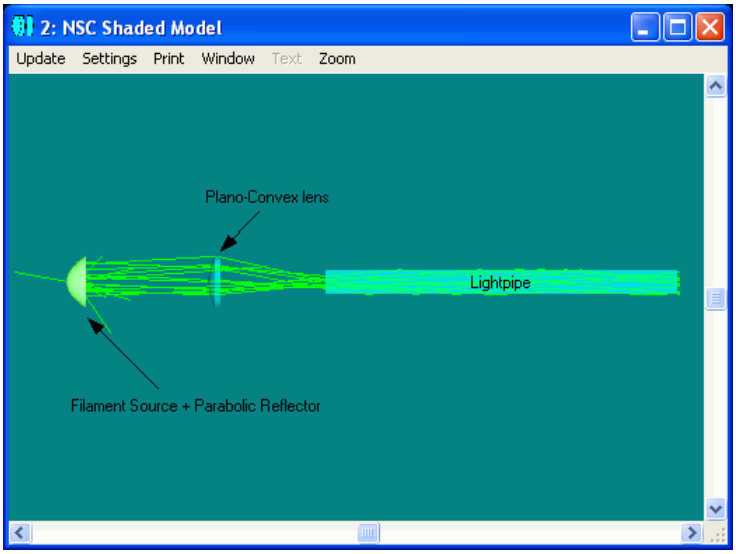
- It is primarily used for non-imaging applications such as illumination systems and/or stray-light analysis
- Surfaces or volume objects are defined in the Non-Sequential Component Editor
- Mechanical components may be easily imported from CAD programs, so that full Opto-Mechanical analysis may be undertaken
- 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
- Partially reflected rays can be generated and traced from a refractive interface, in addition to tracing the refracted ray. This is referred to as *ray splitting*. Hence both the reflected and refracted rays can be traced.
- 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.

In addition, a hybrid mode ("non-sequential with ports" or "mixed-mode") exists in which sequential and non-sequential ray-trace are used in the same system.

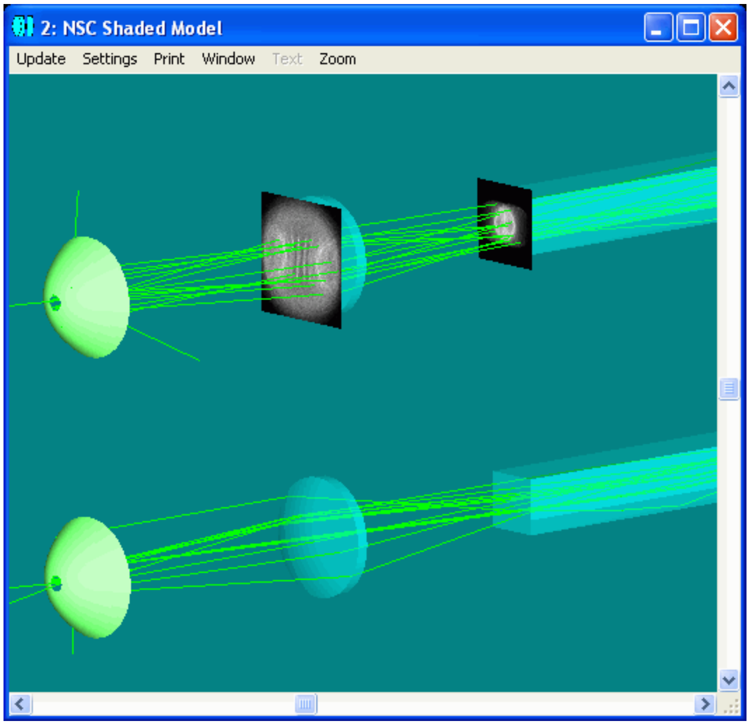
Full details of non-sequential ZEMAX capabilities are given in chapter 12 of the user manual.

Setting up Basic System Properties

We will create a non-sequential system with a filament source, a parabolic reflector and a plano-convex lens that couples light into a rectangular lightpipe, as shown in the layout below.

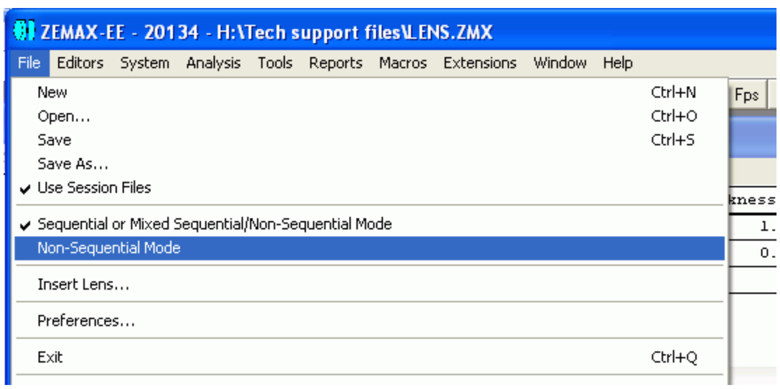


We will also trace analysis rays to the detectors to obtain the irradiance distribution at various points in the optical system. Here is what we will finally produce:

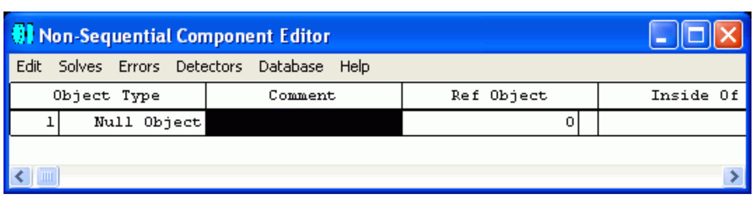


If ZEMAX is not running, please start it now.

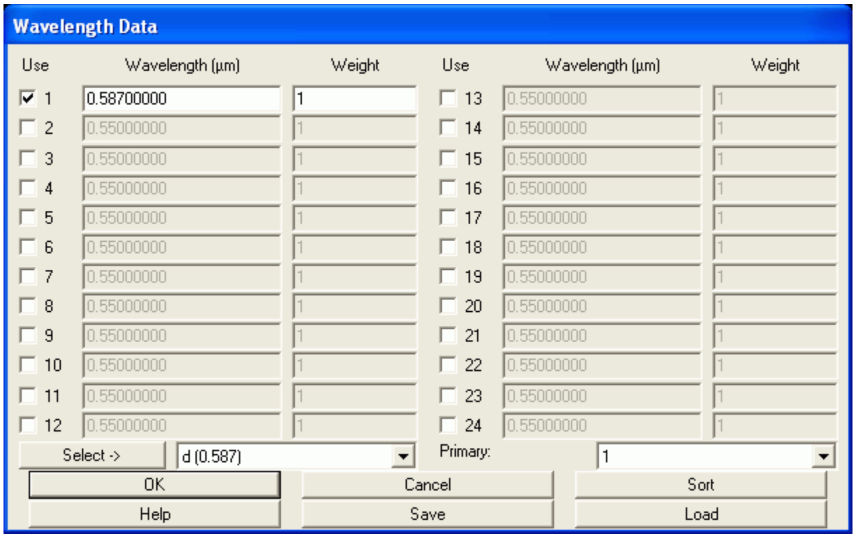
By default, ZEMAX starts in sequential/mixed mode. To switch to pure non-sequential mode, open ZEMAX and click File>Non Sequential Mode.



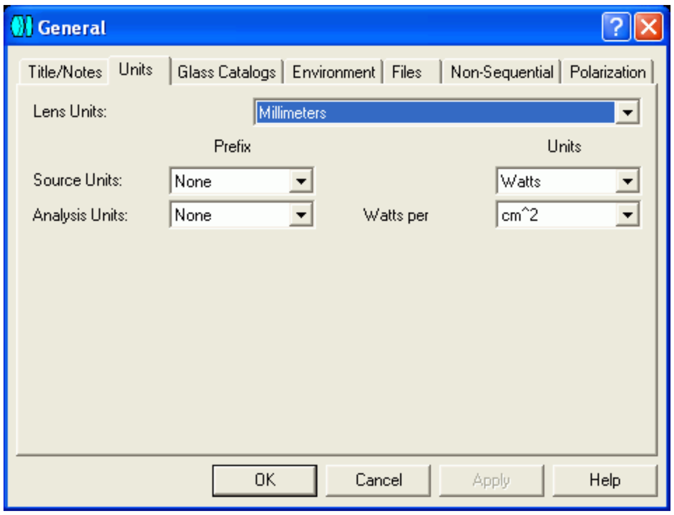
Once in pure non-sequential mode, the window title bar of the editor will display the Non-Sequential Component Editor instead of the Lens Data Editor when in sequential mode. The Lens Data Editor is used only in sequential or mixed-mode systems.



For this exercise, we will set the system wavelength, specified under System>Wavelengths, to 0.587 µm.



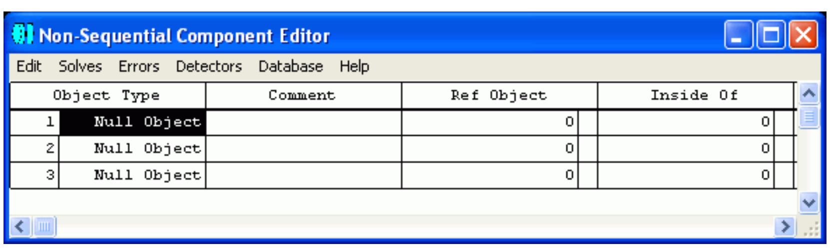
We will also set the units under System>General Unit tab as follows (default).



In addition to radiometric irradiance unit such as Watt.cm^{-2}, you can specify photometric and energy units such as lumen.cm^{-2} or joule.cm^{-2}. We will choose the default radiometric units for this exercise.

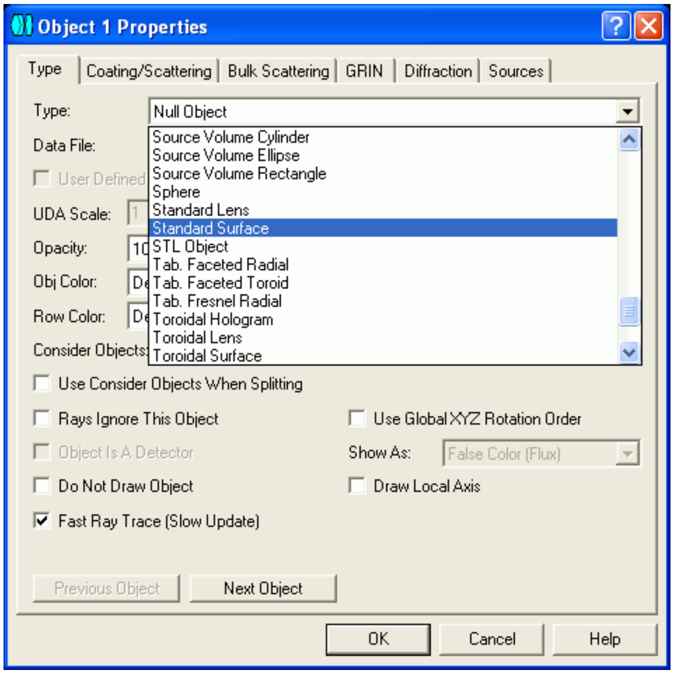
Creating the Reflector

Insert a few lines in the non-sequential component editor by pressing the "Insert" key on your keyboard.



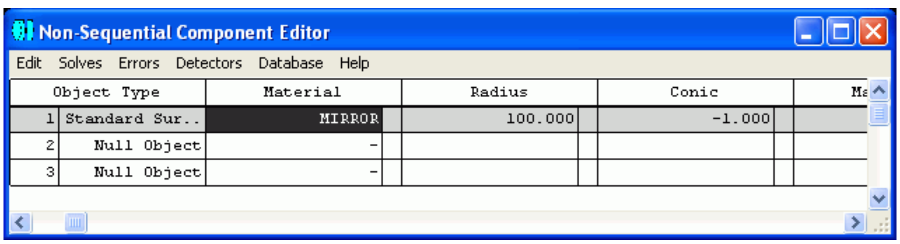
In the first part of the design, we will create a filament source collimated by a parabolic reflector. We will then place a detector object at some distance +Z and look at the irradiance distribution on a detector.

Make the first object a parabolic reflector by double clicking (left clicking) on the "Object type" column of Object 1 in the editor and opening the Object Property window. Under the Type tab set the Type to Standard Surface and click OK.

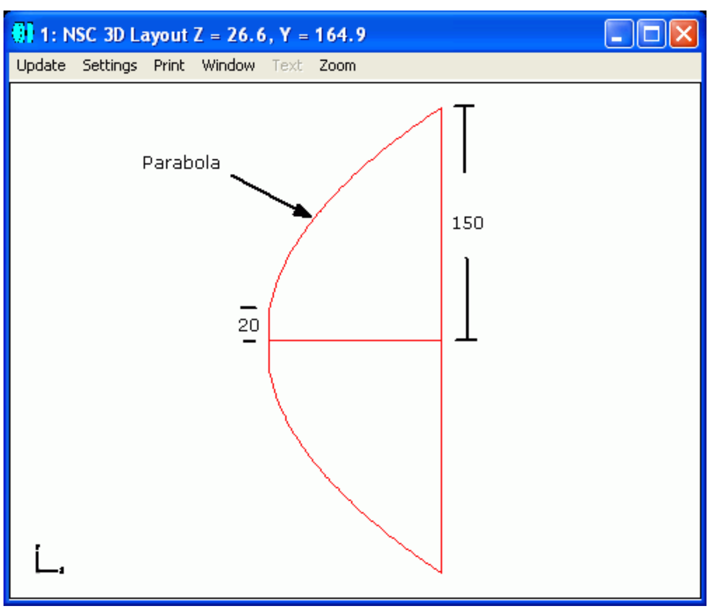


In the editor, type the following parameters in the corresponding column of Standard Surface Object. For some of the parameters, you might have to scroll to the right of the editor to see the title column display the desired parameter name.

Material: Mirror
Radius: 100
Conic: -1 (parabola)
Max Aper: 150
Min Aper: 20 (center hole in the reflector)
All other parameters should be left as default

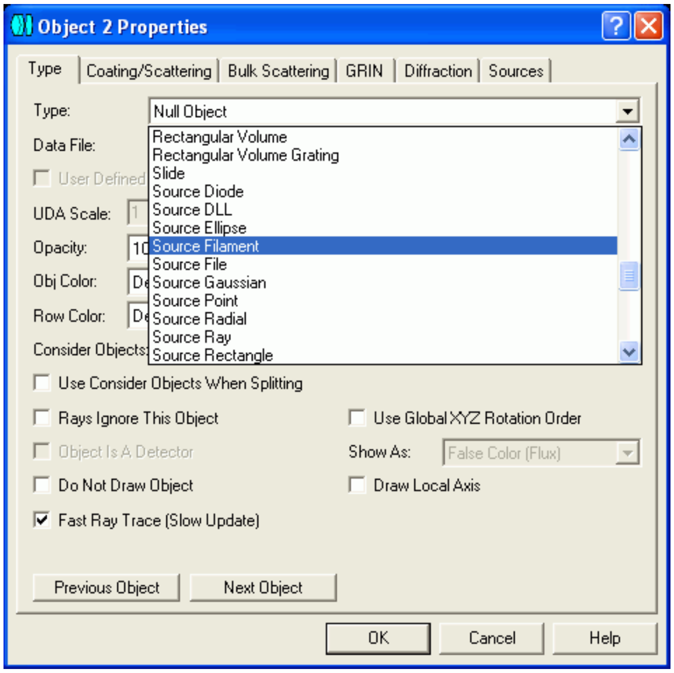


You can open the NSC 3D layout under Analysis>Layout> NSC 3D Layout menu and/or the NSC Shaded model (Analysis>Layout> NSC Shaded model) to see what this reflector looks like.

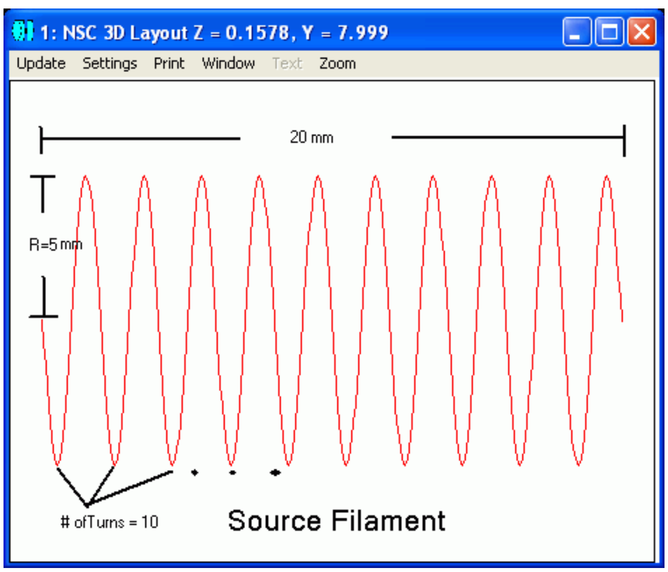


Creating the Source

Change the object #2 type (currently a Null Object) in the editor to Source Filament object by repeating the previous step and choosing Source Filament in the property window.

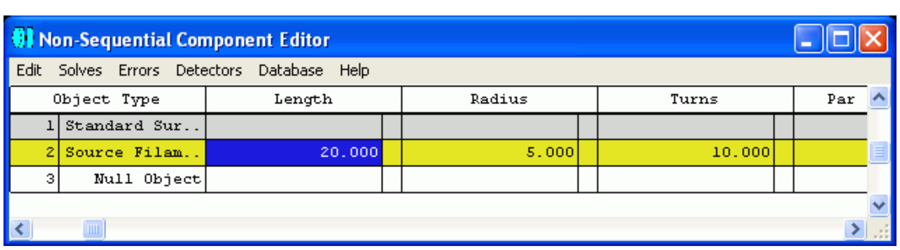


We want the Source Filament to be at the focus of the parabolic reflector to collimate the beam. The filament coil has 10 turns with overall length of 20mm and radius of turn of 5mm.

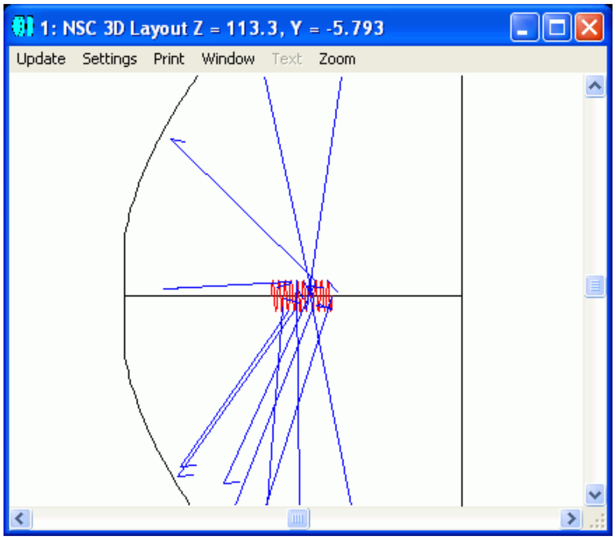


The parameter entered for the Source Filament in the editor should be:

Z position: 50 (focus of the parabolic reflector)
Layout Rays 20
Analysis Rays 5000000
Length: 20
Radius 5
Turns 10



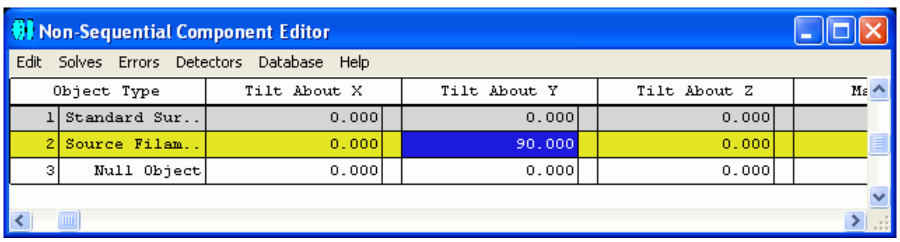
Update the 3D layout by clicking Update in the NSC 3D Layout menu.



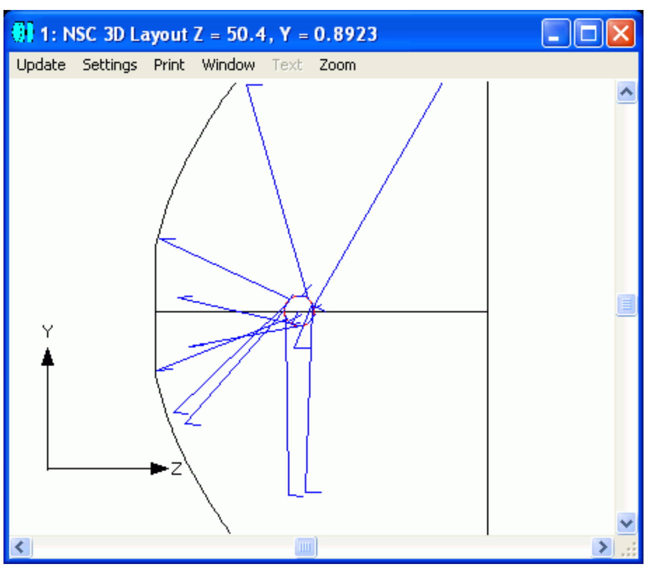
The layout shows 20 rays emanating from the source filament, as specified in the # Layout Rays parameter.

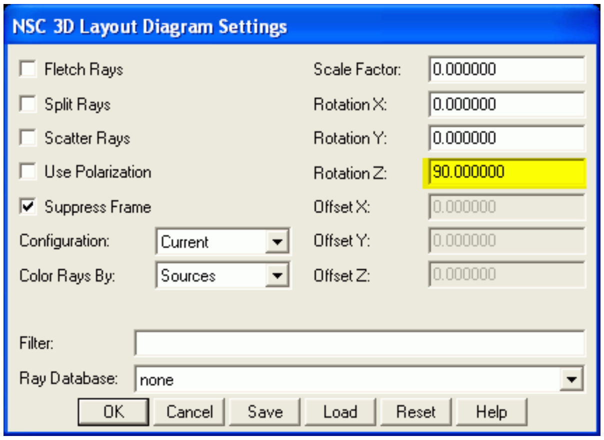
Rotating the Source

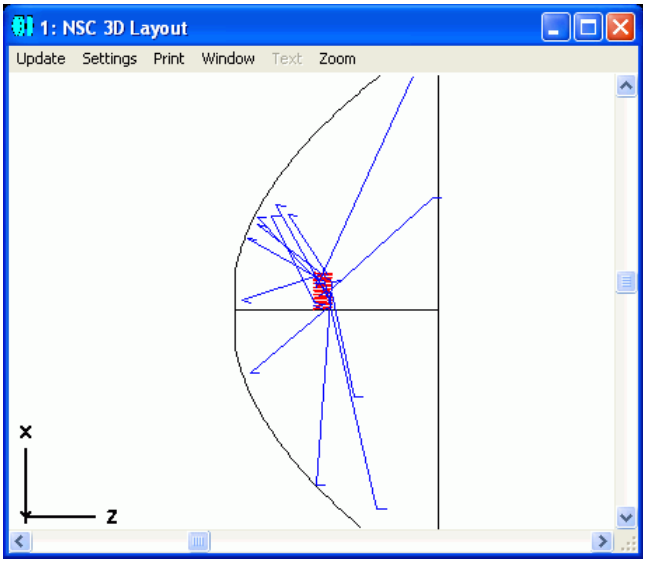
The source is oriented along the Z axis, but suppose we want to orient it along the X axis; we would need to rotate the source object by 90 degrees about the Y axis. Enter 90 for the Tilt About Y parameter of the source.



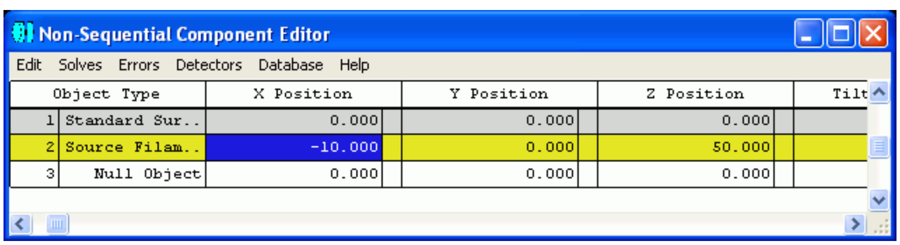
The default YZ plane view of the layout show the filament being oriented along the X axis, however, the XZ plane view reveals that the filament is shifted towards +X axis. To rotate the layout, change the layout view angle in the Layout settings window (click Settings in the Layout menu). You can also rotate the drawing by pressing the left, right up down arrow key and Page Up and Page Down key on your keyboard.







The reason for the decenter is because the rotation axis of the Source Filament is not at the center of the object but at the end. To center the source in the X axis, enter -10 in the X position column.



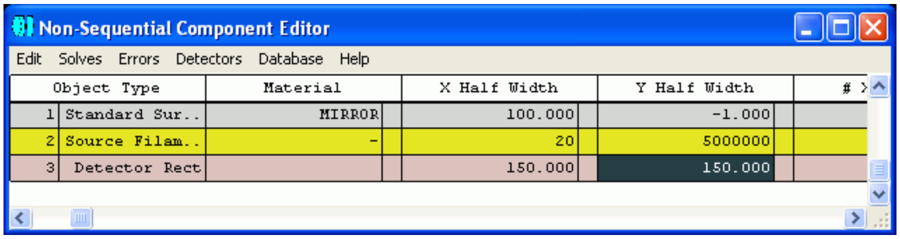
Update the layout and it will now show the desired filament location and orientation.

Placing a Detector

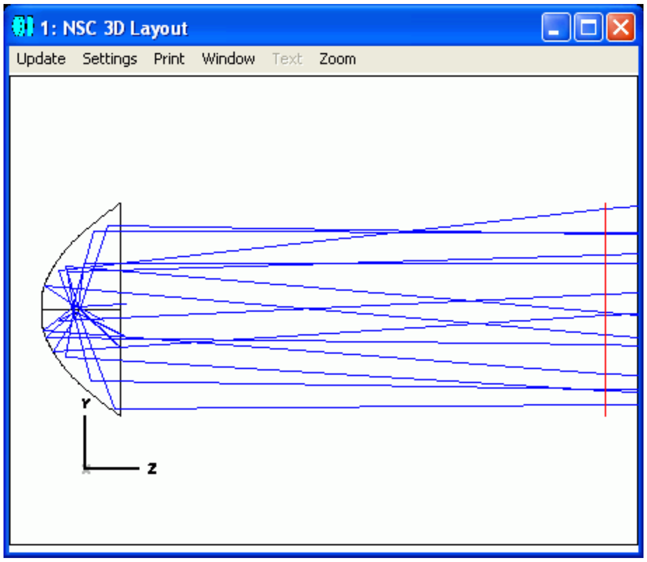
Next step is to place a detector object at some distance from the source to study the irradiance distribution at that location.

Make the 3rd object in the editor a “Detector Rect” and enter the following parameters.

Z position: 800
Material: Blank (do not type the word "Blank" but leave the cell empty)
X Half Width: 150
Y Half Width: 150
X Pixels: 150
Y Pixels: 150
Color: 1 (detector displays inverse greyscale)
All other parameters as default



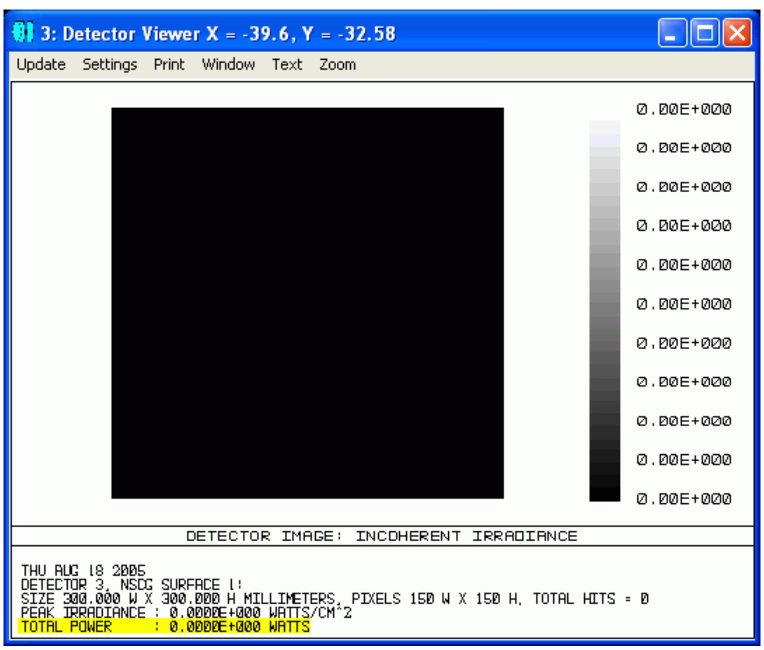
The YZ plane view (default) of the layout shows:



Observe that the layout shows the rays going though the detector. The detector is totally transparent since the material type is air (blank in the editor).

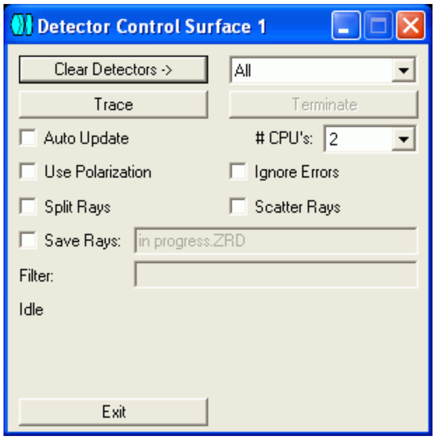
Tracing Analysis Rays to the Detector

To see the optical intensity at the detector, we need to open the Detector Viewer by clicking Analysis > Detectors > Detector Viewer.



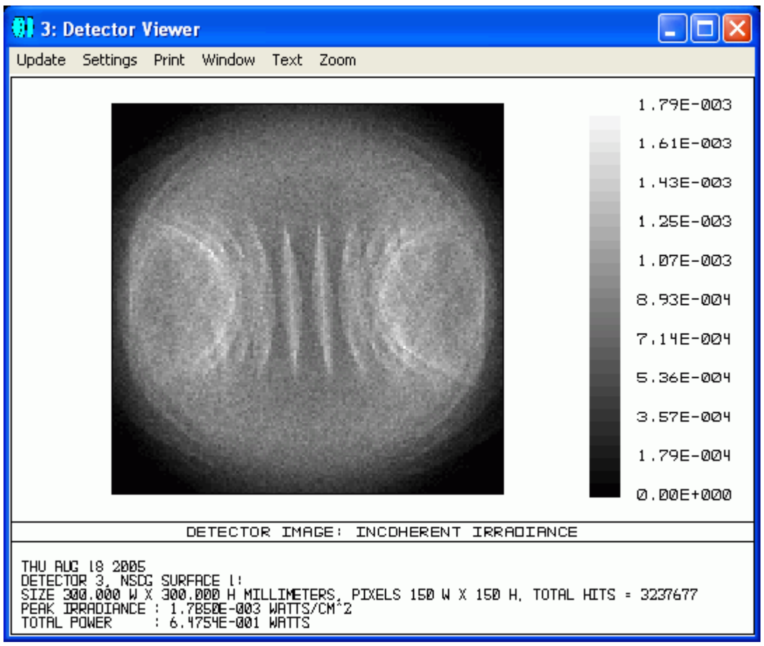
You will notice that the detector viewer is blank with zero total power, even though we see rays reaching the detector in the layout. The reason is because the rays are traced separately for the layout and for the detector viewer. We need to trace the analysis rays to the detector first to see the result. The number of rays traced to the detector is specified in the "# Analysis Rays" parameter column of the Source Filament object in the editor, which is usually a large number: 5 million in this case. **Remember, layout rays do not affect the Detector Viewer results; only analysis rays do**.

To trace analysis rays to the detector, open the Detector Control window under Analysis>Detectors>Ray Trace / Detector Control.

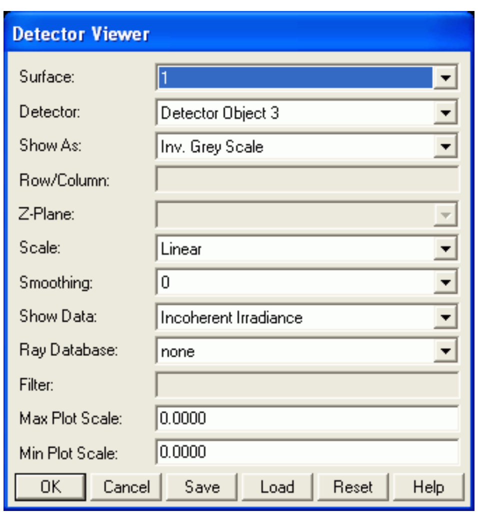


Always remember to the clear the detector by pressing the Clear Detector button, if you do not wish to add the result from the previous trace to the current one. Press Clear Detectors then Trace button followed by Exit.

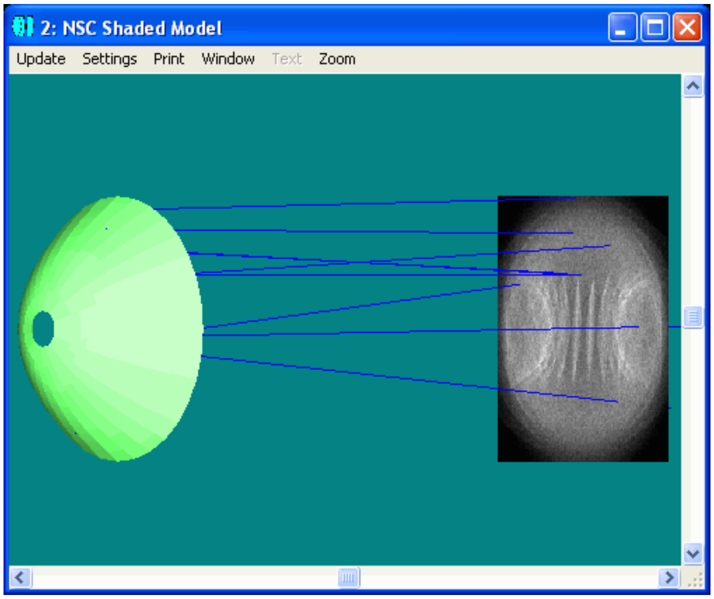
The detector viewer will display the irradiance distribution, revealing the hotspots caused by the filament source.

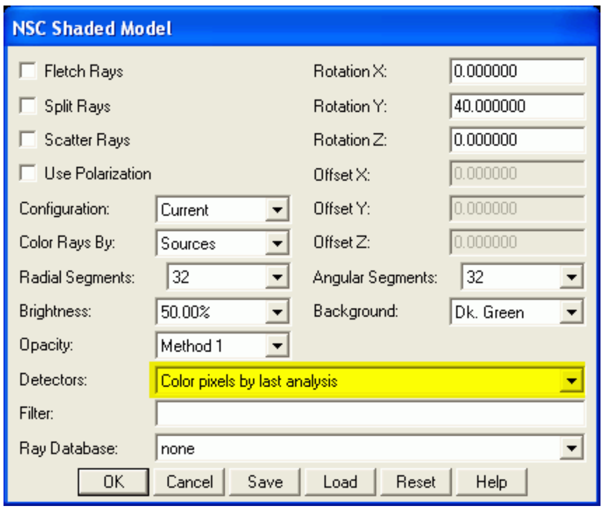


If your Detector Viewer looks different, open the detector viewer settings window and make sure the settings are as follows.



You can also see the detector trace result in the NSC Shaded Model Layout by selecting “Color pixels by last analysis” option in the settings.

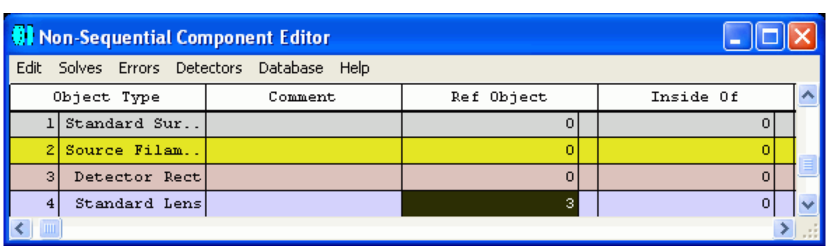




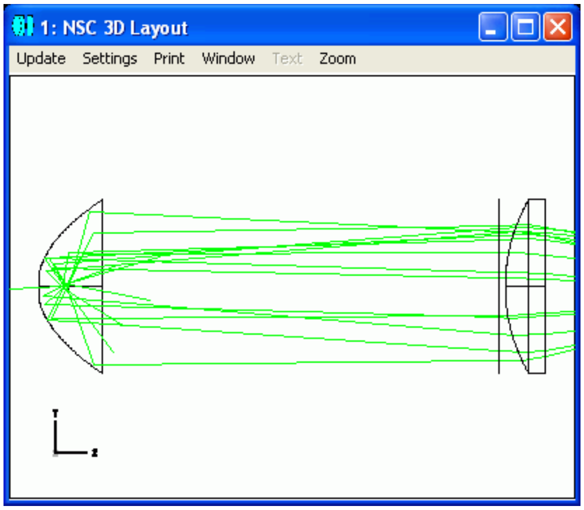
Adding a Plano-Convex Lens

Now that we have a source and a reflector, we will add a refractive plano-convex lens 10mm to the right (+Z) of the detector. Insert a line after Detector Rect in the editor and make the type Standard Lens with the following parameter values.

Ref Object: 3
Z Position: 10
Material: N-BK7
Radius 1: 300
Clear 1: 150
Edge 1: 150
Thickness: 70
Clear 2: 150
Edge 2: 150



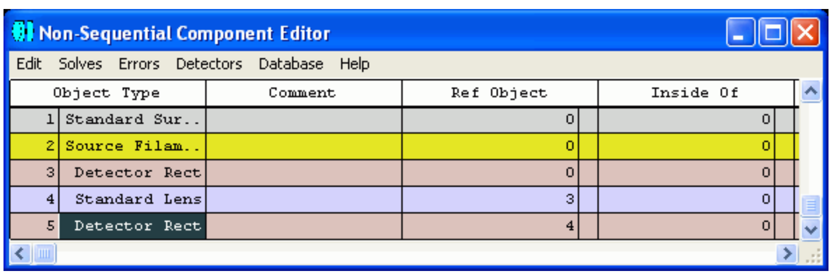
Update the 3D Layout



Notice how we referenced the position of the lens to object 3 (Detector Rect) by entering the value 3 in the Ref Object column and specified the Z position value of 10, instead of referencing to global vertex (Ref Object = 0) and specifying 810mm for the Z position parameter. With the lens positioned referenced to the detector, the lens will always be 10mm to right (+Z) of the detector regardless of the detector position. This is how relative object positions are specified in non-sequential mode.

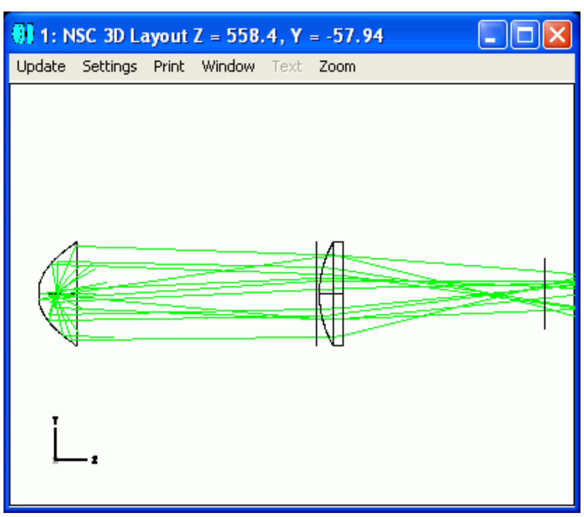
To see how the focused beam looks like, place another detector 650mm to the right (+Z) of the lens with the following parameters.

Ref Object: 4
Z position: 650
Material: Blank
X Half Width: 100
Y Half Width: 100
X Pixels: 150
Y Pixels: 150
Color: 1
All other parameters: Default



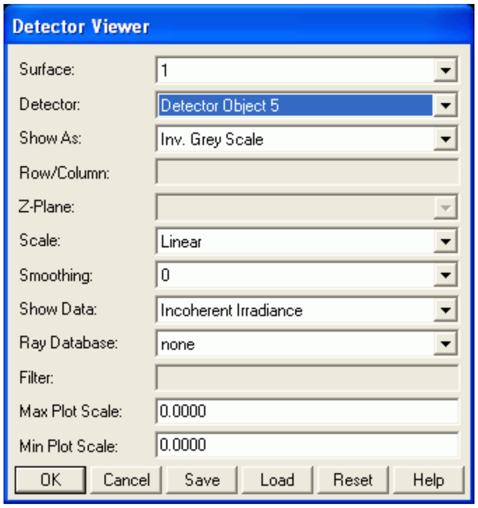
	Object Type	Comment	Ref Object	Inside Of
1	Standard Sur..		0	0
2	Source Filam..		0	0
3	Detector Rect		0	0
4	Standard Lens		3	0
5	Detector Rect		4	0

Update the 3D Layout

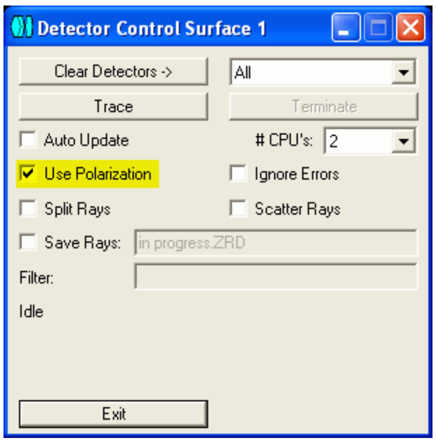


Tracing Analysis Rays and Accounting for Polarization Losses

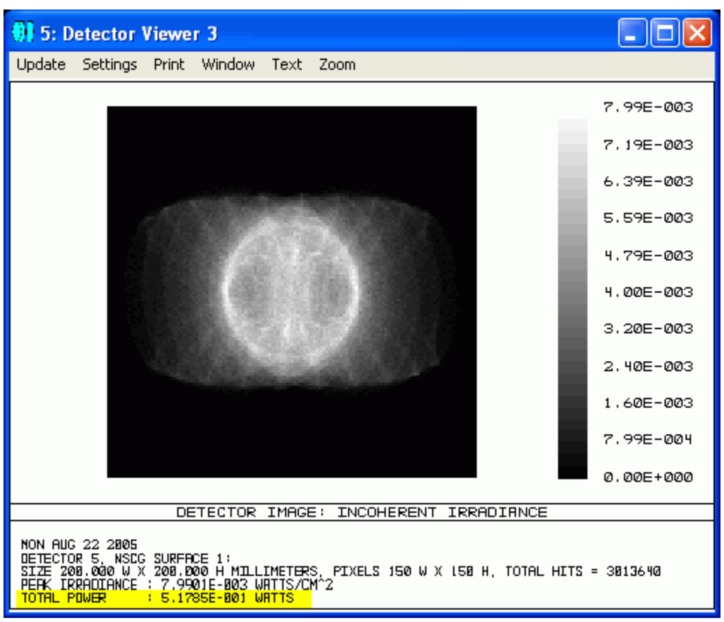
Open another Detector Viewer by clicking Analysis>Detectors>Detector Viewer and make the settings as follows.



Now, we are ready to trace analysis rays to the detector again. Since the N-BK7 lens is uncoated, we need to account for the reflection losses (Fresnel reflection), thus need to enable "Use Polarization" option in the Detector Control window. (Note that we are not splitting rays at this time, and so the reflection losses are accounted for, but the reflected energy is not being propagated. Clicking "Split Rays" will create child rays that take the reflected energy away.)



The total power, reported in the Detector Viewer is now accounting for reflection losses and bulk absorption in the lens.



Adding a Rectangular Lightpipe

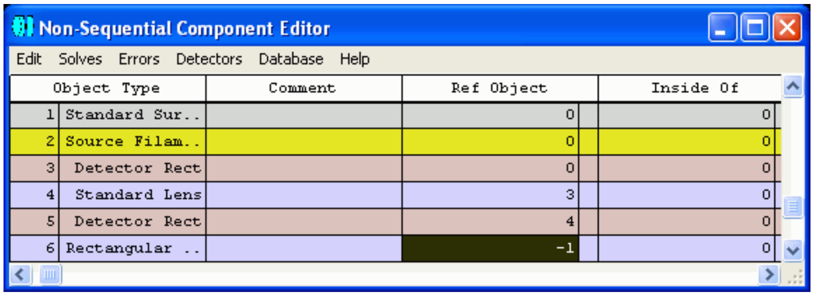
As a final step, we will add a rectangular acrylic lightpipe 20mm to the right (+Z) of the Detector #5.

Add Rectangular Volume object in the editor, after Detector #5, with the following parameters:

Ref Object: -1
Z position: 20
Material: Acrylic
X1 Half Width 70
Y1 Half Width: 70
Z length: 2000
X2 Half Width: 70
Y2 Half Width: 70
All other parameters: Default

When entering the material type Acrylic, you might get the following message. Click Yes and ZEMAX will add to your file the MISC glass catalog, in which the material Acrylic is defined.

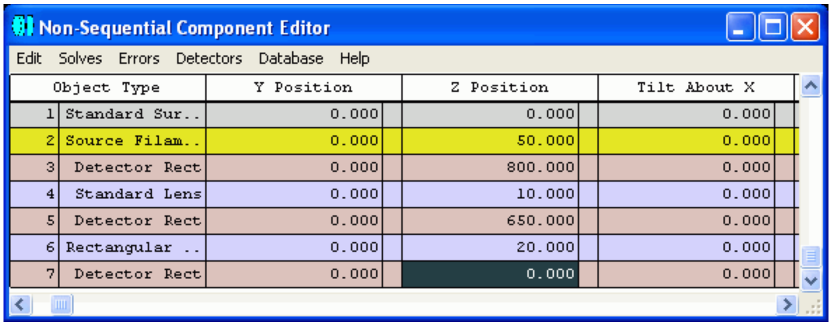
This time, we have set the Ref Object parameter -1, which represent the previous object in the editor (Object #5 Detector Rect). This is same as typing “5” for this parameter. Specifying relative object using negative number for the Ref Object is useful when group of objects in the editor are to be copied and pasted into the same or different non-sequential component editor.



	Object Type	Comment	Ref Object	Inside Of
1	Standard Sur..		0	0
2	Source Filam..		0	0
3	Detector Rect		0	0
4	Standard Lens		3	0
5	Detector Rect		4	0
6	Rectangular ..		-1	0

Place another Detector Rect as object #7 in the editor with following parameters.

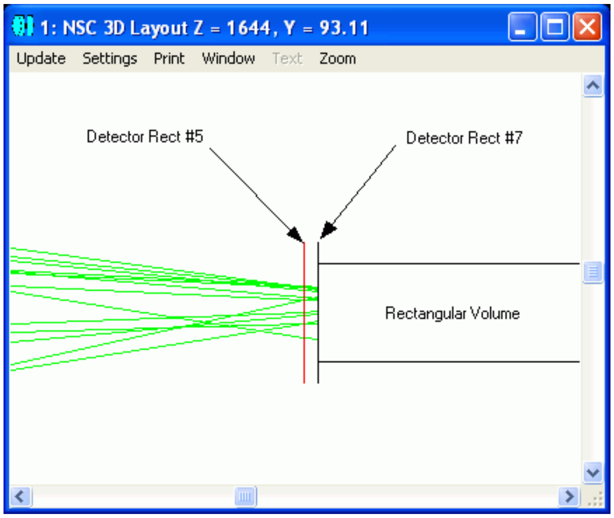
Ref Object: -1 (referenced to Rectangular Volume, using the relative object reference)
Z position: 0 (we will change this value later)
Material: Absorb
X Half Width: 100
Y Half Width: 100
X Pixels: 150
Y Pixels: 150
Color: 1
All other parameters: Default



	Object Type	Y Position	Z Position	Tilt About X
1	Standard Sur..	0.000	0.000	0.000
2	Source Filam..	0.000	50.000	0.000
3	Detector Rect	0.000	800.000	0.000
4	Standard Lens	0.000	10.000	0.000
5	Detector Rect	0.000	650.000	0.000
6	Rectangular ..	0.000	20.000	0.000
7	Detector Rect	0.000	0.000	0.000

Using a Pickup Solve to Position the Detector

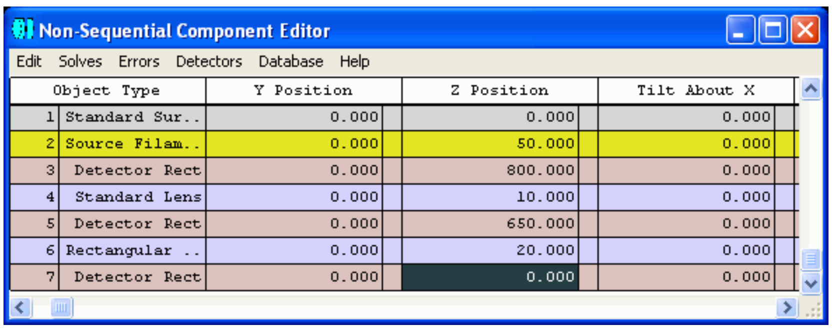
The updates 3D layout will show the following



The material type was set to Absorb to make the detector opaque rather than transparent, evident from the layout.

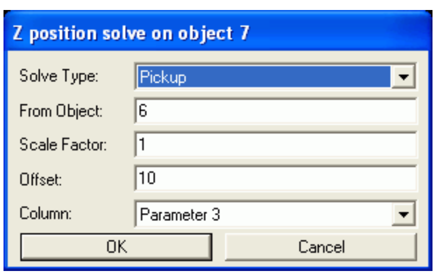
Since we referenced the Detector #7 to the Rectangular Volume and set the Z position as zero, the Detector is located at the front surface of the lightpipe. We want to place this detector 10mm to the right (+Z) of the lightpipe, hence the Z position value should be 2010 mm (thickness of Rectangular Volume + 10). If we change the thickness of the Rectangular Volume to a different value, the Z position of the detector #7 should also be changed. For convenience, instead of typing the value 2010 mm in the editor, we will place a “Pickup solve” for the Z position of the detector. Then the Z position value in the editor will automatically be calculated to be 10 plus whatever the thickness of object 6 is.

Double or right click on the Z position parameter of object #7 in the editor to open the solve window.



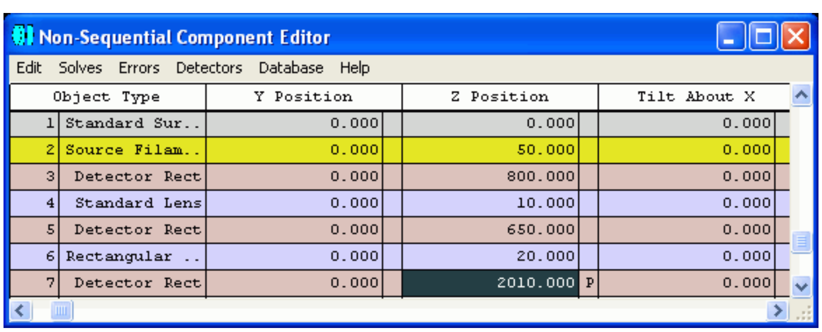
	Object Type	Y Position	Z Position	Tilt About X
1	Standard Sur..	0.000	0.000	0.000
2	Source Filam..	0.000	50.000	0.000
3	Detector Rect	0.000	800.000	0.000
4	Standard Lens	0.000	10.000	0.000
5	Detector Rect	0.000	650.000	0.000
6	Rectangular ..	0.000	20.000	0.000
7	Detector Rect	0.000	0.000	0.000

Type the following parameters.



The Parameter #0 in the Non-Sequential Component Editor corresponds to the “Material” column, so for the Rectangular Volume object, parameter #3 corresponds to “Z Length”.

After pressing OK, a letter “P” will appears next to the parameter in the editor indicating the presence of Pickup solve.



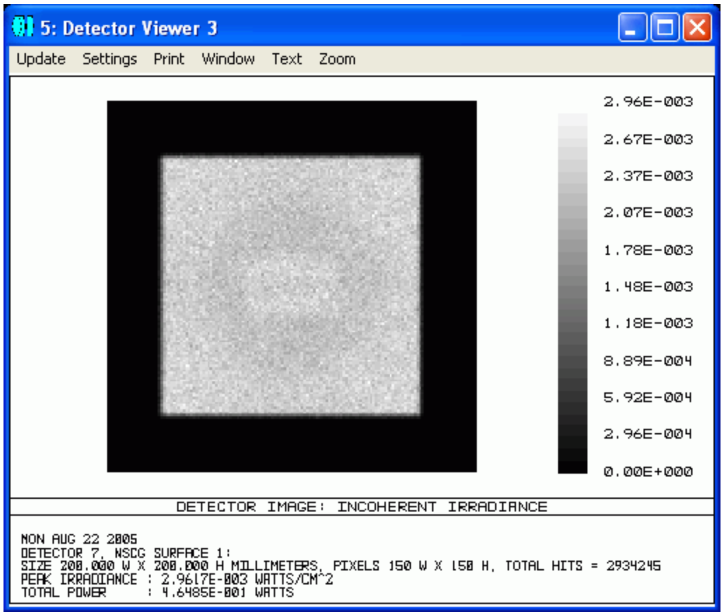
	Object Type	Y Position	Z Position		Tilt About X
1	Standard Sur..	0.000	0.000		0.000
2	Source Filam..	0.000	50.000		0.000
3	Detector Rect	0.000	800.000		0.000
4	Standard Lens	0.000	10.000		0.000
5	Detector Rect	0.000	650.000		0.000
6	Rectangular ..	0.000	20.000		0.000
7	Detector Rect	0.000	2010.000	P	0.000

Ray-Tracing the Complete System

Open a third detector viewer to view detector #7 and re-trace the detector. Remember to use the polarization option and to clear the detectors before tracing the detector, in the Detector Control window.

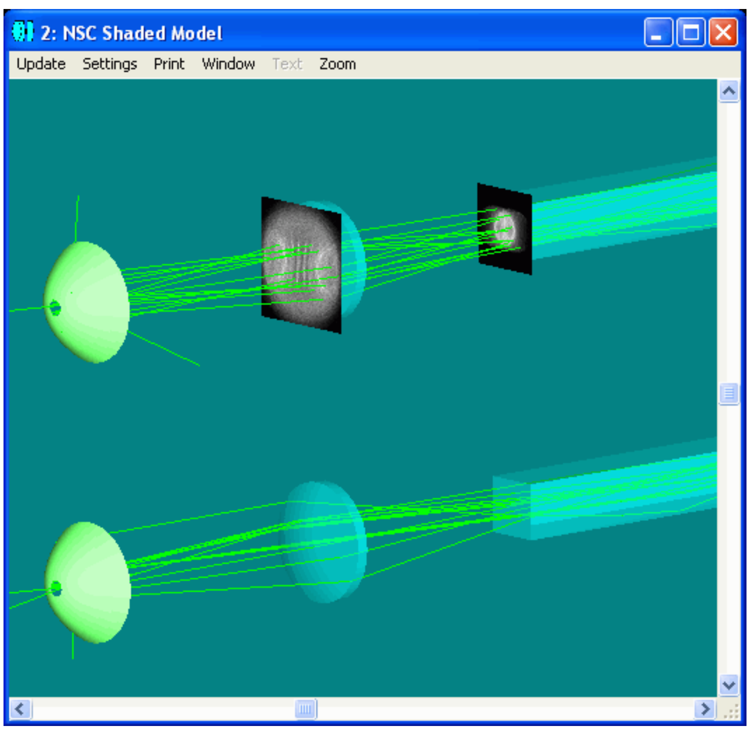
The trace time on a Dell Precision 370 machine running Windows XP Pro, 3.4 GHz Pentium 4 and 1GB of memory is about 2 minutes.

The detector viewer shows that the light pipe has effectively removed the hot spots making the irradiance distribution almost uniform.



The zipped file of the complete system is included with this article as reference.

The NSC Shaded Model can include the detector trace results. For the layout below, multiple-configuration capability of ZEMAX was used to display the system with and without the detector results in the same layout (we will not go into details on how to do this). Users are encouraged to learn about the full non-sequential capacities of ZEMAX by referencing the user manual, reading other knowledge base articles and studying sample files that comes with ZEMAX.



Summary and References

This article has shown how to create and analyze a simple non-sequential system in ZEMAX. In summary:

- There are major differences between the sequential and non-sequential ZEMAX that users need to aware of before attempting to design a non-sequential system
- Layout rays do not affect detector trace results
- To account for Fresnel losses and bulk absorption, the polarization option should be used when tracing analysis rays to the detector

References:

ZEMAX user Manual