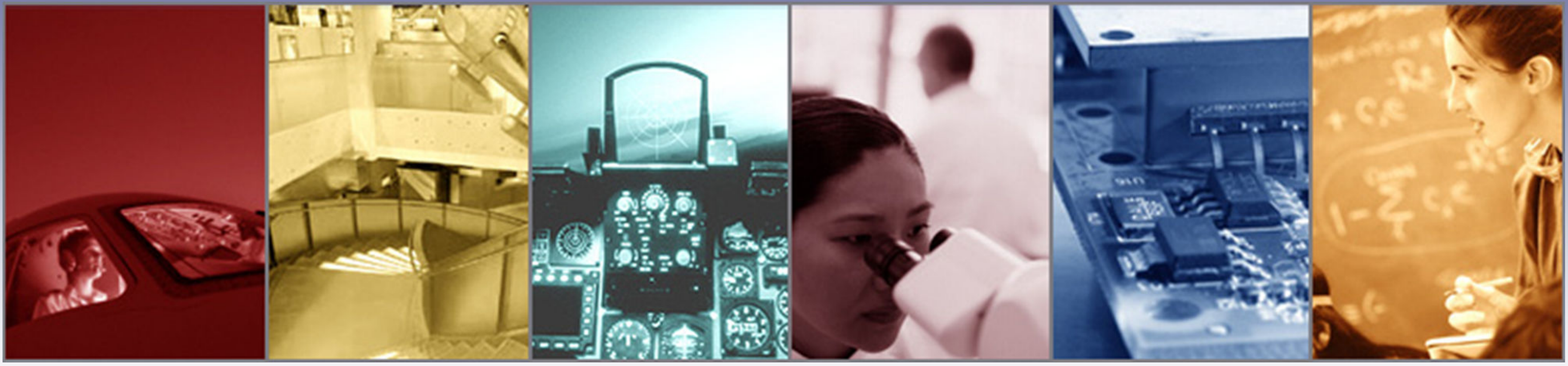

TracePro's Monte Carlo Raytracing Methods, reducing statistical noise, memory usage and raytrace times

Presented by :
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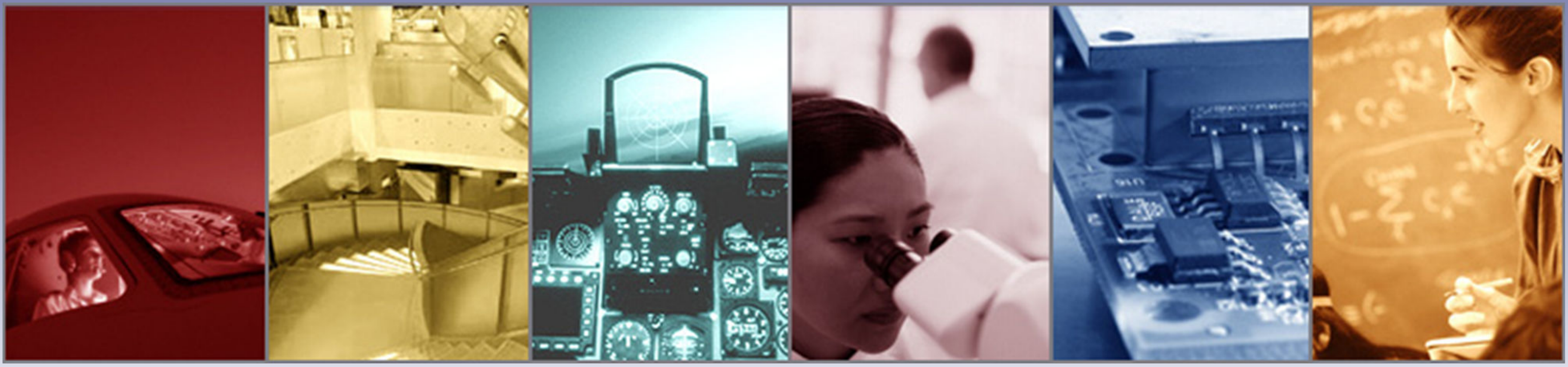


Moderator:
Dave Jacobsen
Senior Application Engineer
Lambda Research Corporation

Presenter:

Michael Gauvin
Vice President of Sales and Marketing
Lambda Research Corporation

Format

The presentation will last approximately 45 minutes followed by a 10-15 minute question and answer session.

Please submit your questions anytime using the GoToWebinar control panel

In this webinar we will:

- Introduce the Monte Carlo Method
- Understand and reduce statistical noise using variance reduction techniques
- Show methods to speed up raytracing
- Show methods to reduce memory usage
- Show both methods of tracing rays in TracePro, splitting and non-splitting
- Understand reverse raytracing

Monte Carlo Ray-tracing and Sampling used in TracePro

- A crude Monte Carlo calculation is the simplest form of a probability experiment
  - Perform an experiment N times, count the number of times n that the event occurs
  - An estimate of the probability is: $p_e = n / N$
  - We can never get an exact value of p_e, but we can make the uncertainty in p_e arbitrarily small by increasing N.
    - The absolute uncertainty in p_e is: $\sigma_{ab} = \sqrt{\frac{p(1-p)}{N}}$
    - The relative uncertainty in p_e is: $\sigma_{rel} = \sqrt{\frac{(1-p)}{pN}}$ (where p denotes the true probability)
  - *Hence, the accuracy of the result is inversely proportional to the square root of the number of trials, quadrupling the number of sampled points halves the error*
- On a higher level, Monte Carlo is a technique of numerical integration for complicated multiple integrals that cannot be done by more conventional numerical methods
  - An integral such as $\int \ldots \int g(x_1, x_2, \ldots, x_L) dx_1 dx_2 \ldots dx_L$ can be estimated by sampling the variables x_i, computing g for this set of samples, and repeating this process N times, summing the terms to obtain the estimate.

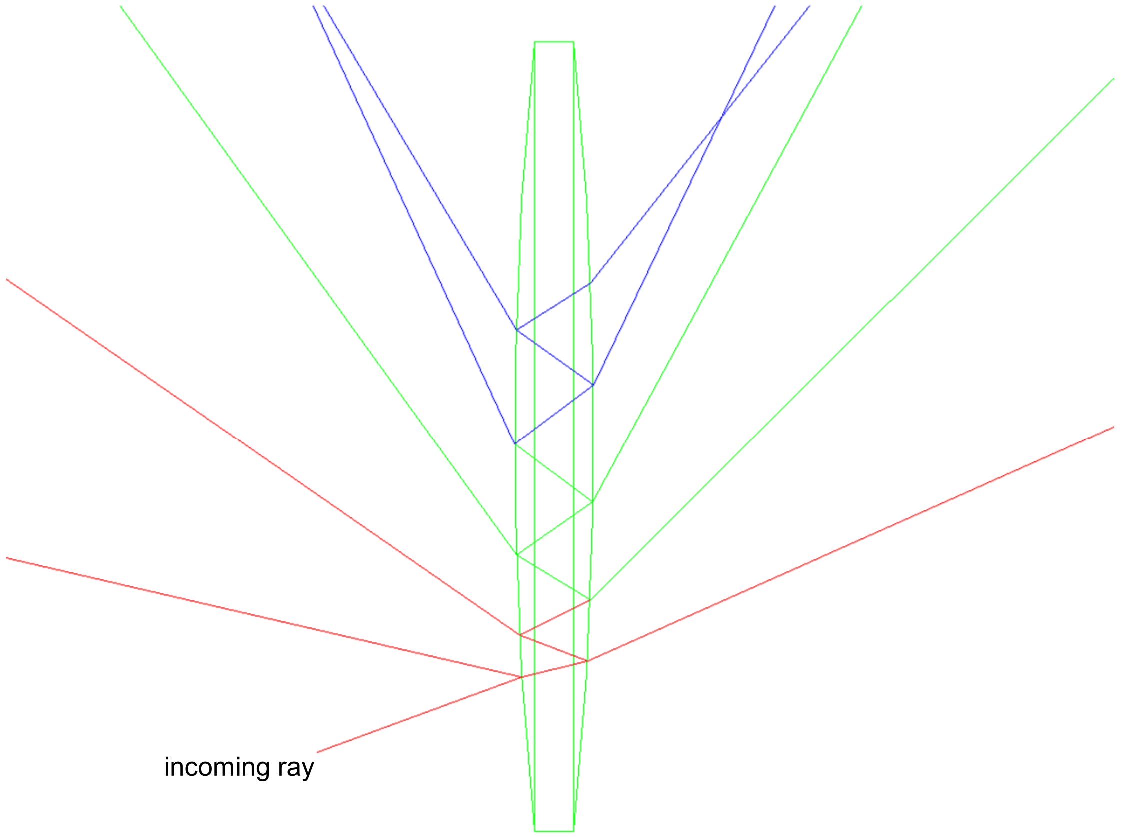
TracePro Variance Reduction Methods

- Variance reduction techniques are used to reduce the variance or uncertainty in the result of a Monte Carlo calculation after a given number of trials. Conversely, the number of trials needed to obtain a given uncertainty can be reduced.
- Splitting is a variance reduction technique used in Monte Carlo simulation. Ray splitting is used in TracePro.
- Importance sampling is a commonly used method for variance reduction.

TracePro's Default Ray Splitting Method

- Ray splitting is a technique in which a ray that strikes a surface can be split into several component rays, namely absorbed, specularly reflected, reflectively scattered, specularly transmitted, and transmissively scattered.
- The flux of the incident ray will also be split, with a fraction of the incident flux assigned to each component ray according to the properties of the surface.
- The process of splitting is repeated at each surface intercept, so that a tree-like structure of rays results.
- This process tremendously improves sampling in most cases, with a tolerable slowing of the raytrace.

Ray Splitting to reduce sampling issues



Importance Sampling

- As a simple example, consider a probability experiment to determine the chance of obtaining 3 on the roll of a pair of dice. Using crude Monte Carlo, we would roll the dice N times and count the number of times n that we get 3. We can also calculate the exact probability of obtaining 3 using the knowledge that each die face is equally likely to come up. The probability is

$$p = 2 \cdot \frac{1}{6} \cdot \frac{1}{6} = \frac{1}{18}$$

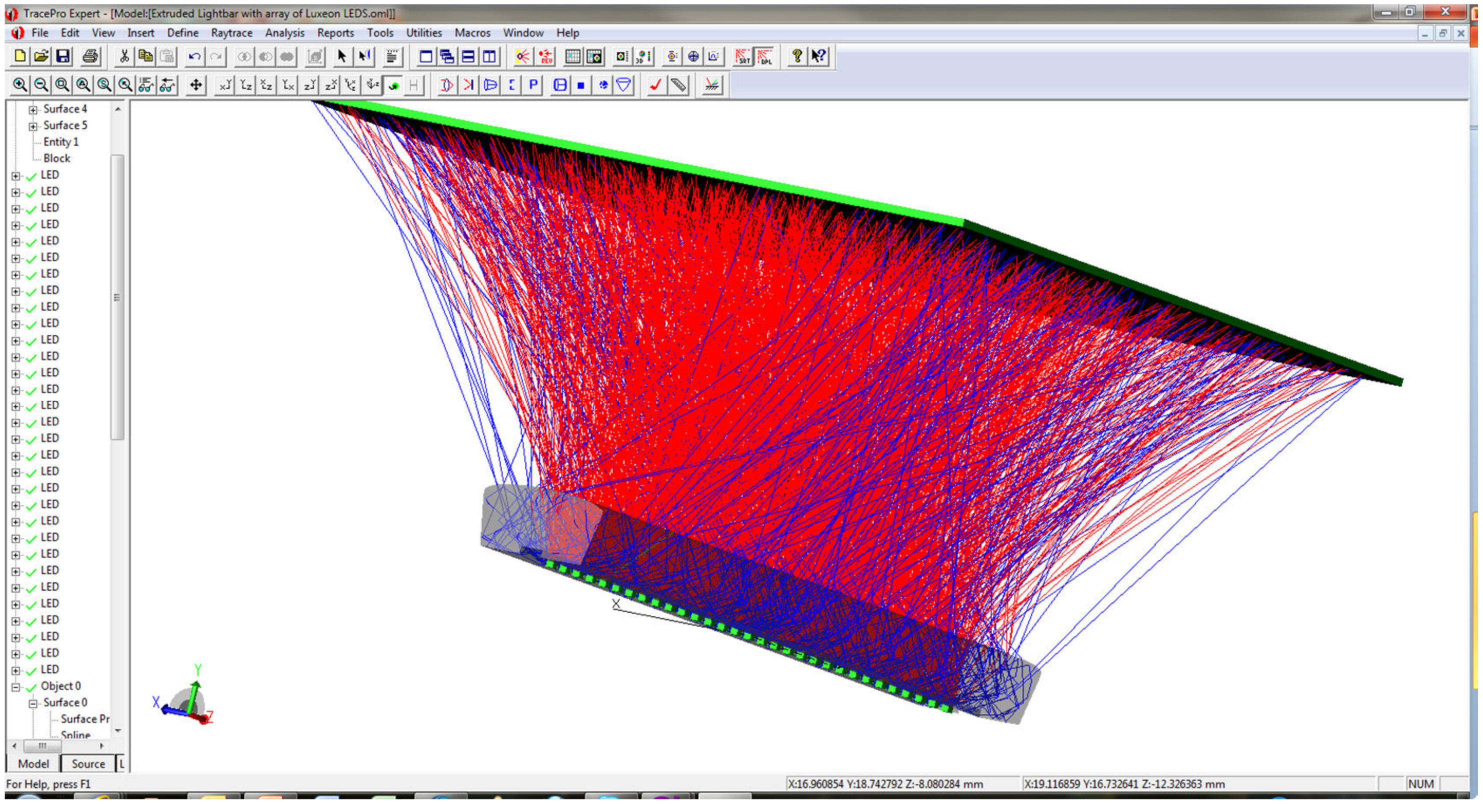
- Now suppose we load the dice so that ones and twos occur with probability 1/3 instead of 1/6. Then 3 would occur 4 times as often as before. The estimated probability of obtaining 3 is now

$$\hat{p} = \frac{1}{4} \cdot \frac{n}{N}$$

- That is, we increase the probability of threes occurring by a factor of 4, then divide the result of our experiment by 4 to obtain the true probability. This is the basis of importance sampling.
- This technique as applied in TracePro causes scattered rays to go in certain directions with higher probability than they would if scattered at random.

Methods to Reduce Noise

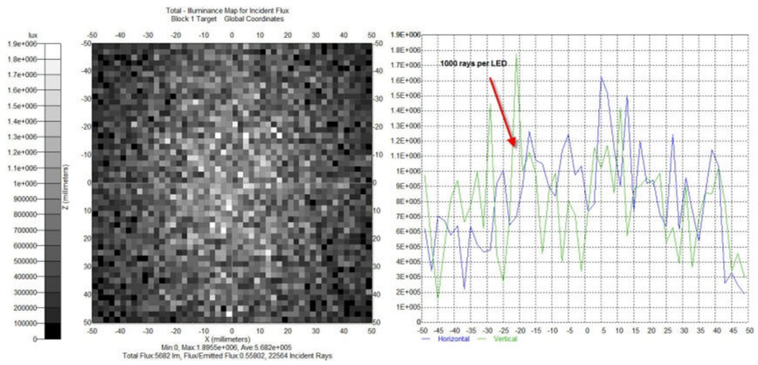
Trace more rays, TracePro is now 64 bit compliant and has multi-threading to trace more rays and in much less time. For example; to achieve best results accurate raytracing of LEDs should be done with over 100,000 rays to reduce sampling noise to find artifacts in the light pattern. We will use the following system shown below with 31 LEDs and a light pipe to discuss the number of rays that should be traced for a simulation.

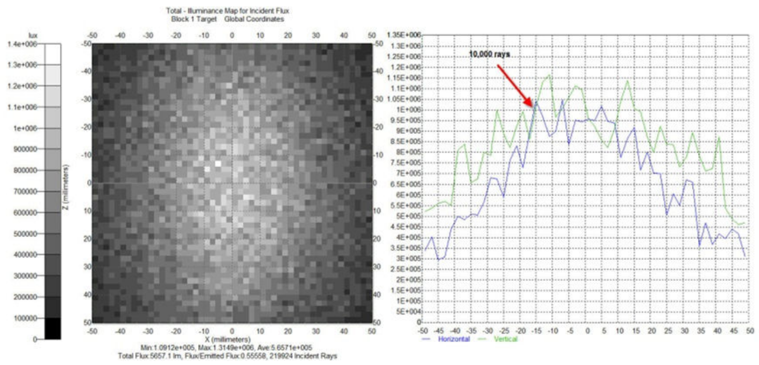

TracePro Expert - [Model:[Extruded Lightbar with array of Luxeon LEDS.oml]]
File Edit View Insert Define Raytrace Analysis Reports Tools Utilities Macros Window Help
Surface 4
Surface 5
Entity 1
Block
LED
Object 0
Surface 0
Surface Pr
Spline
Model
Source
For Help, press F1
NUM

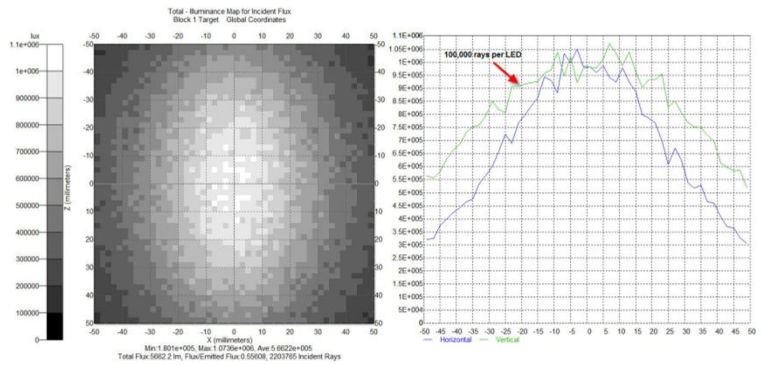
X:16.960854 Y:18.742792 Z:-8.080284 mm   X:19.116859 Y:16.732641 Z:-12.326363 mm

Methods to Reduce Noise

- Lets look at the raw data for 3 cases where we trace 1000, 10000 and 100000 rays from each LED without smoothing and a pixel count of 50.
- If we look at the flux for each case, we see very good agreement, 1000 rays - 5682 lumens, 10,000 rays - 5657 lumens and for 100,000 rays – 5598 lumens.
- But the illuminance plots are quite a bit different and we can easily see the noise in each plot, especially in the profiles on the right of each plot.
- We can see by tracing more and more rays that the pattern fills in and that in the end we will expect to see a smooth line if we trace even more rays.

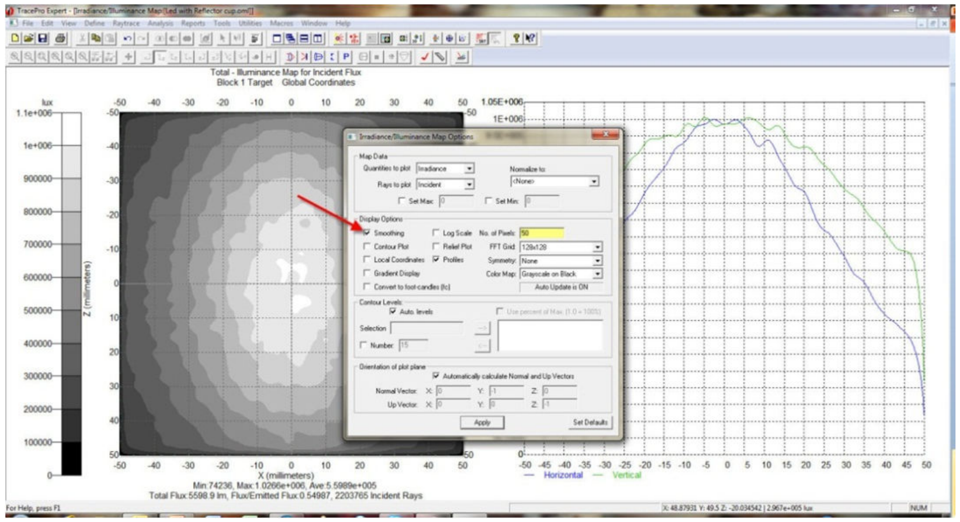






Methods to Reduce Noise

- If we use smoothing we start to approach a smooth line curve. If we look at max flux for the smooth and unsmoothed curves the maximum changes from 1.026E+6 for the smooth case to 1.07E+6 for the non-smoothed case. Not much of a change.
- If we change the number of pixels to 100, 4 times as many bins are used to catch the rays but the maximum flux on the plot stays constant at 1.07E+6.
- So we must run a fine line between smoothing, number of pixels and number of rays to trace to get the best answer



TracePro Expert - [Irradiance/Illuminance Map:Led with Reflector cup.oml]

Total - Illuminance Map for Incident Flux
Block 1 Target   Global Coordinates

Min:74236, Max:1.0266e+006, Ave:5.5989e+005
Total Flux:5598.9 lm, Flux/Emitted Flux:0.54987, 2203765 Incident Rays

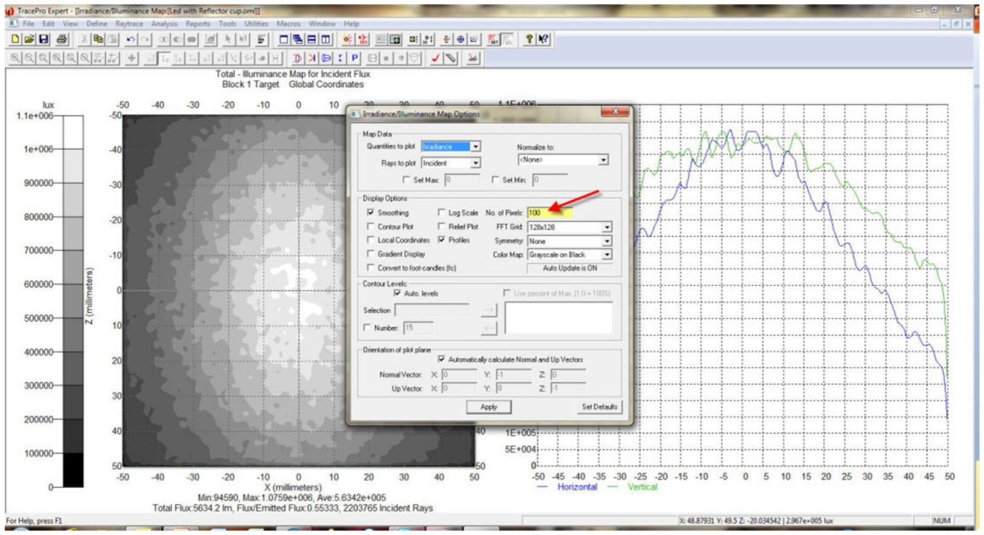
Irradiance/Illuminance Map Options

Map Data: Quantities to plot: Irradiance; Rays to plot: Incident; Normalize to: <None>; Set Max: 0; Set Min: 0

Display Options: [✓ Smoothing]; Log Scale; No. of Pixels: 50; Contour Plot; Relief Plot; FFT Grid: 128x128; Local Coordinates; [✓ Profiles]; Symmetry: None; Gradient Display; Color Map: Grayscale on Black; Convert to foot-candles (fc); Auto Update is ON

Contour Levels: [✓ Auto. levels]; Use percent of Max (1.0 = 100%); Selection; Number: 15

Orientation of plot plane: [✓ Automatically calculate Normal and Up Vectors]; Normal Vector: X: 0 Y: -1 Z: 0; Up Vector: X: 0 Y: 0 Z: -1



TracePro Expert - [Irradiance/Illuminance Map:Led with Reflector cup.oml]

Total - Illuminance Map for Incident Flux
Block 1 Target   Global Coordinates

Min:94590, Max:1.0759e+006, Ave:5.6342e+005
Total Flux:5634.2 lm, Flux/Emitted Flux:0.55333, 2203765 Incident Rays

Irradiance/Illuminance Map Options

Map Data: Quantities to plot: Irradiance; Rays to plot: Incident; Normalize to: <None>; Set Max: 0; Set Min: 0

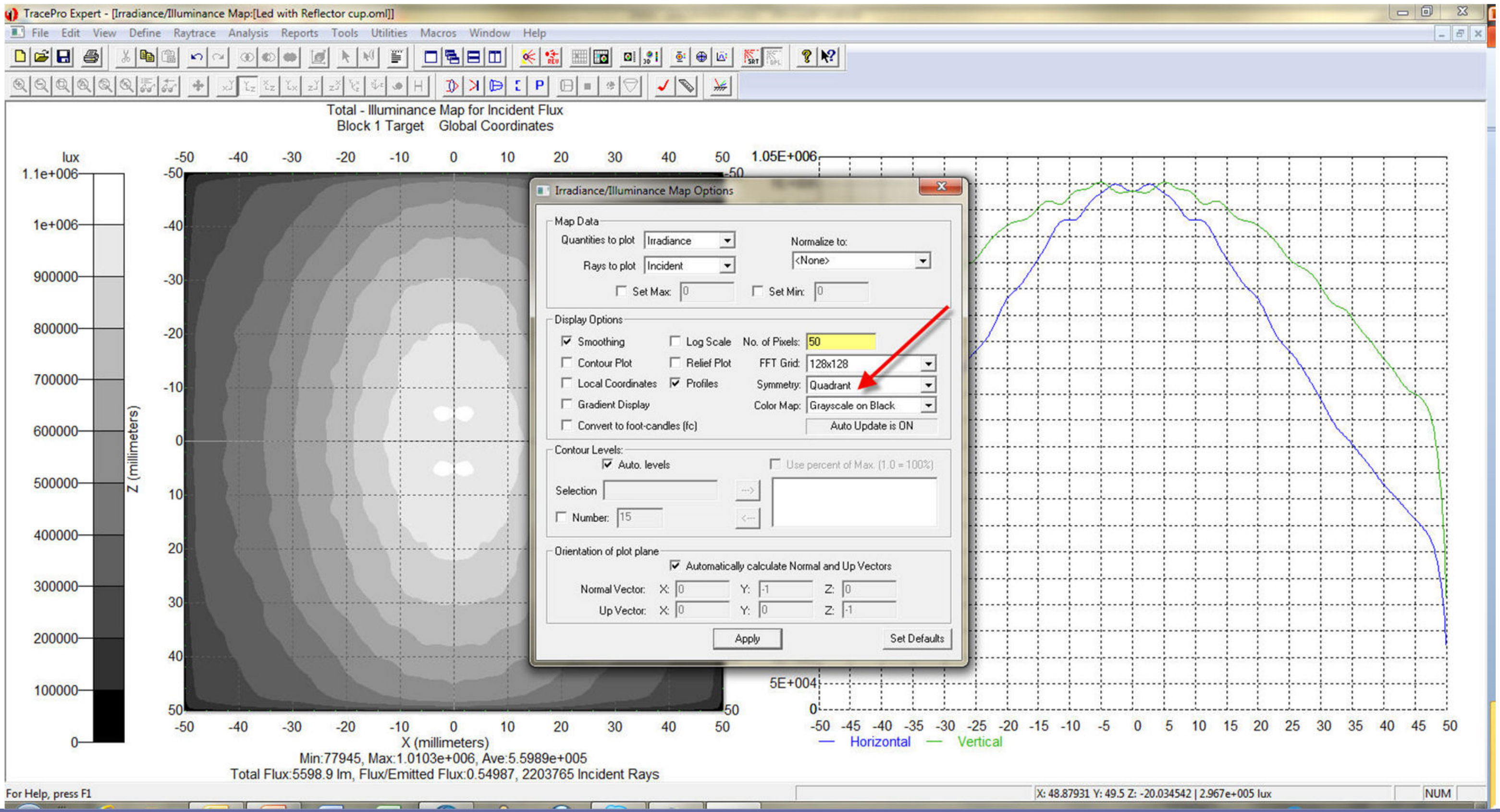
Display Options: [✓ Smoothing]; Log Scale; No. of Pixels: 100; Contour Plot; Relief Plot; FFT Grid: 128x128; Local Coordinates; [✓ Profiles]; Symmetry: None; Gradient Display; Color Map: Grayscale on Black; Convert to foot-candles (fc); Auto Update is ON

Contour Levels: [✓ Auto. levels]; Use percent of Max (1.0 = 100%); Selection; Number: 15

Orientation of plot plane: [✓ Automatically calculate Normal and Up Vectors]; Normal Vector: X: 0 Y: -1 Z: 0; Up Vector: X: 0 Y: 0 Z: -1

Methods to Reduce Noise

Use symmetry conditions when possible in illuminance maps and candela plots to get better answers. We know that in our LED/lightpipe system that we have quadrant symmetry in the system. The lightpipe is symmetric about both axes. This allows the user to add the illuminance from all four quadrants together and then divide the result by 4 to get a more accurate answer.


TracePro Expert - [Irradiance/Illuminance Map:[Led with Reflector cup.oml]]
File Edit View Define Raytrace Analysis Reports Tools Utilities Macros Window Help
lux
Z (millimeters)
X (millimeters)
1.05E+006
5E+004
Horizontal
Vertical
Apply
Set Defaults

Total - Illuminance Map for Incident Flux
Block 1 Target Global Coordinates

Min:77945, Max:1.0103e+006, Ave:5.5989e+005
Total Flux:5598.9 lm, Flux/Emitted Flux:0.54987, 2203765 Incident Rays

Irradiance/Illuminance Map Options

Map Data
- Quantities to plot: Irradiance
- Rays to plot: Incident
- Normalize to: <None>
- ☐ Set Max: 0
- ☐ Set Min: 0

Display Options
- ☑ Smoothing
- ☐ Contour Plot
- ☐ Local Coordinates
- ☐ Gradient Display
- ☐ Convert to foot-candles (fc)
- ☐ Log Scale
- ☐ Relief Plot
- ☑ Profiles
- No. of Pixels: 50
- FFT Grid: 128x128
- Symmetry: Quadrant
- Color Map: Grayscale on Black
- Auto Update is ON

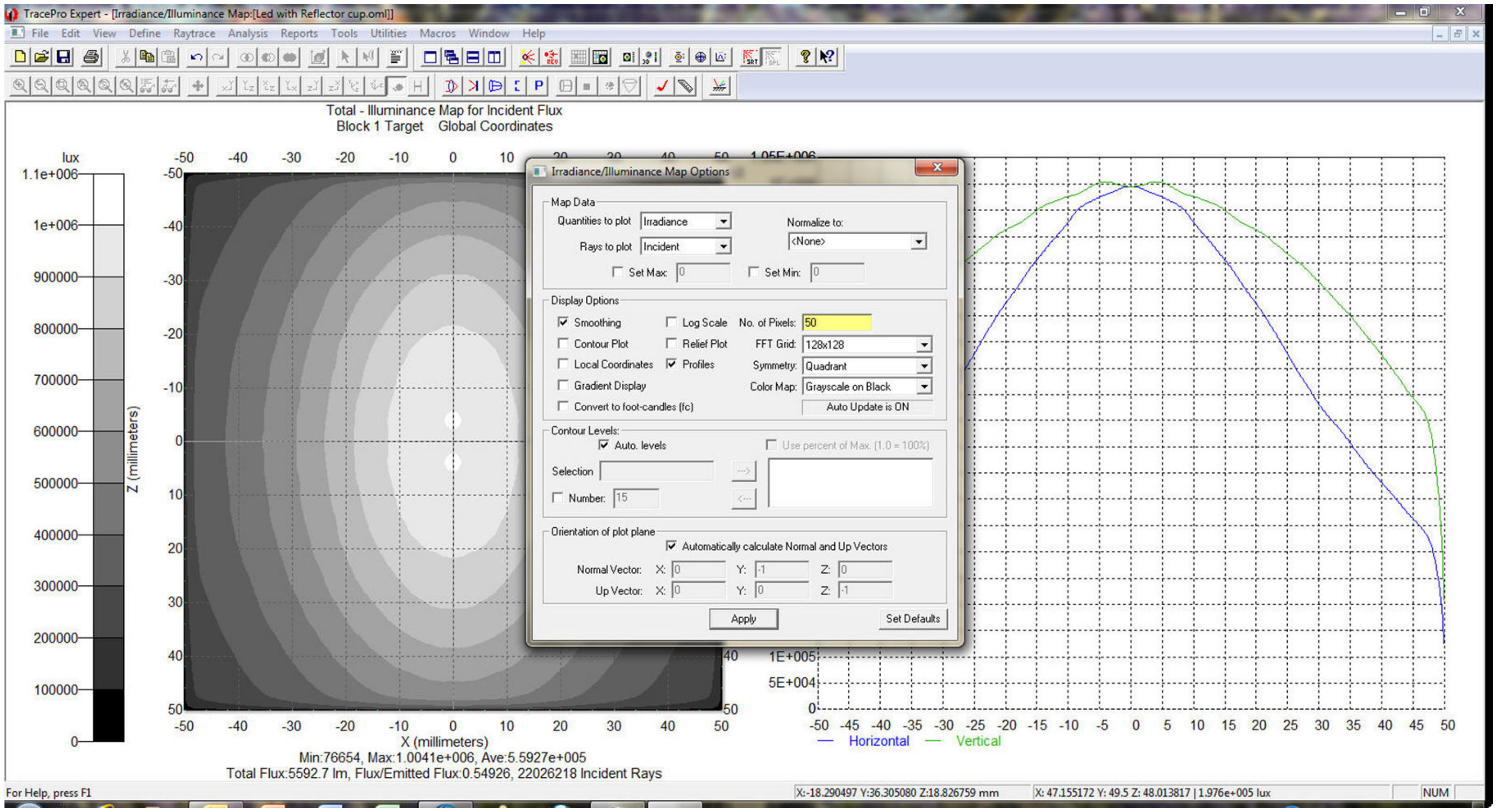
Contour Levels:
- ☑ Auto. levels
- ☐ Use percent of Max. (1.0 = 100%)
- Selection
- ☐ Number: 15

Orientation of plot plane
- ☑ Automatically calculate Normal and Up Vectors
- Normal Vector: X: 0 Y: -1 Z: 0
- Up Vector: X: 0 Y: 0 Z: -1

For Help, press F1
X: 48.87931 Y: 49.5 Z: -20.034542 | 2.967e+005 lux
NUM

Methods to Reduce Noise

A final raytrace with 1 million rays per LED for a total of 31 million rays is shown below, over 22 million hit the target. The final answer with smoothing, 50 pixels and quadrant symmetry is shown below. As you can see the lines are very smooth and there is very little noise in the plot.


TracePro Expert - [Irradiance/Illuminance Map:[Led with Reflector cup.oml]]
File Edit View Define Raytrace Analysis Reports Tools Utilities Macros Window Help
Total - Illuminance Map for Incident Flux
Block 1 Target Global Coordinates
lux
1.1e+006
1e+006
900000
800000
700000
600000
500000
400000
300000
200000
100000
0
Z (millimeters)
X (millimeters)
1.05E+006
1E+005
5E+004
Horizontal
Vertical

Irradiance/Illuminance Map Options

Map Data
- Quantities to plot: Irradiance
- Rays to plot: Incident
- Normalize to: <None>
- ☐ Set Max: 0
- ☐ Set Min: 0

Display Options
- ☑ Smoothing
- ☐ Log Scale
- No. of Pixels: 50
- ☐ Contour Plot
- ☐ Relief Plot
- FFT Grid: 128x128
- ☐ Local Coordinates
- ☑ Profiles
- Symmetry: Quadrant
- ☐ Gradient Display
- Color Map: Grayscale on Black
- ☐ Convert to foot-candles (fc)
- Auto Update is ON

Contour Levels:
- ☑ Auto. levels
- ☐ Use percent of Max. (1.0 = 100%)
- Selection
- ☐ Number: 15

Orientation of plot plane
- ☑ Automatically calculate Normal and Up Vectors
- Normal Vector: X: 0 Y: -1 Z: 0
- Up Vector: X: 0 Y: 0 Z: -1

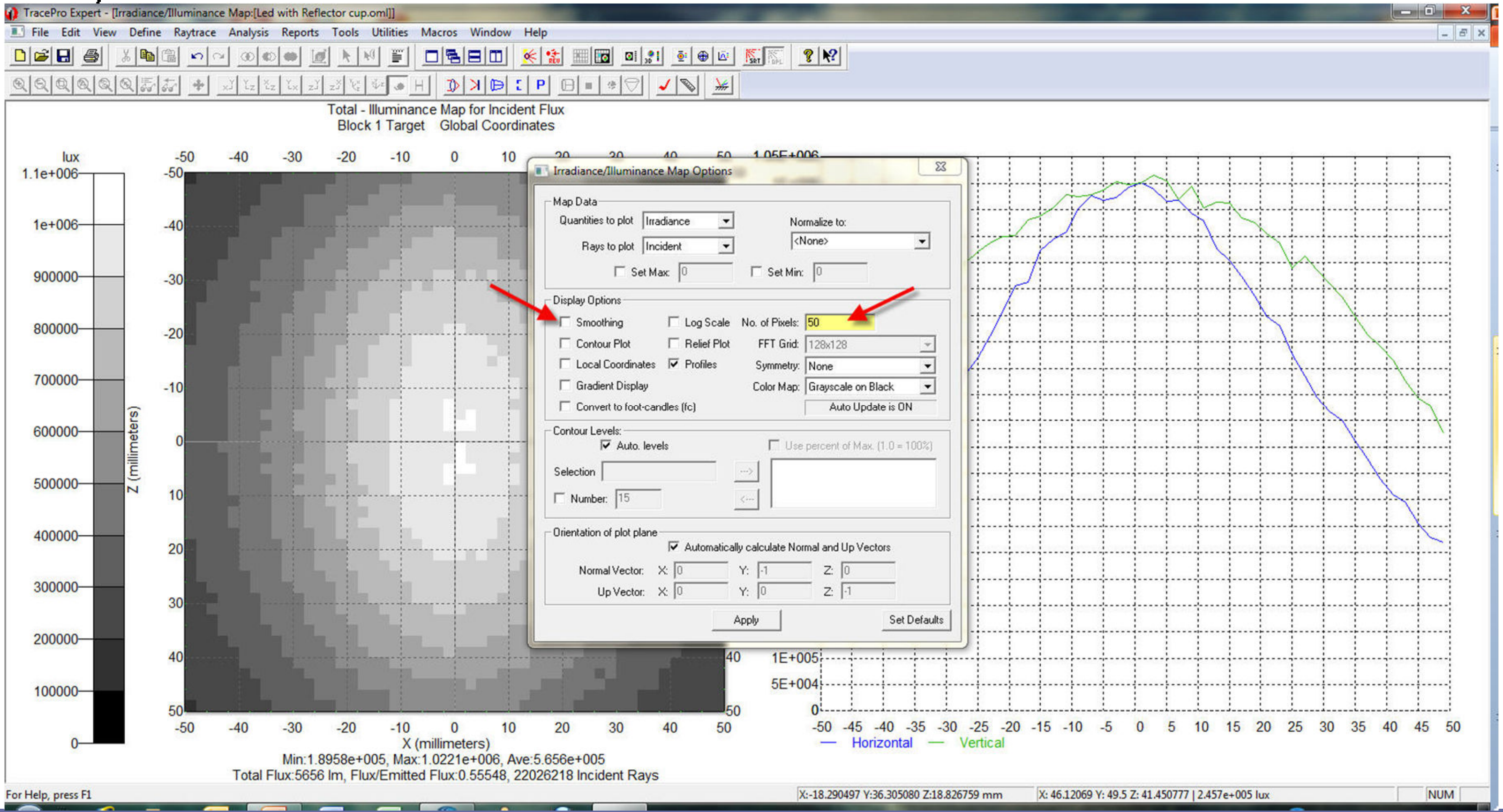
Apply Set Defaults

Min:76654, Max:1.0041e+006, Ave:5.5927e+005
Total Flux:5592.7 lm, Flux/Emitted Flux:0.54926, 22026218 Incident Rays

For Help, press F1 X:-18.290497 Y:36.305080 Z:18.826759 mm X: 47.155172 Y: 49.5 Z: 48.013817 | 1.976e+005 lux NUM

Methods to Find Artifacts

The illuminance map for the same 1 million per LED raytrace is shown below. This map has no smoothing or quadrant symmetry. If you are looking for artifacts, this is the plot you should use. Each one of the pixels or bins is 2 mm in size, 100 mm square target with 50 bins. If you are looking for artifacts smaller than 2 mm in size you will need to increase the number of pixels or bins.


TracePro Expert - [Irradiance/Illuminance Map:[Led with Reflector cup.oml]]
File Edit View Define Raytrace Analysis Reports Tools Utilities Macros Window Help
Total - Illuminance Map for Incident Flux
Block 1 Target Global Coordinates
lux
Z (millimeters)
X (millimeters)
1.05E+006
1E+005
5E+004
Horizontal
Vertical

Irradiance/Illuminance Map Options

Map Data
Quantities to plot: Irradiance
Rays to plot: Incident
Normalize to: <None>
☐ Set Max: 0 ☐ Set Min: 0

Display Options
☐ Smoothing ☐ Log Scale No. of Pixels: 50
☐ Contour Plot ☐ Relief Plot FFT Grid: 128x128
☐ Local Coordinates ☑ Profiles Symmetry: None
☐ Gradient Display Color Map: Grayscale on Black
☐ Convert to foot-candles (fc) Auto Update is ON

Contour Levels:
☑ Auto. levels ☐ Use percent of Max. (1.0 = 100%)
Selection
☐ Number: 15

Orientation of plot plane
☑ Automatically calculate Normal and Up Vectors
Normal Vector: X: 0 Y: -1 Z: 0
Up Vector: X: 0 Y: 0 Z: -1

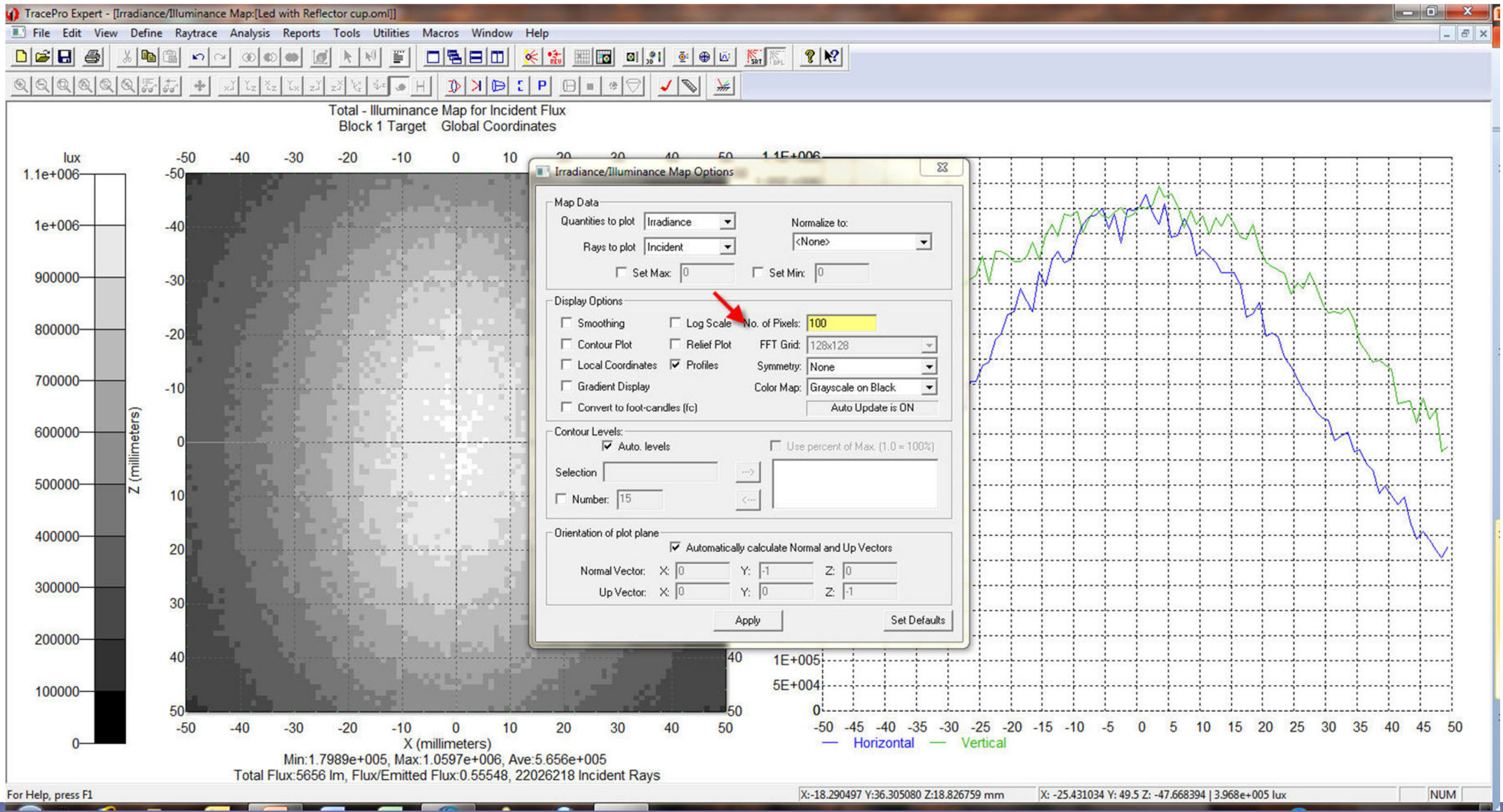
Apply Set Defaults

Min:1.8958e+005, Max:1.0221e+006, Ave:5.656e+005
Total Flux:5656 lm, Flux/Emitted Flux:0.55548, 22026218 Incident Rays

For Help, press F1 | X:-18.290497 Y:36.305080 Z:18.826759 mm | X: 46.12069 Y: 49.5 Z: 41.450777 | 2.457e+005 lux | NUM

Methods to Find Artifacts

If we want to find artifacts that are 1 mm in size, all we need to do is set the number of pixels in the illuminance options to 100 and now the pixel or bin size will be set to 1 mm in size. The illuminance map for the 100 pixel setting is shown below. So judicious use of the illuminance map options and an understanding of how many rays to trace is important to output a correct answer.


TracePro Expert - [Irradiance/Illuminance Map:[Led with Reflector cup.oml]]
File Edit View Define Raytrace Analysis Reports Tools Utilities Macros Window Help
Total - Illuminance Map for Incident Flux
Block 1 Target Global Coordinates
lux
Z (millimeters)
X (millimeters)
Horizontal
Vertical
For Help, press F1
NUM

Min:1.7989e+005, Max:1.0597e+006, Ave:5.656e+005
Total Flux:5656 lm, Flux/Emitted Flux:0.55548, 22026218 Incident Rays

X:-18.290497 Y:36.305080 Z:18.826759 mm
X: -25.431034 Y: 49.5 Z: -47.668394 | 3.968e+005 lux

Irradiance/Illuminance Map Options

Map Data
- Quantities to plot: Irradiance
- Rays to plot: Incident
- Normalize to: <None>
- ☐ Set Max: 0
- ☐ Set Min: 0

Display Options
- ☐ Smoothing
- ☐ Contour Plot
- ☐ Local Coordinates
- ☐ Gradient Display
- ☐ Convert to foot-candles (fc)
- ☐ Log Scale
- ☐ Relief Plot
- ☑ Profiles
- No. of Pixels: 100
- FFT Grid: 128x128
- Symmetry: None
- Color Map: Grayscale on Black
- Auto Update is ON

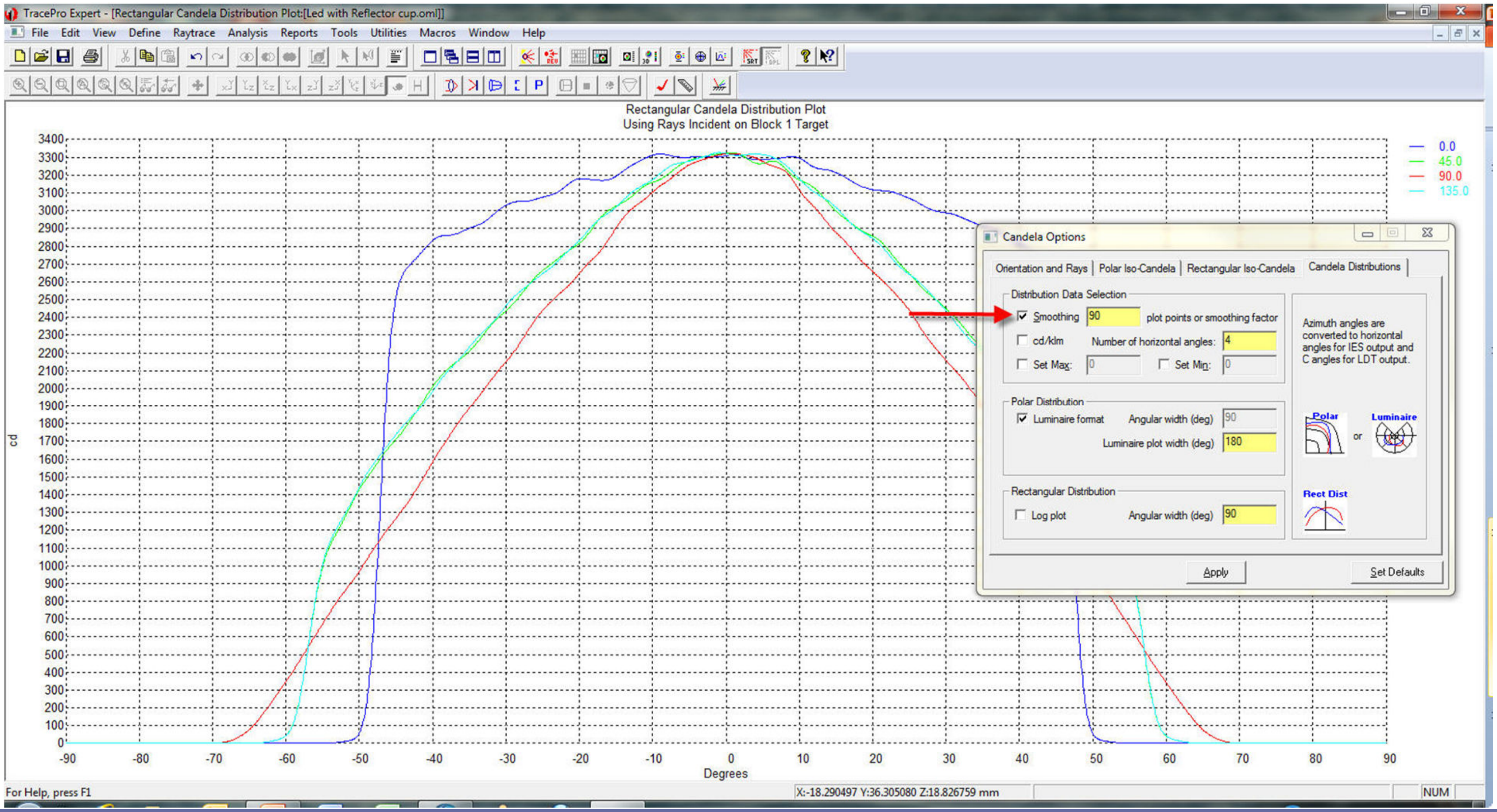
Contour Levels:
- ☑ Auto. levels
- ☐ Use percent of Max. (1.0 = 100%)
- Selection
- ☐ Number: 15

Orientation of plot plane
- ☑ Automatically calculate Normal and Up Vectors
- Normal Vector: X: 0 Y: -1 Z: 0
- Up Vector: X: 0 Y: 0 Z: -1

Apply | Set Defaults

Methods to Find Angular Artifacts

For candela plots, the number of bins is in angular space for the rectangular candela distribution plot. The plot points refer to the angular bins for the entire hemispherical plot which is set to for this plot to be 90 bins which specifies an angular bin resolution of 360 degrees for the extent of the plot divided by 90 bins or 4 degrees for each bin.



File Edit View Define Raytrace Analysis Reports Tools Utilities Macros Window Help
Rectangular Candela Distribution Plot
Using Rays Incident on Block 1 Target
cd
Degrees
0.0
45.0
90.0
135.0
Polar
or
Luminaire
Rect Dist

TracePro Expert - [Rectangular Candela Distribution Plot:[Led with Reflector cup.oml]]

Candela Options

Orientation and Rays | Polar Iso-Candela | Rectangular Iso-Candela | Candela Distributions

Distribution Data Selection

[✓] Smoothing 90 plot points or smoothing factor

[ ] cd/klm Number of horizontal angles: 4

[ ] Set Max: 0 [ ] Set Min: 0

Azimuth angles are converted to horizontal angles for IES output and C angles for LDT output.

Polar Distribution

[✓] Luminaire format Angular width (deg) 90

Luminaire plot width (deg) 180

Rectangular Distribution

[ ] Log plot Angular width (deg) 90

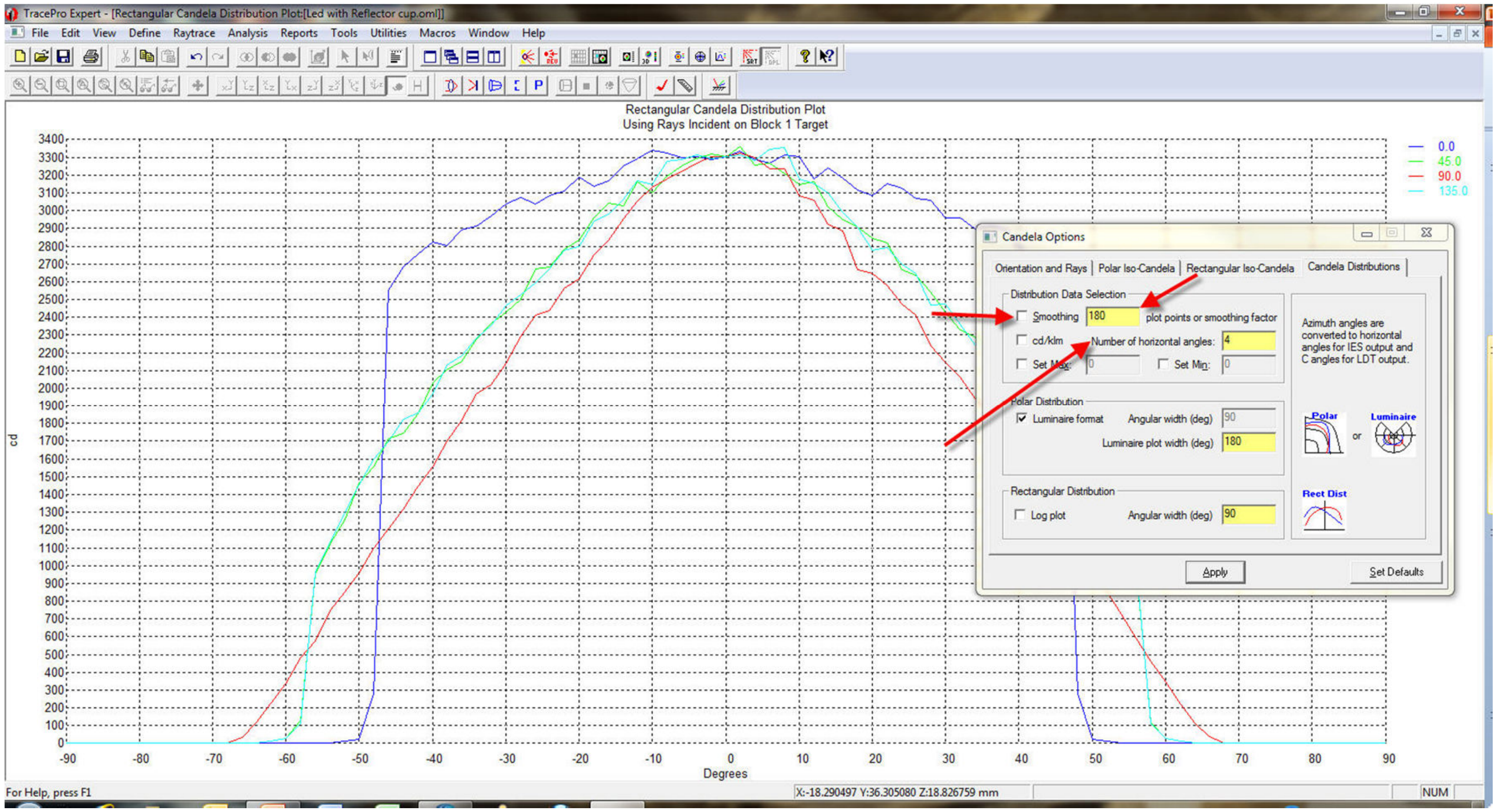
Apply Set Defaults

For Help, press F1 X:-18.290497 Y:36.305080 Z:18.826759 mm NUM

TracePro Lambda Research Corporation

Methods to Find Angular Artifacts

If we set the options to no smoothing and 180 bins then we are plotting raw data at 2 degree increments. Now the plot has more noise even though we have a high number of rays, over 22 million hitting the target. When you think about plotting the entire angular space, this is 64,800 bins which is 360 degree horizontal by 180 degrees vertical. A good ray number fore each bin is 8 for decent data collection, especially at the outer angles. This means we need to trace at least 518,400 rays if the rays are evenly distributed across the bins.



TracePro Expert - [Rectangular Candela Distribution Plot:[Led with Reflector cup.oml]]
File Edit View Define Raytrace Analysis Reports Tools Utilities Macros Window Help
Rectangular Candela Distribution Plot
Using Rays Incident on Block 1 Target
cd
Degrees
0.0
45.0
90.0
135.0
For Help, press F1
X:-18.290497 Y:36.305080 Z:18.826759 mm
NUM
Polar
or
Luminaire
Rect Dist

Candela Options

Orientation and Rays | Polar Iso-Candela | Rectangular Iso-Candela | Candela Distributions

Distribution Data Selection
- ☐ Smoothing: 180 plot points or smoothing factor
- ☐ cd/klm — Number of horizontal angles: 4
- ☐ Set Max: 0 — ☐ Set Min: 0

Polar Distribution
- ☑ Luminaire format — Angular width (deg): 90
- Luminaire plot width (deg): 180

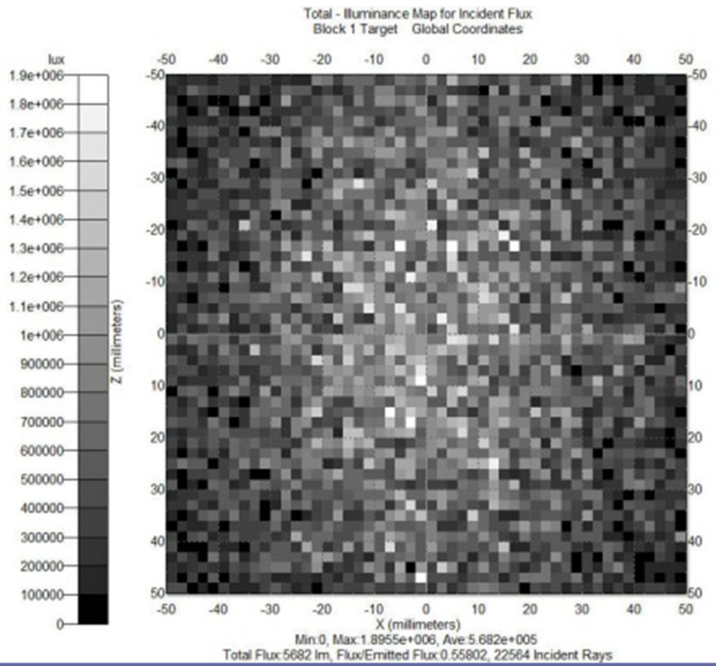
Rectangular Distribution
- ☐ Log plot — Angular width (deg): 90

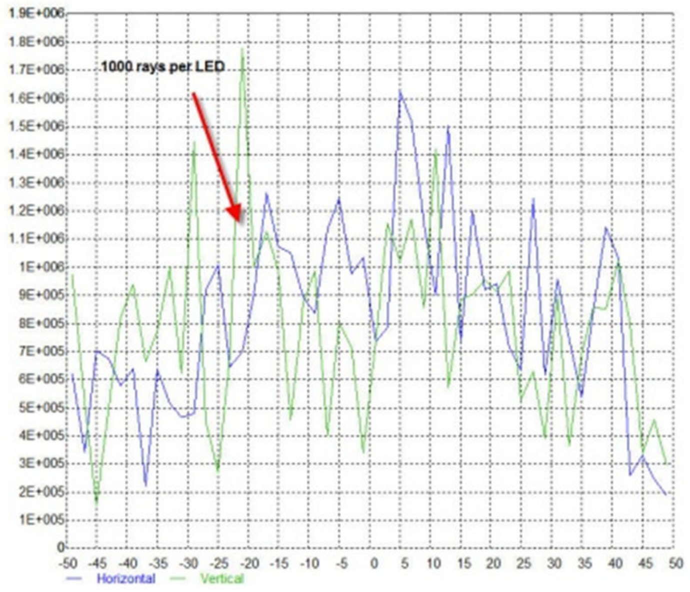
Azimuth angles are converted to horizontal angles for IES output and C angles for LDT output.

Apply | Set Defaults

Methods to Validate Data

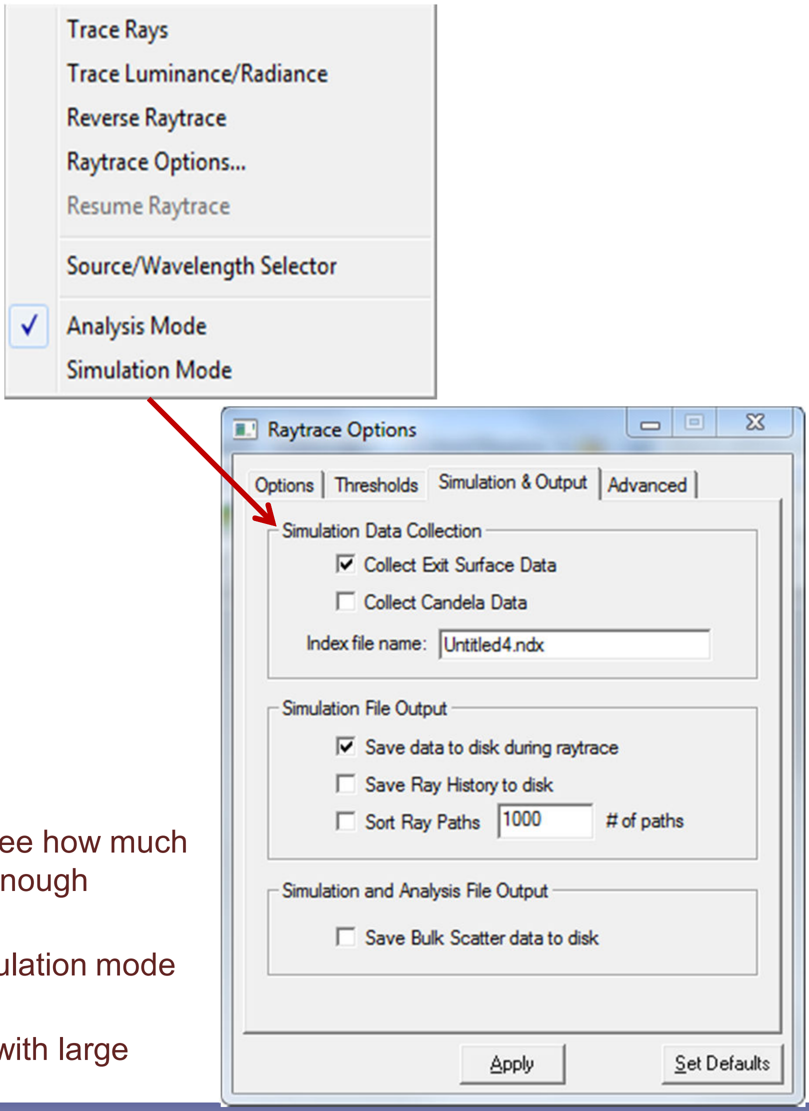
Look at the data without smoothing to determine if you have enough rays to create a good figure. In the first case, when we traced 1000 rays, we just don’t have enough data to determine a good result. But if we look at the 1000 ray raytrace, then the 10000 and finally the 100,000 ray trace, we can finally see the answer emerging. If you have the time to trace 1,000,000 rays per LED and you are looking for artifacts in a design, you just have to trace this number or rays. 100,000 rays per LED is not sufficient to find artifacts, the results are just too noisy





Analysis and Simulation Modes

- Analysis Mode
  - Stores all ray tree nodes
  - Very memory intensive
  - Allows plots and tables for all model surfaces
  - Permits Ray History
  - Display rays
  - Path Sorting Table
  - 3D irradiance/illuminance
- Simulation Mode
  - Stores ray data incident on a single surface
  - Stores ray data for missed rays
  - Much less memory used
  - No Ray Histories
  - No Ray display
  - Path Sorting available saved in file
- You can run out of memory in both modes
  - Be judicious about flux threshold
  - Use the task manager to monitor memory use
  - Use TracePro's Raytrace report to do small ray traces and see how much memory is used and then extrapolate to make sure there is enough memory before starting the raytrace
  - Raytraces of 50 million – 100 million rays are possible in simulation mode with 8GB on a medium PC system
  - 1 Billion rays have been raytraced with 16GB RAM systems with large virtual page sizes



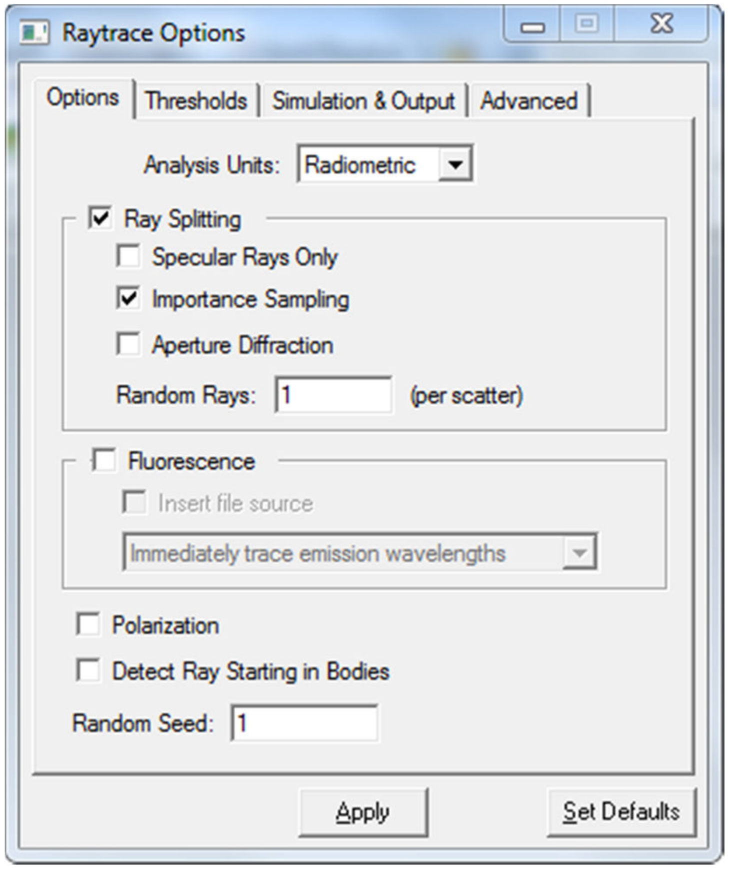
Simulation Data Collection
- [✓] Collect Exit Surface Data
- [ ] Collect Candela Data
- Index file name: Untitled4.ndx

Simulation File Output
- [✓] Save data to disk during raytrace
- [ ] Save Ray History to disk
- [ ] Sort Ray Paths 1000 # of paths

Simulation and Analysis File Output
- [ ] Save Bulk Scatter data to disk

Methods to Speed up Raytracing and Reduce Memory Requirements

- Ray-trace features may be turned off to skip some processing during the ray trace to save memory
- Multiple random rays may be used to increase sampling but requires a lower flux threshold and more processing time and memory to trace the rays.
- Fluorescence ray tracing can be controlled and set to run as a single or two-stage operation.
- Changing the random seed provides a "new set" of random numbers for a raytrace.



Analysis Units: Radiometric

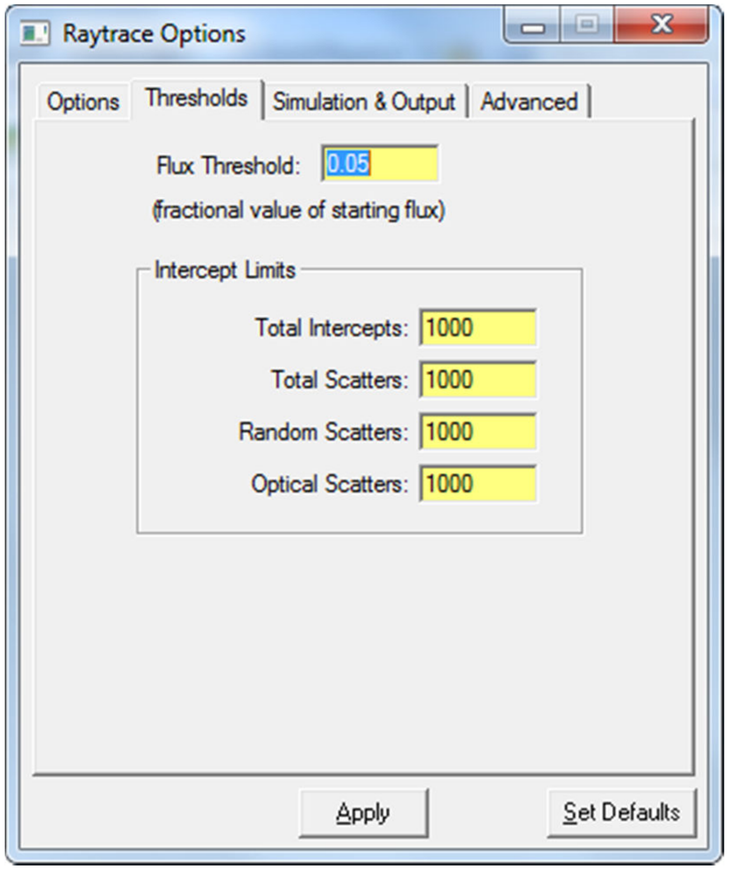
[✓] Ray Splitting
[ ] Specular Rays Only
[✓] Importance Sampling
[ ] Aperture Diffraction
Random Rays: 1 (per scatter)

[ ] Fluorescence
[ ] Insert file source
Immediately trace emission wavelengths

[ ] Polarization
[ ] Detect Ray Starting in Bodies
Random Seed: 1

Methods to Speed up Raytracing and Reduce Memory Requirements

- Thresholds specify how rays are terminated.
- Five thresholds can be set by the user
  - Flux Threshold
    - fractional value of starting flux
    - Good value for illumination system is .05
    - Ghost analysis should be set to .001
    - For stray light and importance sampling1E-6
  - Total Intercepts
  - Total Scatters
  - Random Scatters
  - Optical Scatters



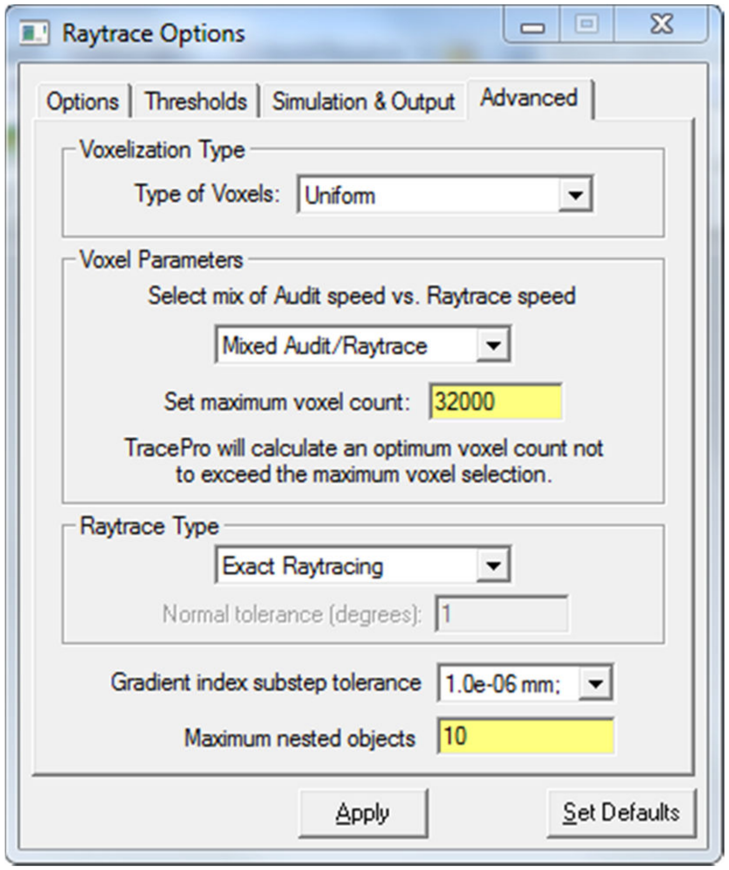
Flux Threshold: 0.05
(fractional value of starting flux)

Intercept Limits

Total Intercepts: 1000
Total Scatters: 1000
Random Scatters: 1000
Optical Scatters: 1000

Methods to Speed up Raytracing and Reduce Memory Requirements

- TracePro uses Space Partitioning to improve raytrace speed via two types of Voxels.
  - Uniform
    - You can select voxel count:
      - Raytrace speed increases with more voxels.
      - Audit speed decreases with more voxels.
    - Use Fastest Audit during initial model development.
    - Use Fastest Raytrace during simulation.
  - Octree
    - Improves raytrace efficiency for models with large distances between objects which is especially good for systems with far away targets
  - Use View|Display Voxels after an Audit to view voxelization



Voxelization Type

Type of Voxels: Uniform

Voxel Parameters

Select mix of Audit speed vs. Raytrace speed

Mixed Audit/Raytrace

Set maximum voxel count: 32000

TracePro will calculate an optimum voxel count not to exceed the maximum voxel selection.

Raytrace Type

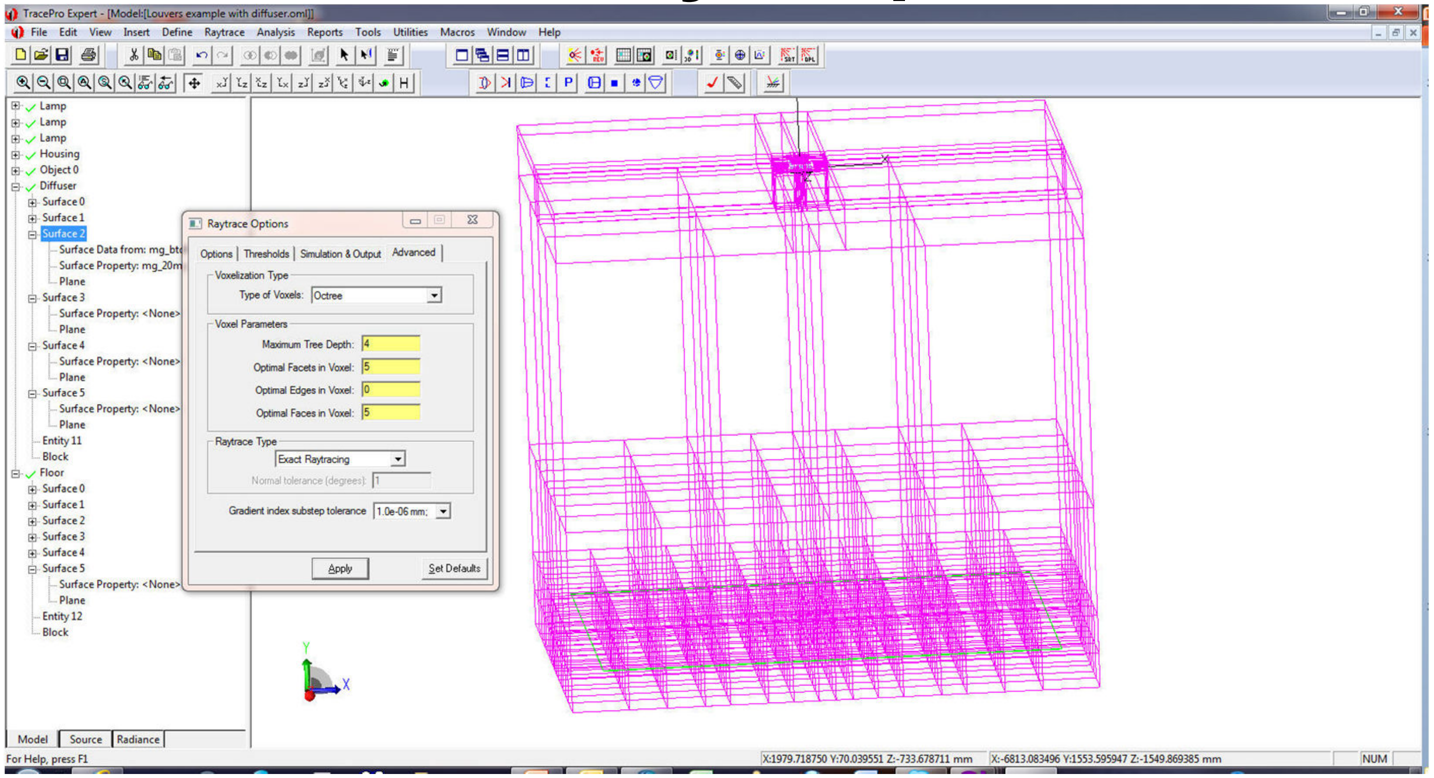
Exact Raytracing

Normal tolerance (degrees): 1

Gradient index substep tolerance 1.0e-06 mm;

Maximum nested objects 10

Methods to Speed up Raytracing and Reduce Memory Requirements



Voxelization Type

Type of Voxels: Octree

Voxel Parameters

Maximum Tree Depth: 4

Optimal Facets in Voxel: 5

Optimal Edges in Voxel: 0

Optimal Faces in Voxel: 5

Raytrace Type

Exact Raytracing

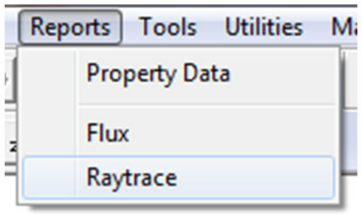
Normal tolerance (degrees): 1

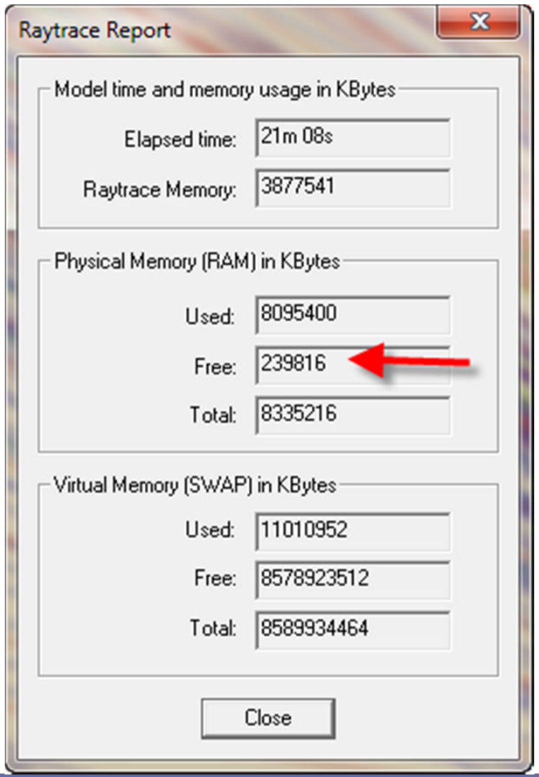
Gradient index substep tolerance 1.0e-06 mm;

Use Octree Voxels if you have large amounts of unused space in your model to speed up raytracing. Use the View|Display Voxel option to show the voxels in your model after you audit the model.

Methods to Speed up Raytracing and Reduce Memory Requirements

Use the Reports|Raytrace menu option to see how much memory was used in a raytrace. For our sample system with 100,000 rays for all 31 LEDs this totaled 3.1 million rays. This left us with only 239816 Kbytes of free memory. We are not going to be able to trace many more rays before running out of memory.




Raytrace Report

Model time and memory usage in KBytes

Elapsed time:	21m 08s
Raytrace Memory:	3877541

Physical Memory (RAM) in KBytes

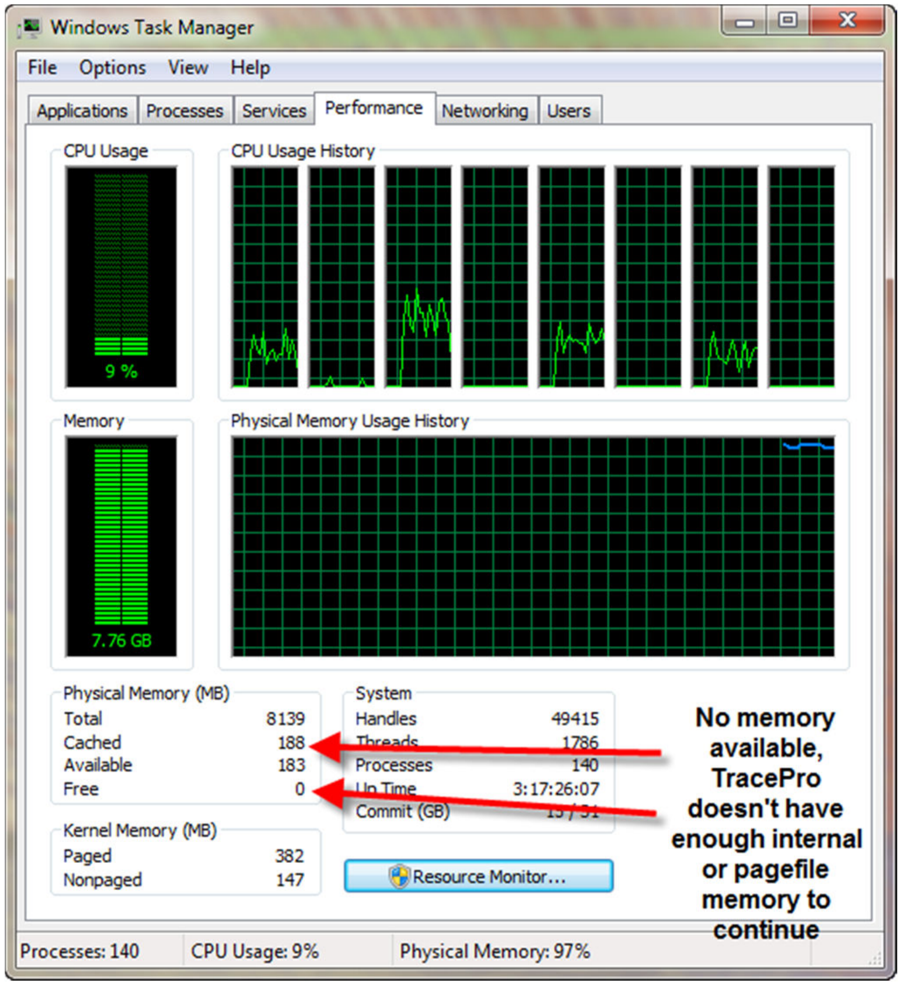
Used:	8095400
Free:	239816
Total:	8335216

Virtual Memory (SWAP) in KBytes

Used:	11010952
Free:	8578923512
Total:	8589934464

Methods to Speed up Raytracing and Reduce Memory Requirements

Use the Windows Task Manager to keep tabs on your memory and how well the multi-core raytrace is taking advantage of all the cores in your computer. If you run into a memory situation as shown at right, (3.1 million rays for our sample system) you will need to switch from analysis mode to simulation mode or change your threshold or scattering settings to be able to raytrace more rays. Adding RAM, or increasing Virtual Page Size will also help this memory problem.



Physical Memory (MB)	
Total	8139
Cached	188
Available	183
Free	0

Kernel Memory (MB)	
Paged	382
Nonpaged	147

System	
Handles	49415
Threads	1786
Processes	140
Up Time	3:17:26:07
Commit (GB)	15 / 31

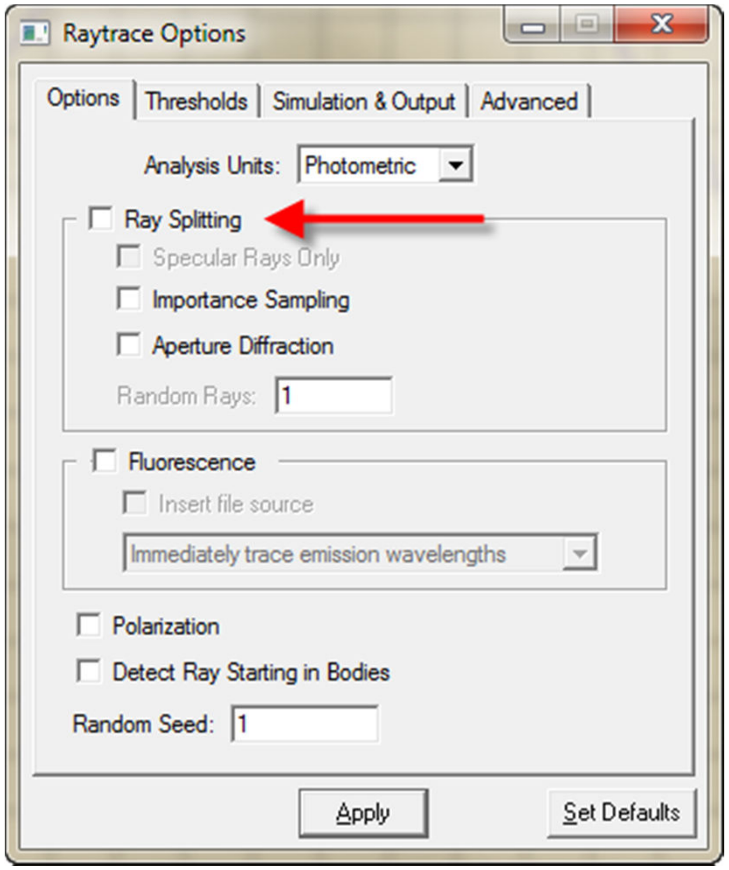
No memory available, TracePro doesn't have enough internal or pagefile memory to continue

Processes: 140 CPU Usage: 9% Physical Memory: 97%

Methods to Speed up Raytracing and Reduce Memory Requirements

There is a second method of ray splitting in TracePro, turning off ray splitting and this mode is activated when we deselect ray splitting in the RayTrace Options.

Instead of splitting the ray at each surface, the total ray count is apportioned where the number or rays correspond to the surface property at each surface. So for this method if we trace 100 rays to a lens surface that is 95% transmitting, 4% fresnel reflecting and 1% reflective scattering here is how TracePro would handle this case. 95 rays would transmit through the surface, 4 would reflect off and 1 ray would be scattered using random number generation on average. This technique uses much less memory, speed up raytracing and provides excellent answers when enough rays are traced.


Raytrace Options

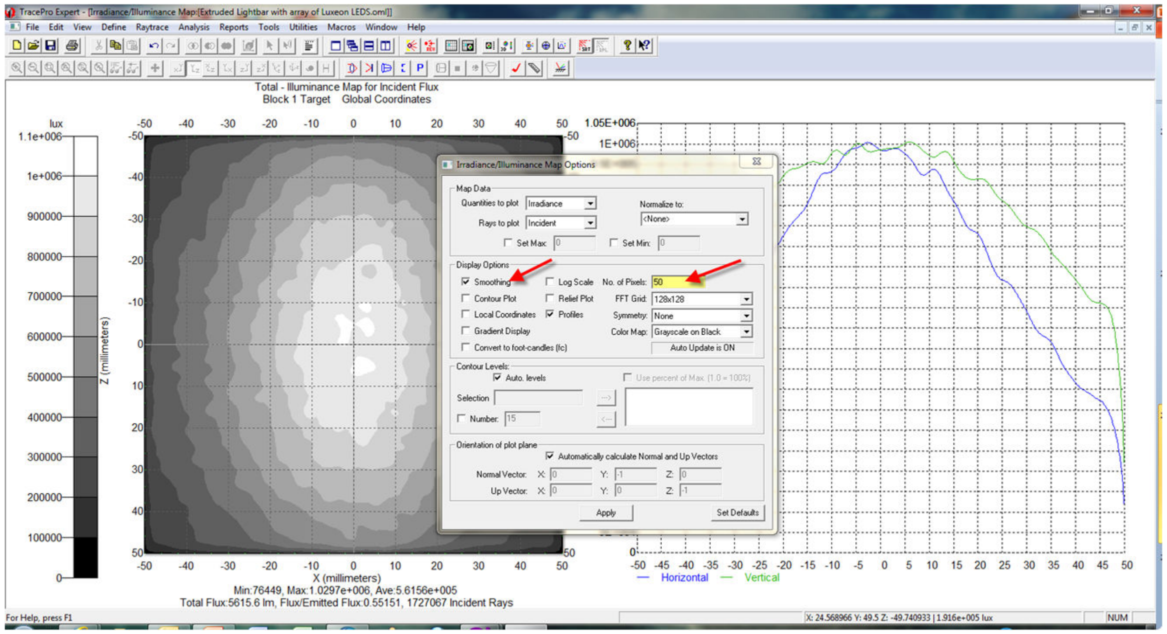
Options | Thresholds | Simulation & Output | Advanced

Analysis Units: Photometric

- [ ] Ray Splitting
  - [ ] Specular Rays Only
  - [ ] Importance Sampling
  - [ ] Aperture Diffraction
  - Random Rays: 1
- [ ] Fluorescence
  - [ ] Insert file source
  - Immediately trace emission wavelengths
- [ ] Polarization
- [ ] Detect Ray Starting in Bodies

Random Seed: 1

Methods to Speed up Raytracing and Reduce Memory Requirements


TracePro Expert - [Irradiance/Illuminance Map:[Extruded Lightbar with array of Luxeon LEDS.oml]]
File Edit View Define Raytrace Analysis Reports Tools Utilities Macros Window Help
lux
Z (millimeters)
X (millimeters)
Horizontal
Vertical
Apply
Set Defaults
For Help, press F1
NUM

Total - Illuminance Map for Incident Flux
Block 1 Target Global Coordinates

Min:76449, Max:1.0297e+006, Ave:5.6156e+005
Total Flux:5615.6 lm, Flux/Emitted Flux:0.55151, 1727067 Incident Rays

X: 24.568966 Y: 49.5 Z: -49.740933 | 1.916e+005 lux

Irradiance/Illuminance Map Options

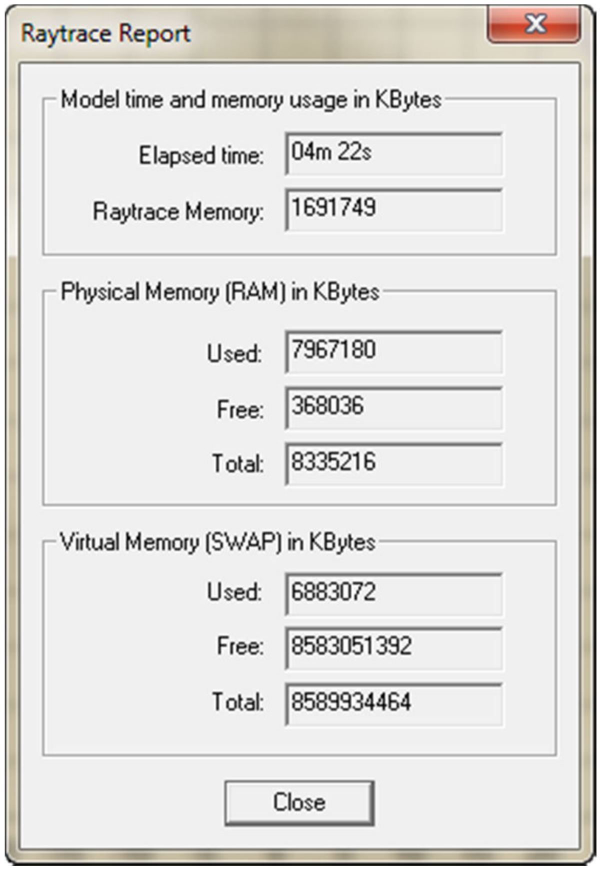
Map Data
- Quantities to plot: Irradiance
- Rays to plot: Incident
- Normalize to: <None>
- ☐ Set Max: 0
- ☐ Set Min: 0

Display Options
- ☑ Smoothing
- ☐ Log Scale
- No. of Pixels: 50
- ☐ Contour Plot
- ☐ Relief Plot
- FFT Grid: 128x128
- ☐ Local Coordinates
- ☑ Profiles
- Symmetry: None
- ☐ Gradient Display
- Color Map: Grayscale on Black
- ☐ Convert to foot-candles (fc)
- Auto Update is ON

Contour Levels:
- ☑ Auto. levels
- ☐ Use percent of Max. (1.0 = 100%)
- Selection
- ☐ Number: 15

Orientation of plot plane
- ☑ Automatically calculate Normal and Up Vectors
- Normal Vector: X: 0 Y: -1 Z: 0
- Up Vector: X: 0 Y: 0 Z: -1

Using this second raytracing method, we get very similar results for the illuminance map for 10,000 rays per LED for our sample system. But it only takes 4 minutes to raytrace instead of 21 minutes and only uses 1691749 Kbytes of memory instead of 3.8 million for the ray splitting raytrace. But for this method to be accurate you need to trace large quantities of rays. If you are going to trace a small number of rays it is best to use ray splitting mode.



Raytrace Report

Model time and memory usage in KBytes

Elapsed time:	04m 22s
Raytrace Memory:	1691749

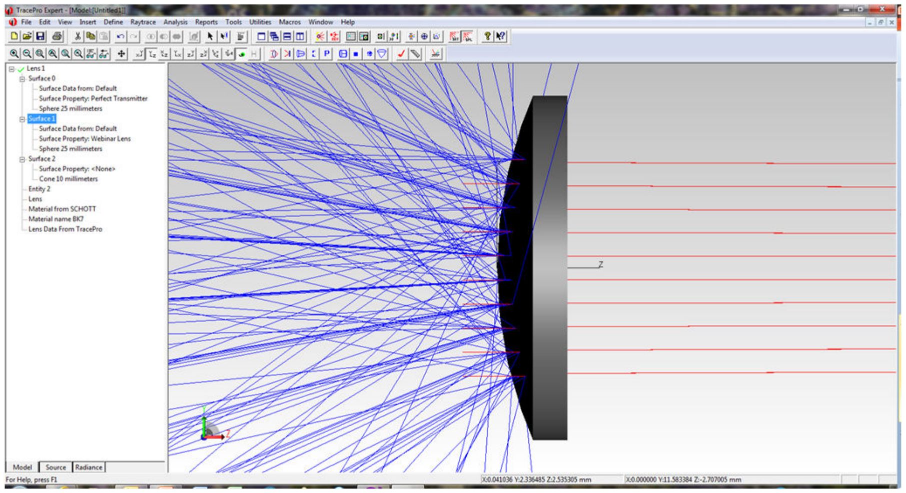
Physical Memory (RAM) in KBytes

Used:	7967180
Free:	368036
Total:	8335216

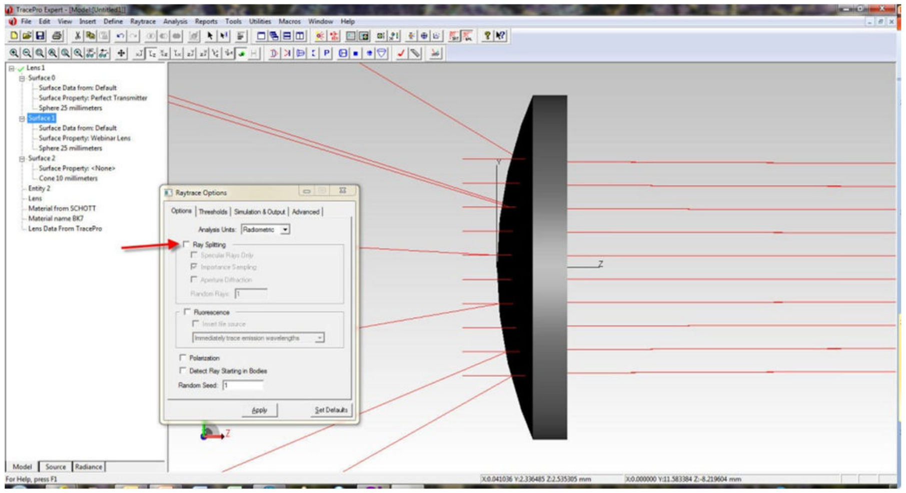
Virtual Memory (SWAP) in KBytes

Used:	6883072
Free:	8583051392
Total:	8589934464

Methods to Speed up Raytracing and Reduce Memory Requirements



Ray Splitting On



Raytrace Options

Options | Thresholds | Simulation & Output | Advanced

Analysis Units: Radiometric

☐ Ray Splitting

☐ Specular Rays Only

☑ Importance Sampling

☐ Aperture Diffraction

Random Rays: 1

☐ Fluorescence

☐ Insert file source

Immediately trace emission wavelengths

☐ Polarization

☐ Detect Ray Starting in Bodies

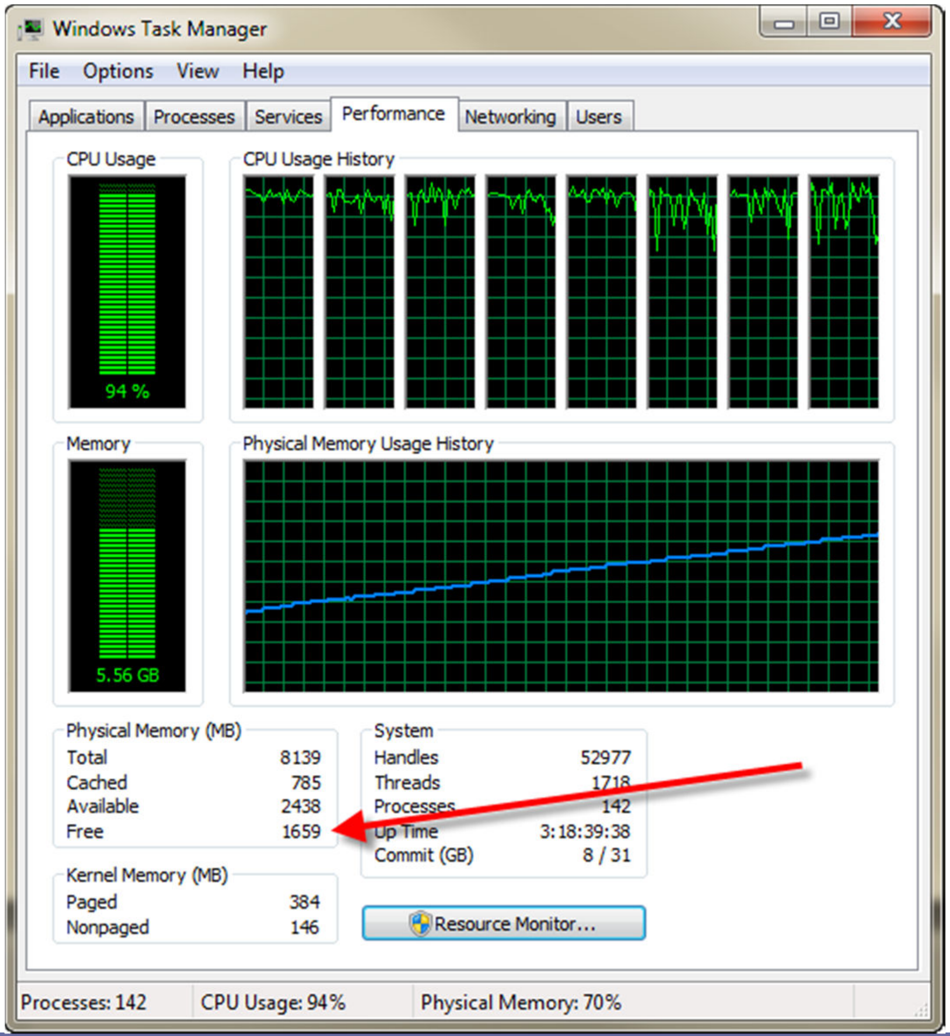
Random Seed: 1

Apply | Set Defaults

Ray Splitting Off – poor answers for scattered or reflected rays for this simulation, use ray splitting

Methods to speed up Raytracing and reduce memory requirements

The task manager at right shows the sample system with 100,000 rays per LED with only a few seconds left in the non-splitting raytrace. You can see that there is still quite a bit of memory left and that the non-splitting raytrace mode is also multi-threaded. You can also see the Physical Memory Usage creep up over the simulation.



Physical Memory (MB)	
Total	8139
Cached	785
Available	2438
Free	1659

Kernel Memory (MB)	
Paged	384
Nonpaged	146

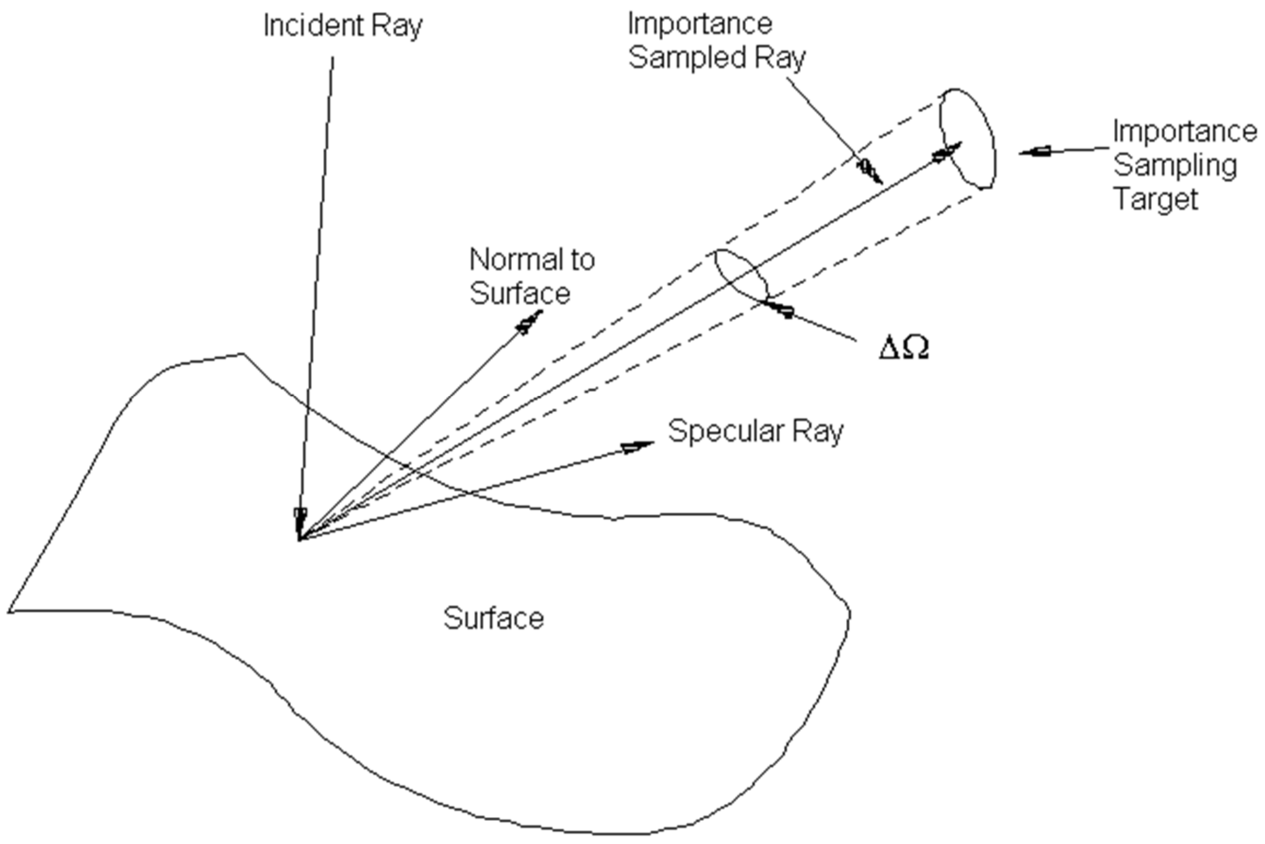
System	
Handles	52977
Threads	1718
Processes	142
Up Time	3:18:39:38
Commit (GB)	8 / 31

Processes: 142 CPU Usage: 94% Physical Memory: 70%

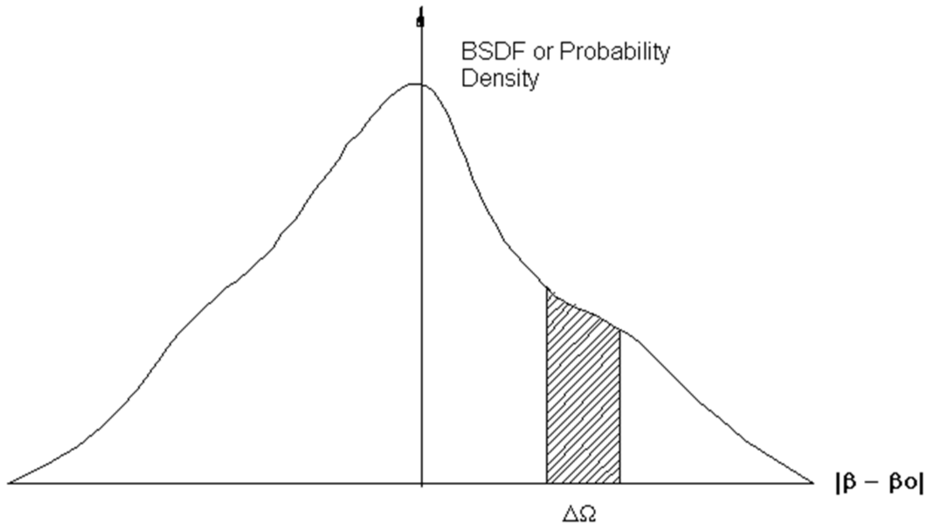
Scatter and Source Methods to Reduce Noise

- Importance Sampling is used to improve the sampling of random events without dramatically increasing the number of rays started.
- Uses the scattering distribution function as a probability density to apportion a fraction of the scattered ray flux into a desired direction.
- May be used for emitted, scattered and diffracted rays only, on surface sources, scattering surfaces, diffracting surfaces and bulk scattering objects.
- Apply to object(s) for Bulk Scatter.
- Apply to surface(s) for all others.

Scatter and Source Methods to Reduce Noise - Importance Sampling



Scatter and Source Methods to Reduce Noise - Importance Sampling for Flux

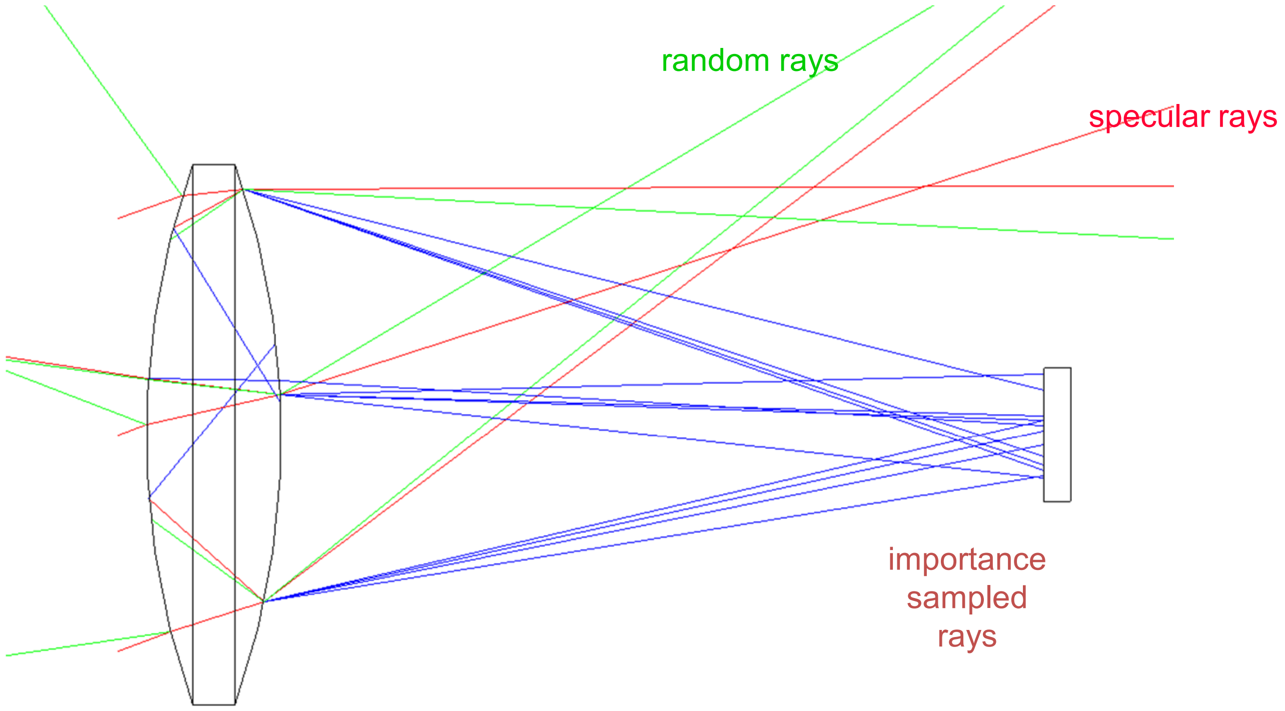


$$\Phi_{imp.samp.} = \Phi_{inc.} \int_{\Delta\Omega} BSDF \cos\theta \, d\Omega$$

$$\Phi_{random} = \Phi_{inc.} \cdot TS - \Phi_{imp.samp.}$$

$$TS = \int_{hemisphere} BSDF \cos\theta \, d\Omega$$

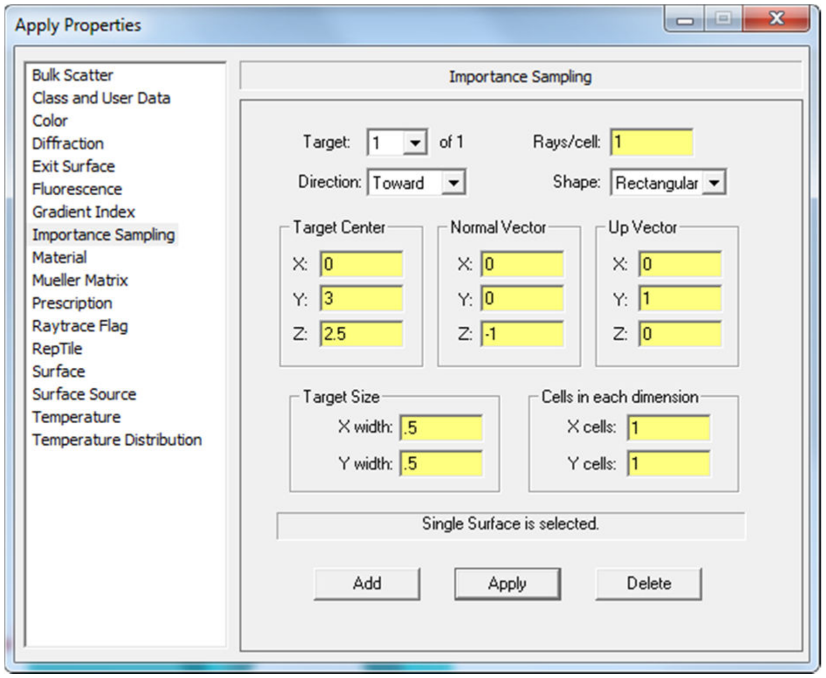
Scatter and Source Methods to Reduce Noise - Importance Sampling Scatter Example



Scatter and Source Methods to Reduce Noise - Importance Sampling Scatter Example

Surface Example

- Flux threshold typically set very low



Apply Properties

- Bulk Scatter
- Class and User Data
- Color
- Diffraction
- Exit Surface
- Fluorescence
- Gradient Index
- Importance Sampling
- Material
- Mueller Matrix
- Prescription
- Raytrace Flag
- RepTile
- Surface
- Surface Source
- Temperature
- Temperature Distribution

Importance Sampling

Target: 1 of 1 Rays/cell: 1

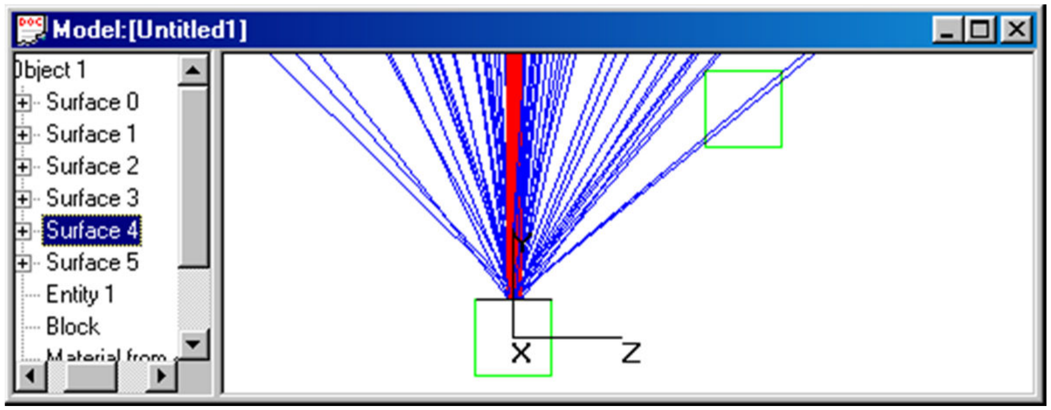
Direction: Toward Shape: Rectangular

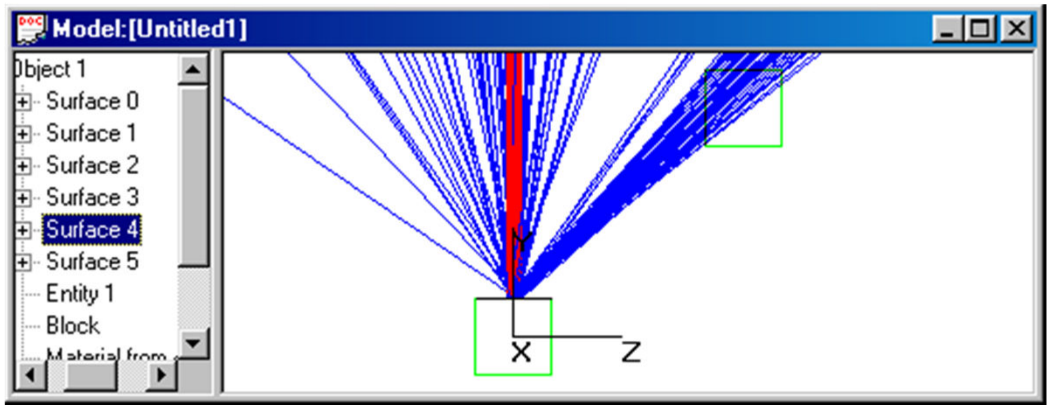
	Target Center	Normal Vector	Up Vector
X:	0	0	0
Y:	3	0	1
Z:	2.5	-1	0

Target Size: X width: .5 Y width: .5

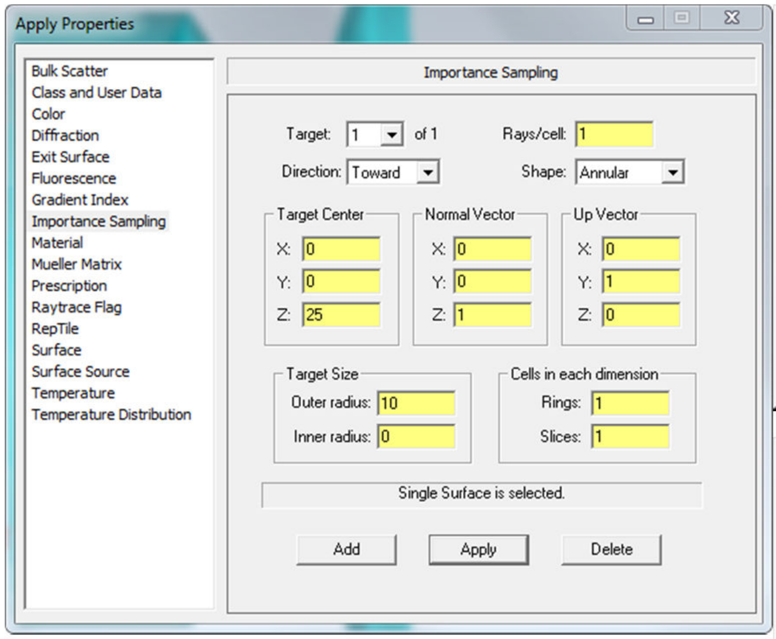
Cells in each dimension: X cells: 1 Y cells: 1

Single Surface is selected.





Scatter and Source Methods to Reduce Noise - Importance Sampling Source Example



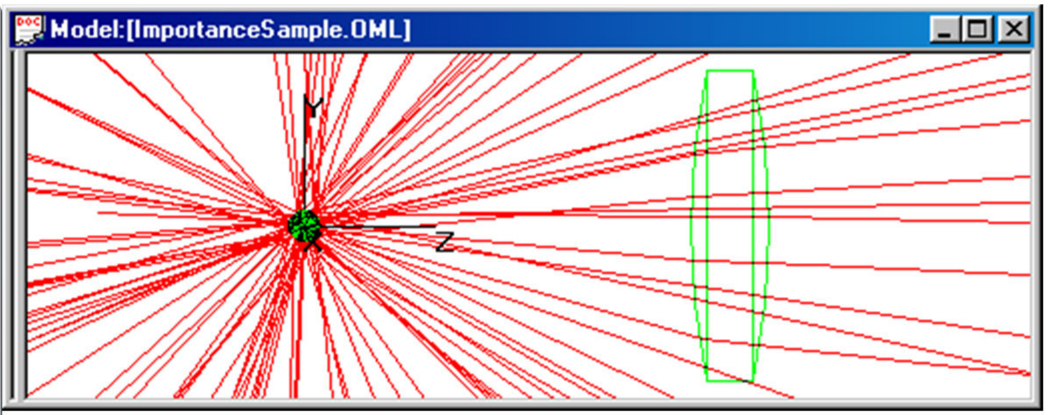
Target: 1 of 1
Rays/cell: 1
Direction: Toward
Shape: Annular

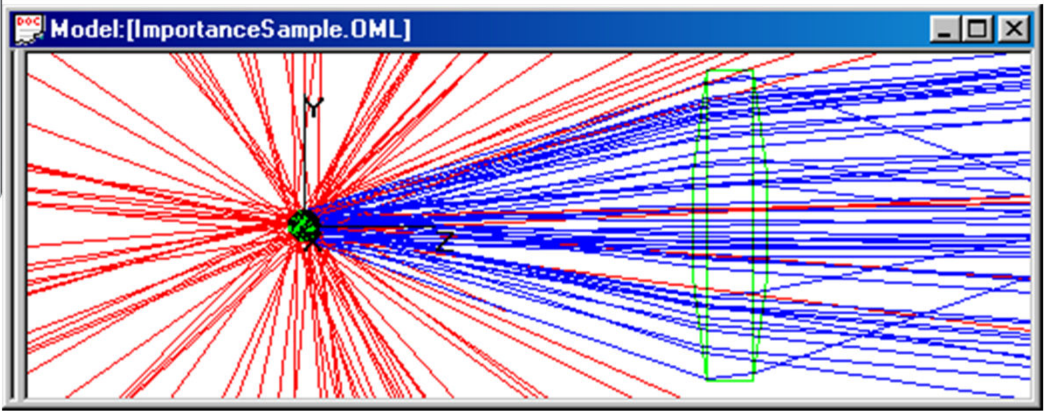
	Target Center	Normal Vector	Up Vector
X:	0	0	0
Y:	0	0	1
Z:	25	1	0

Target Size
Outer radius: 10
Inner radius: 0

Cells in each dimension
Rings: 1
Slices: 1

Single Surface is selected.

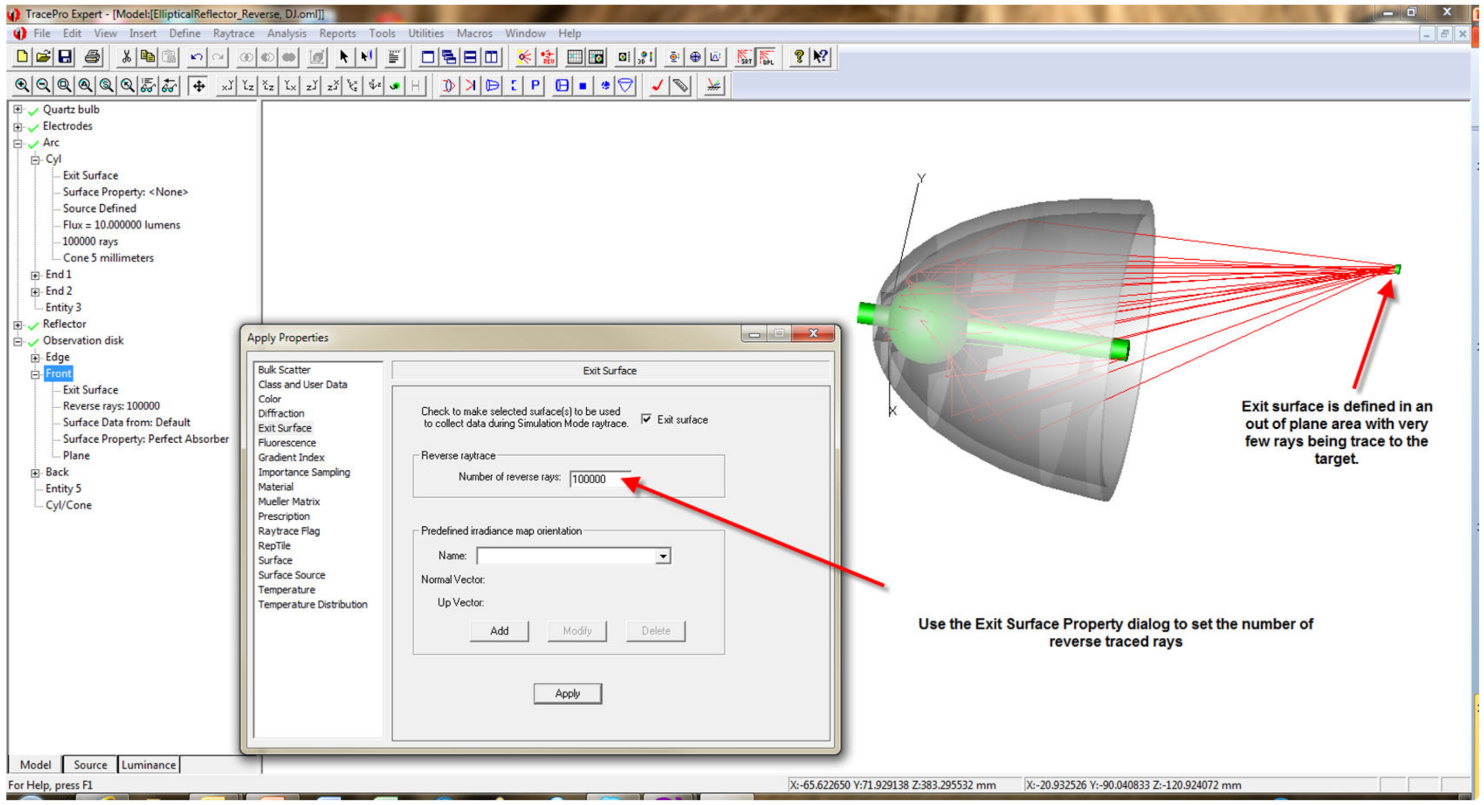




Methods to Speed-up Raytracing - Reverse Ray Trace

- Ray trace from all defined Exit Surfaces to defined Surface Sources
  - Sources are defined using Apply Properties dialog and applying Exit Surface property and entering number of rays.
- Useful in situations where importance sampling in the forward direction is difficult or impossible
  - Example: Design of illumination reflectors with a small source

Methods to Speed-up Raytracing - Reverse Ray Trace


TracePro Expert - [Model:[EllipticalReflector_Reverse_DJ.oml]]
File Edit View Insert Define Raytrace Analysis Reports Tools Utilities Macros Window Help
Model Source Luminance
For Help, press F1
X:-65.622650 Y:71.929138 Z:383.295532 mm
X:-20.932526 Y:-90.040833 Z:-120.924072 mm
Y
X

- Quartz bulb
- Electrodes
- Arc
  - Cyl
    - Exit Surface
    - Surface Property: <None>
    - Source Defined
    - Flux = 10.000000 lumens
    - 100000 rays
    - Cone 5 millimeters
  - End 1
  - End 2
  - Entity 3
- Reflector
- Observation disk
  - Edge
  - Front
    - Exit Surface
    - Reverse rays: 100000
    - Surface Data from: Default
    - Surface Property: Perfect Absorber
    - Plane
  - Back
  - Entity 5
  - Cyl/Cone

Apply Properties

Bulk Scatter
Class and User Data
Color
Diffraction
Exit Surface
Fluorescence
Gradient Index
Importance Sampling
Material
Mueller Matrix
Prescription
Raytrace Flag
RepTile
Surface
Surface Source
Temperature
Temperature Distribution

Exit Surface

Check to make selected surface(s) to be used to collect data during Simulation Mode raytrace. [✓ Exit surface]

Reverse raytrace
Number of reverse rays: 100000

Predefined irradiance map orientation
Name:
Normal Vector:
Up Vector:
Add Modify Delete

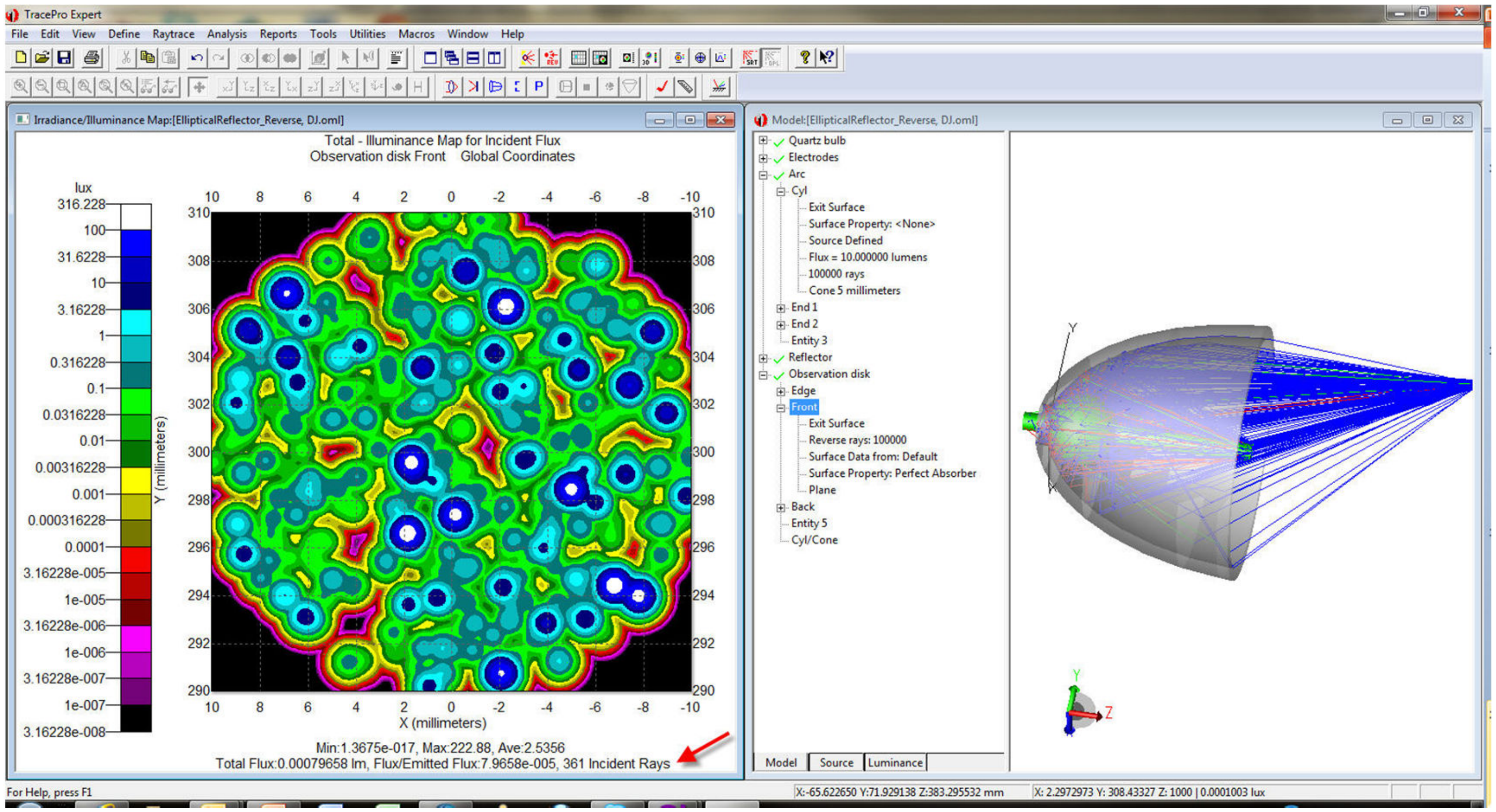
Apply

Exit surface is defined in an out of plane area with very few rays being trace to the target.

Use the Exit Surface Property dialog to set the number of reverse traced rays

Use the Apply Properties|Exit surface dialog to specify the number of reverse rays that you want to trace

Methods to Speed-up Raytracing - Reverse Ray Trace


TracePro Expert
File Edit View Define Raytrace Analysis Reports Tools Utilities Macros Window Help
Irradiance/Illuminance Map:[EllipticalReflector_Reverse, DJ.oml]
lux
Y (millimeters)
X (millimeters)
Model:[EllipticalReflector_Reverse, DJ.oml]
Model
Source
Luminance
For Help, press F1

Total - Illuminance Map for Incident Flux
Observation disk Front   Global Coordinates

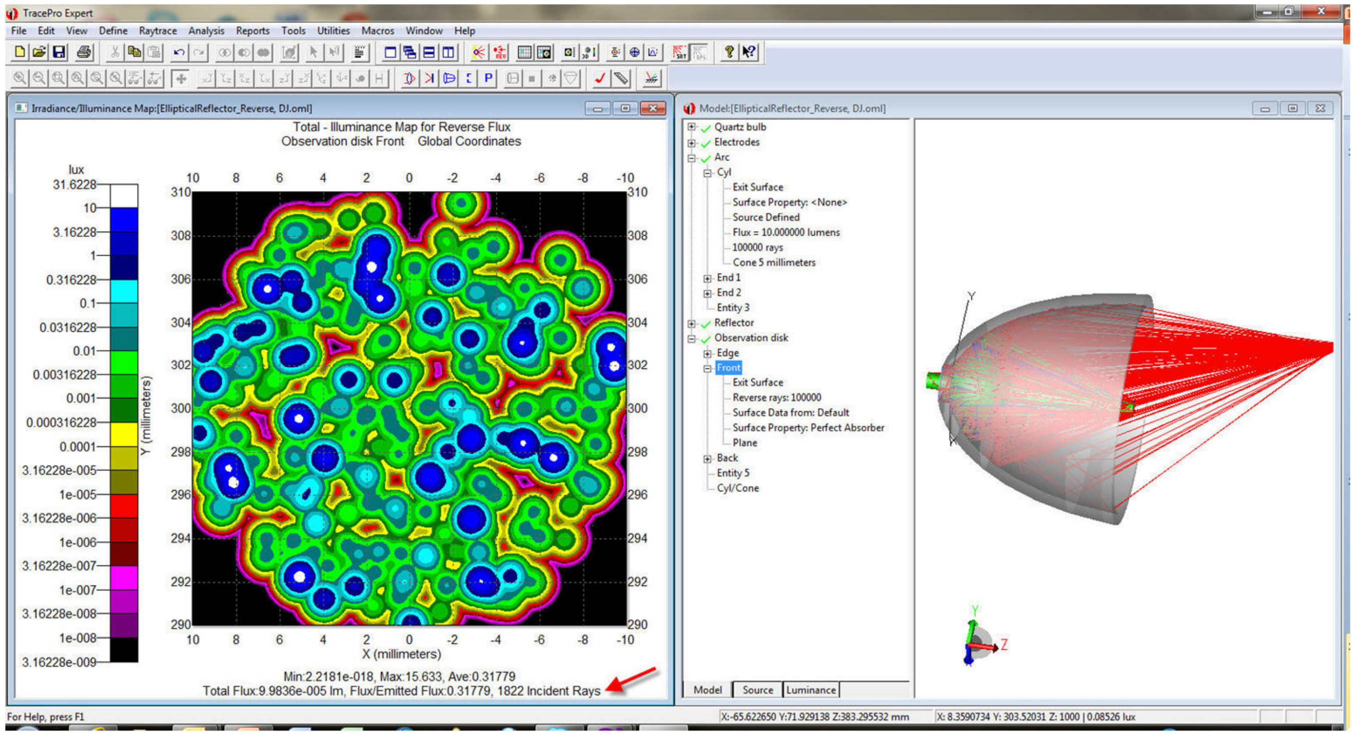
Min:1.3675e-017, Max:222.88, Ave:2.5356
Total Flux:0.00079658 lm, Flux/Emitted Flux:7.9658e-005, 361 Incident Rays

- Quartz bulb
- Electrodes
- Arc
  - Cyl
    - Exit Surface
    - Surface Property: <None>
    - Source Defined
    - Flux = 10.000000 lumens
    - 100000 rays
    - Cone 5 millimeters
  - End 1
  - End 2
  - Entity 3
- Reflector
- Observation disk
  - Edge
  - Front
    - Exit Surface
    - Reverse rays: 100000
    - Surface Data from: Default
    - Surface Property: Perfect Absorber
    - Plane
  - Back
  - Entity 5
  - Cyl/Cone

X:-65.622650 Y:71.929138 Z:383.295532 mm
X: 2.2972973 Y: 308.43327 Z: 1000 | 0.0001003 lux

For this Elliptical Reflector example it takes 1 minute to forward raytrace 100,000 rays. 361 rays reach the target as shown in the irradiance map at left

Methods to Speed-up Raytracing - Reverse Ray Trace


TracePro Expert
File Edit View Define Raytrace Analysis Reports Tools Utilities Macros Window Help
Irradiance/Illuminance Map:[EllipticalReflector_Reverse, DJ.oml]
Total - Illuminance Map for Reverse Flux
Observation disk Front Global Coordinates
lux
31.6228
10
3.16228
1
0.316228
0.1
0.0316228
0.01
0.00316228
0.001
0.000316228
0.0001
3.16228e-005
1e-005
3.16228e-006
1e-006
3.16228e-007
1e-007
3.16228e-008
1e-008
3.16228e-009
Y (millimeters)
X (millimeters)
Model:[EllipticalReflector_Reverse, DJ.oml]
Model
Source
Luminance
Y
Z
For Help, press F1

Min:2.2181e-018, Max:15.633, Ave:0.31779
Total Flux:9.9836e-005 lm, Flux/Emitted Flux:0.31779, 1822 Incident Rays

- Quartz bulb
- Electrodes
- Arc
  - Cyl
    - Exit Surface
    - Surface Property: <None>
    - Source Defined
    - Flux = 10.000000 lumens
    - 100000 rays
    - Cone 5 millimeters
  - End 1
  - End 2
  - Entity 3
- Reflector
- Observation disk
  - Edge
  - Front
    - Exit Surface
    - Reverse rays: 100000
    - Surface Data from: Default
    - Surface Property: Perfect Absorber
    - Plane
  - Back
  - Entity 5
  - Cyl/Cone

X:-65.622650 Y:71.929138 Z:383.295532 mm

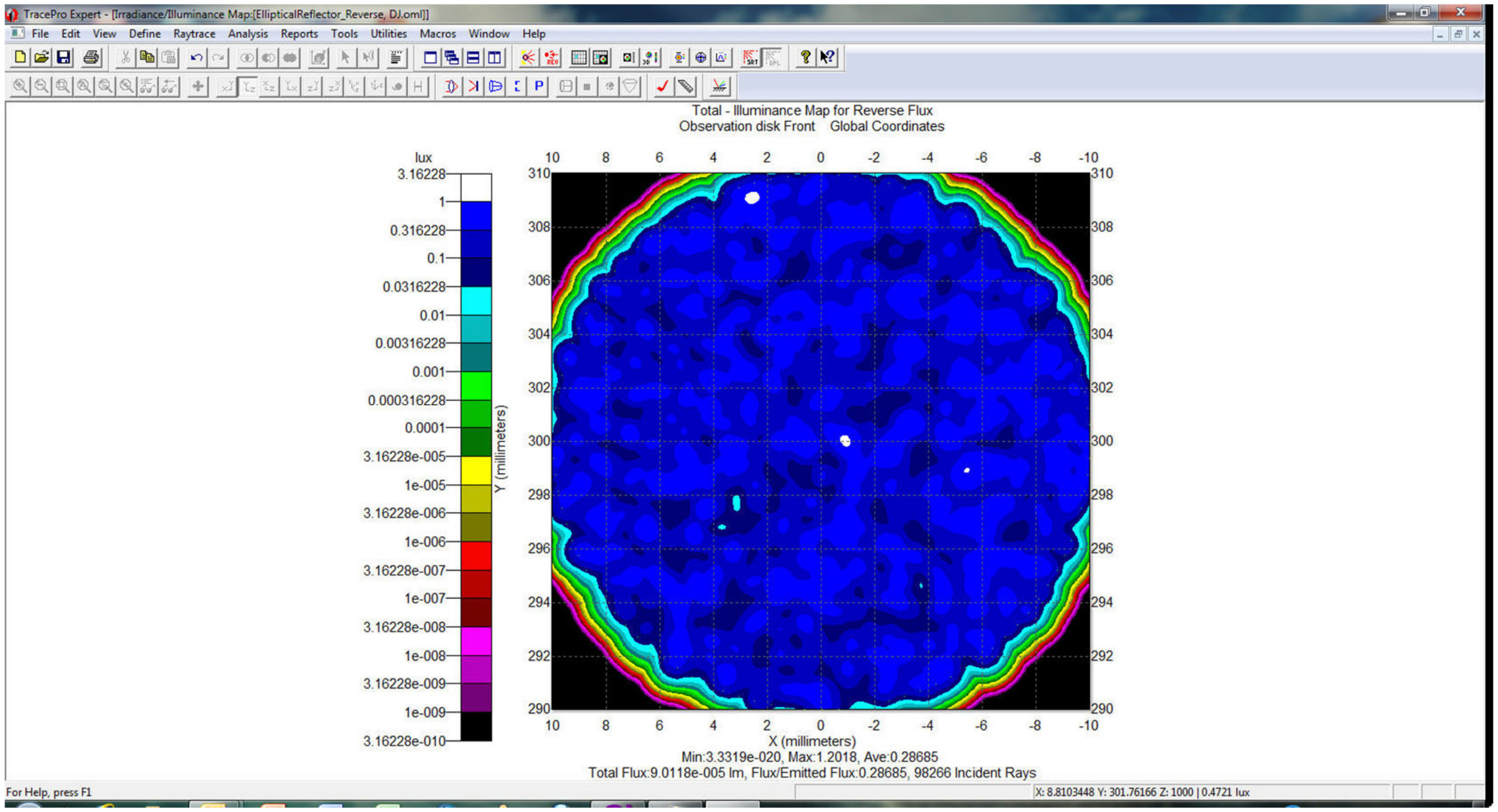
X: 8.3590734 Y: 303.52031 Z: 1000 | 0.08526 lux

For this Elliptical Reflector example it takes 4 seconds to reverse raytrace 100,000 rays. 1822 rays reach the target as shown in the irradiance map at left. 6 times as many rays reach the target 15 times faster reverse raytracing.

TracePro

Lambda Research Corporation

Methods to Speed-up Raytracing - Reverse Ray Trace



Total - Illuminance Map for Reverse Flux
Observation disk Front   Global Coordinates

Min:3.3319e-020, Max:1.2018, Ave:0.28685
Total Flux:9.0118e-005 lm, Flux/Emitted Flux:0.28685, 98266 Incident Rays

X: 8.8103448 Y: 301.76166 Z: 1000 | 0.4721 lux

For this Elliptical Reflector example it takes 5 minutes to reverse raytrace 5,000,000 rays. 98266 incident rays reach the target as shown in the irradiance map above.