

# Efficient Luminaire Design Using Virtual Prototyping

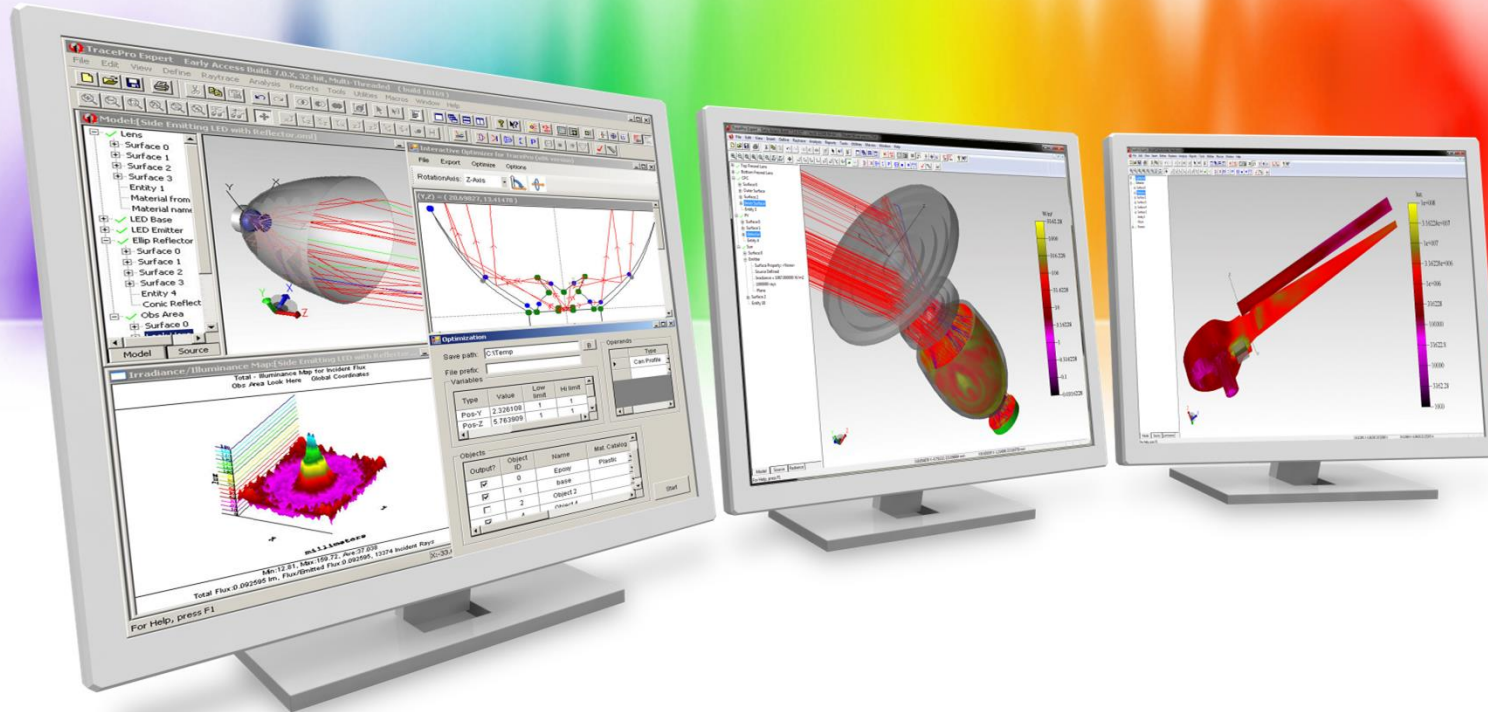
A Photonics Online and Lambda Research Corporation Webinar

October 12, 2017



# Agenda

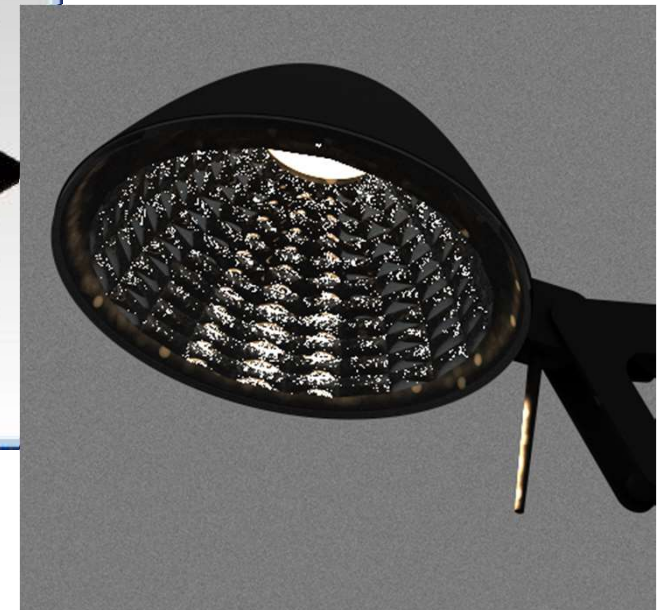
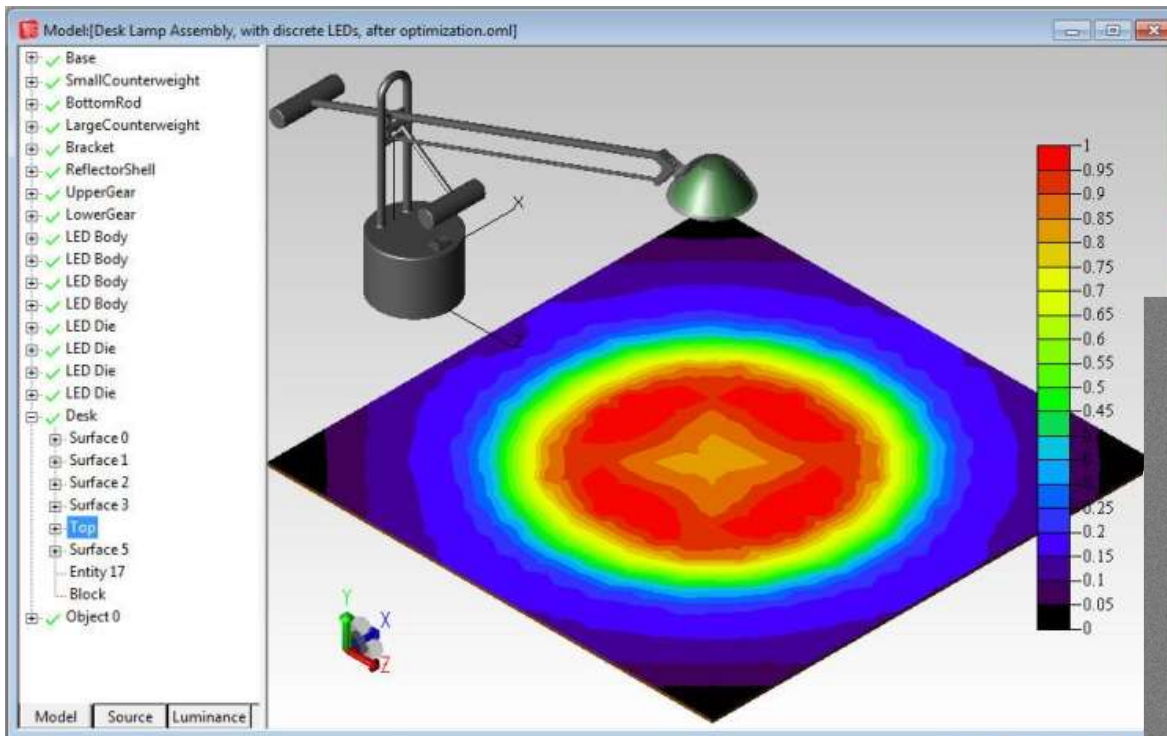
- Why use virtual prototyping?
- Workflow for designing luminaires in software
- Analysis tools for design verification
- Optimizing luminaires in software
- Examples
- Questions and Answers



## Why Use Virtual Prototyping?

# Why use virtual prototyping?

- In luminaire design applications virtual prototyping is done using optical design and analysis software.



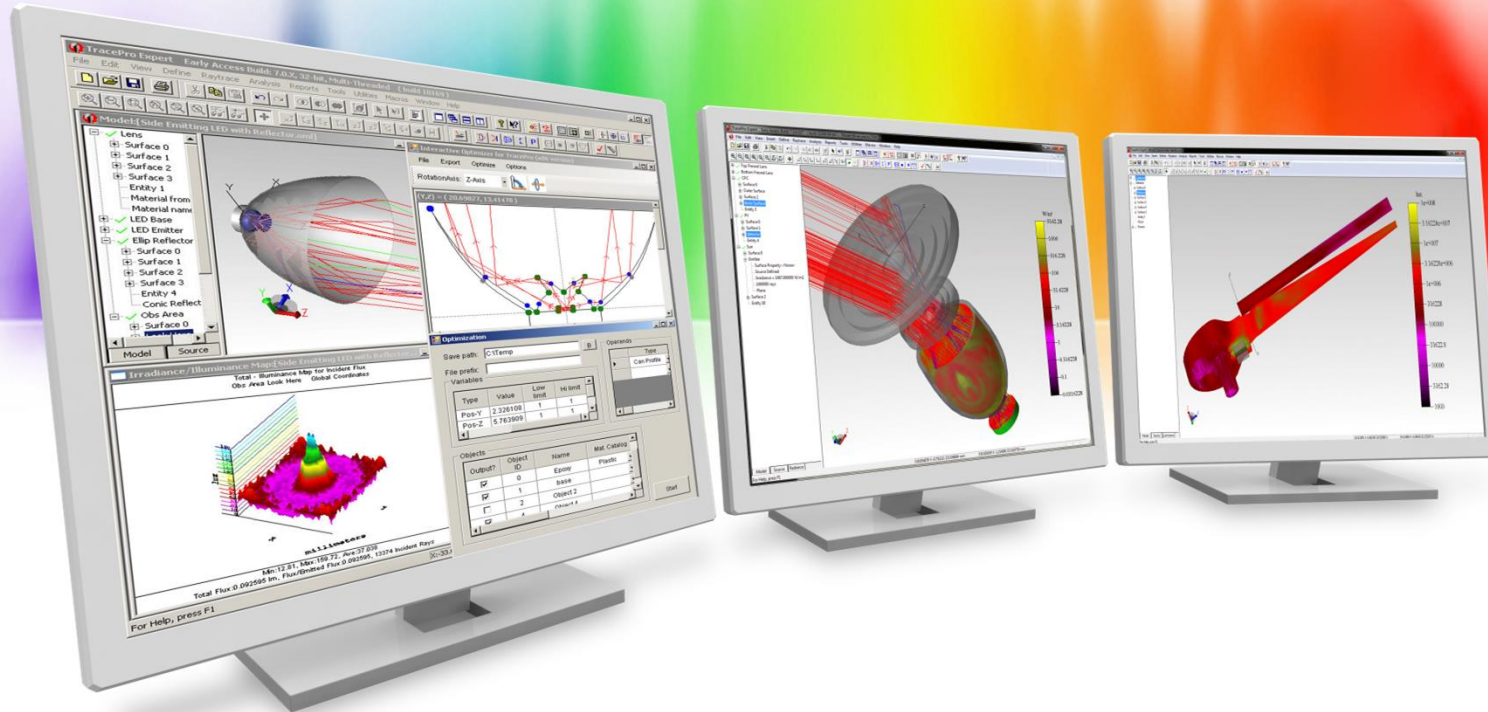
## Advantages of virtual prototyping

- Easier to make multiple designs in software compared to physical prototypes
- Luminaire performance can be checked quickly and easily in software
- Multiple designs can be compared quickly and easily in software
- Faster to make multiple designs in software compared to physical prototypes
- Better to make mistakes in software instead of with physical prototypes
- Less expensive to make mistakes in software compared to physical prototypes



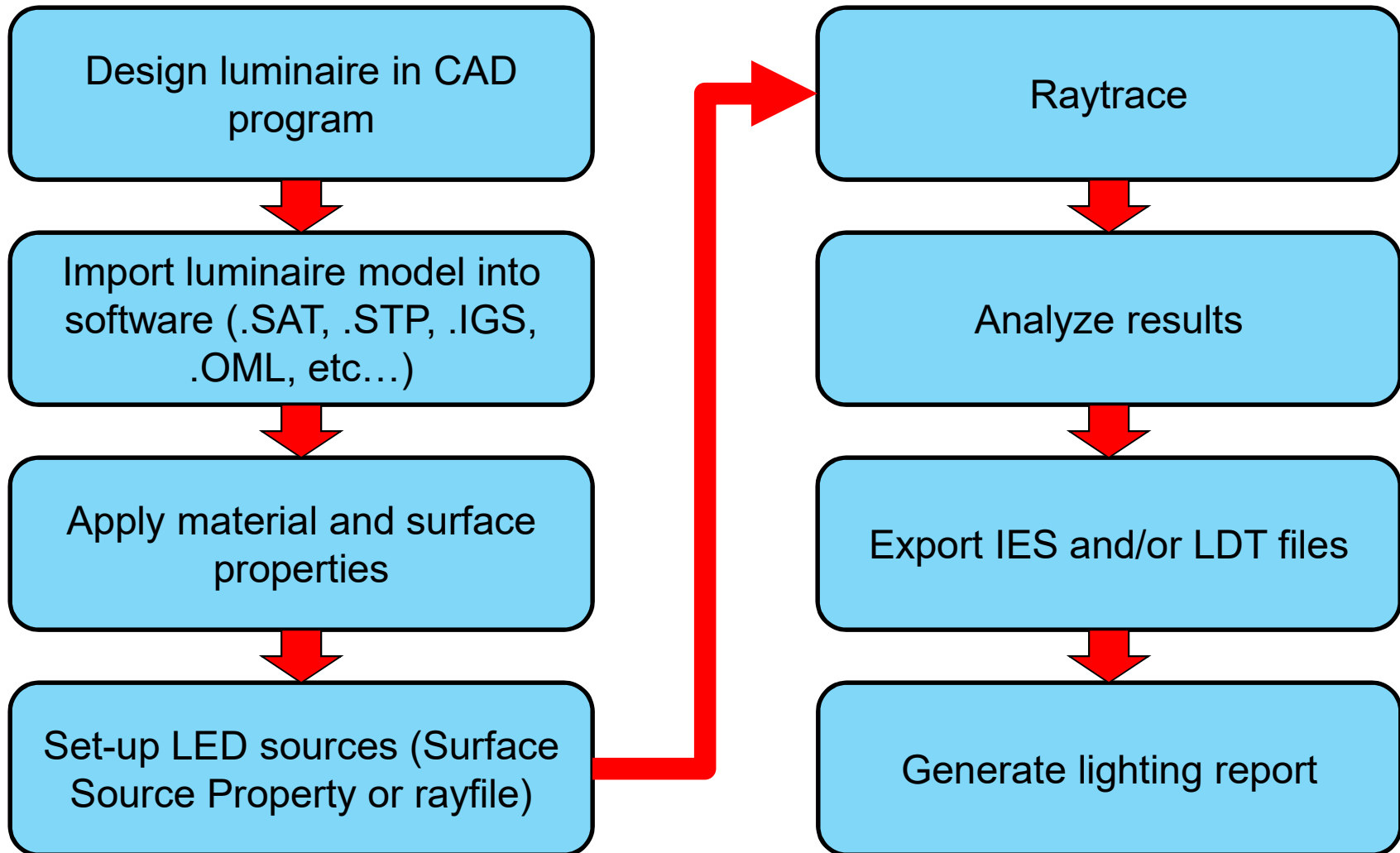
## Disadvantages of virtual prototyping

- Initial cost of software
- Ongoing cost of software – maintenance and support
- Learning curve – training and learning how to use the software
- Initial correlation of model vs. actual results
- Need to have accurate property data
- Possible cost of having materials measured for accurate property data



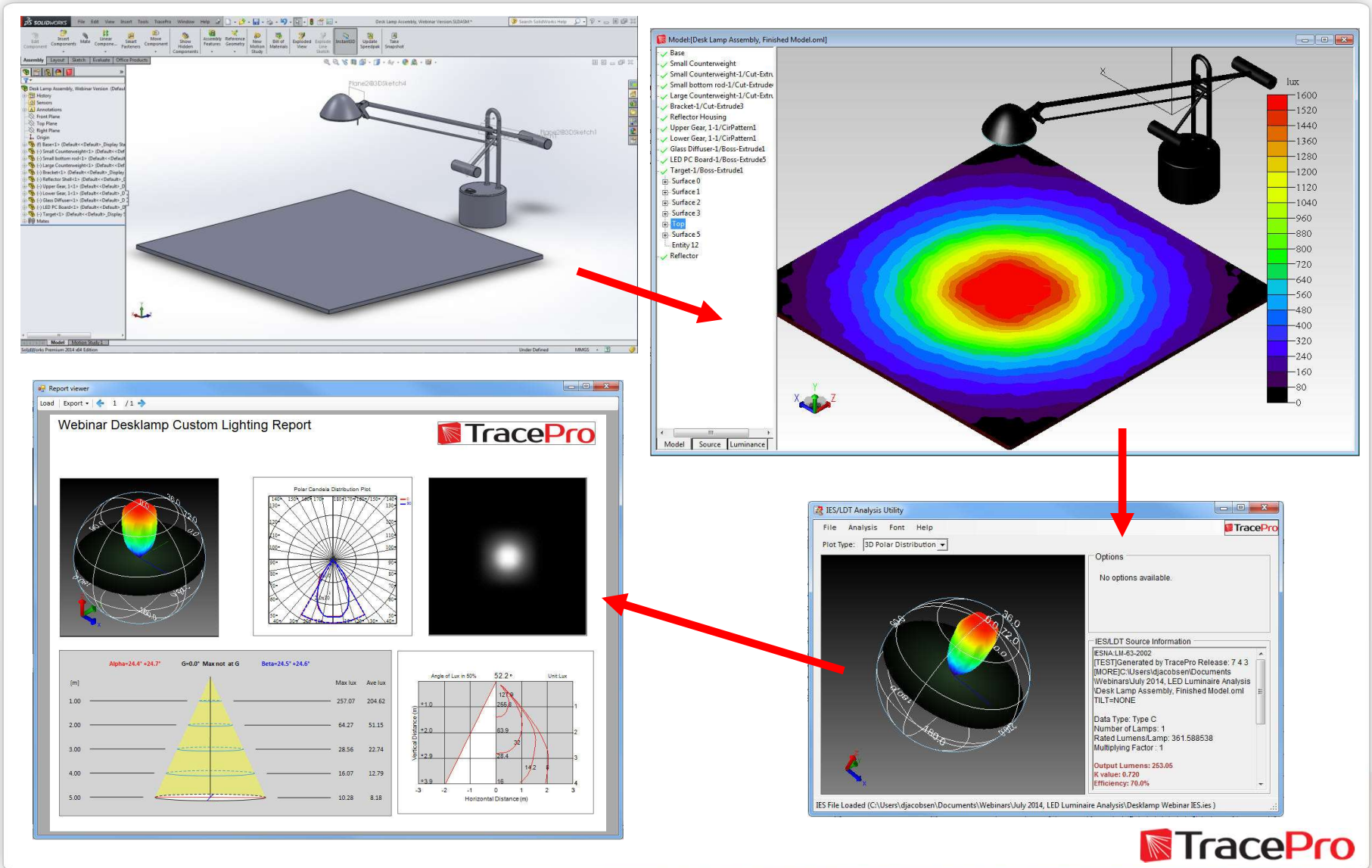
# Workflow

## Simplified workflow

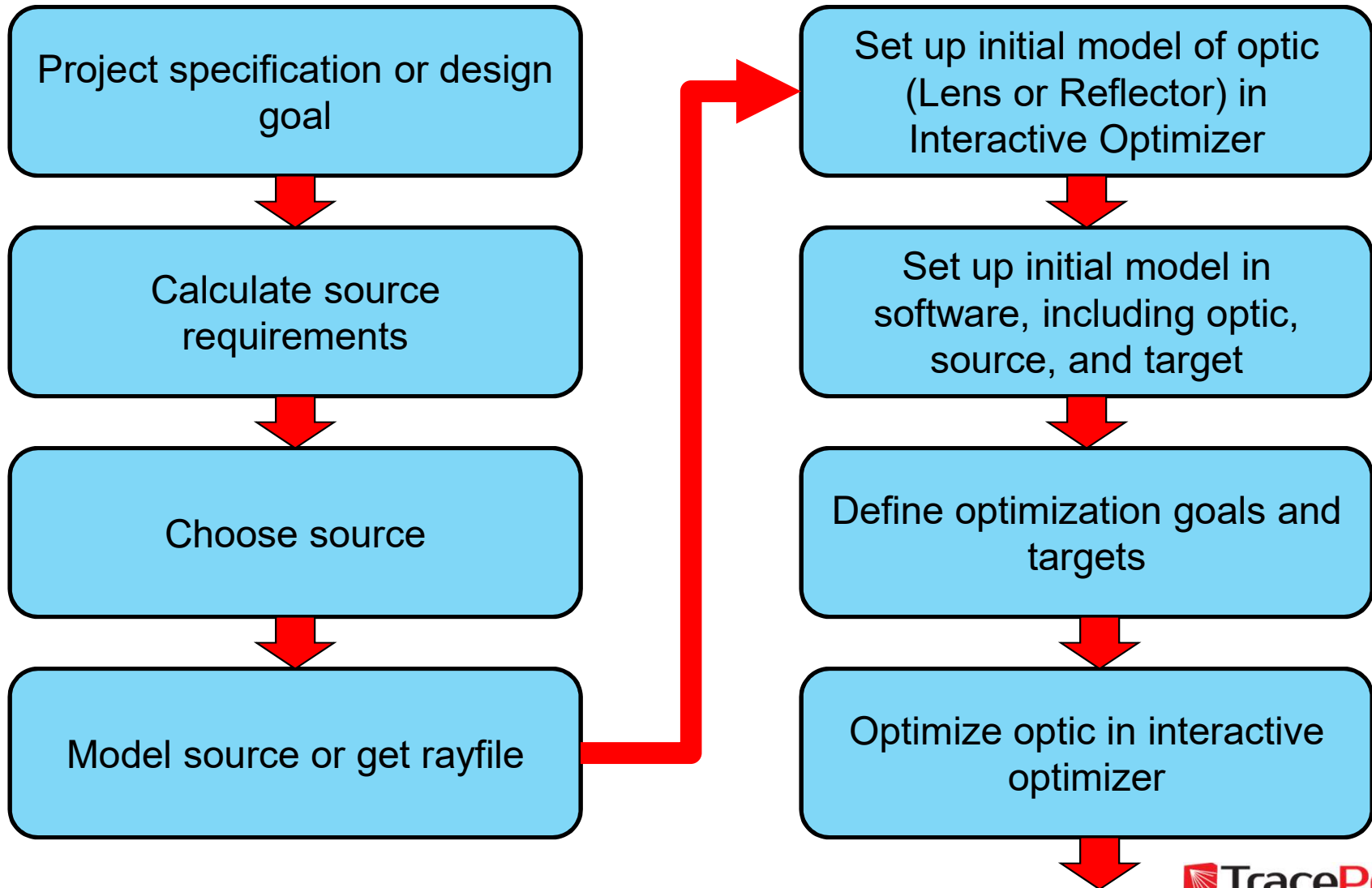




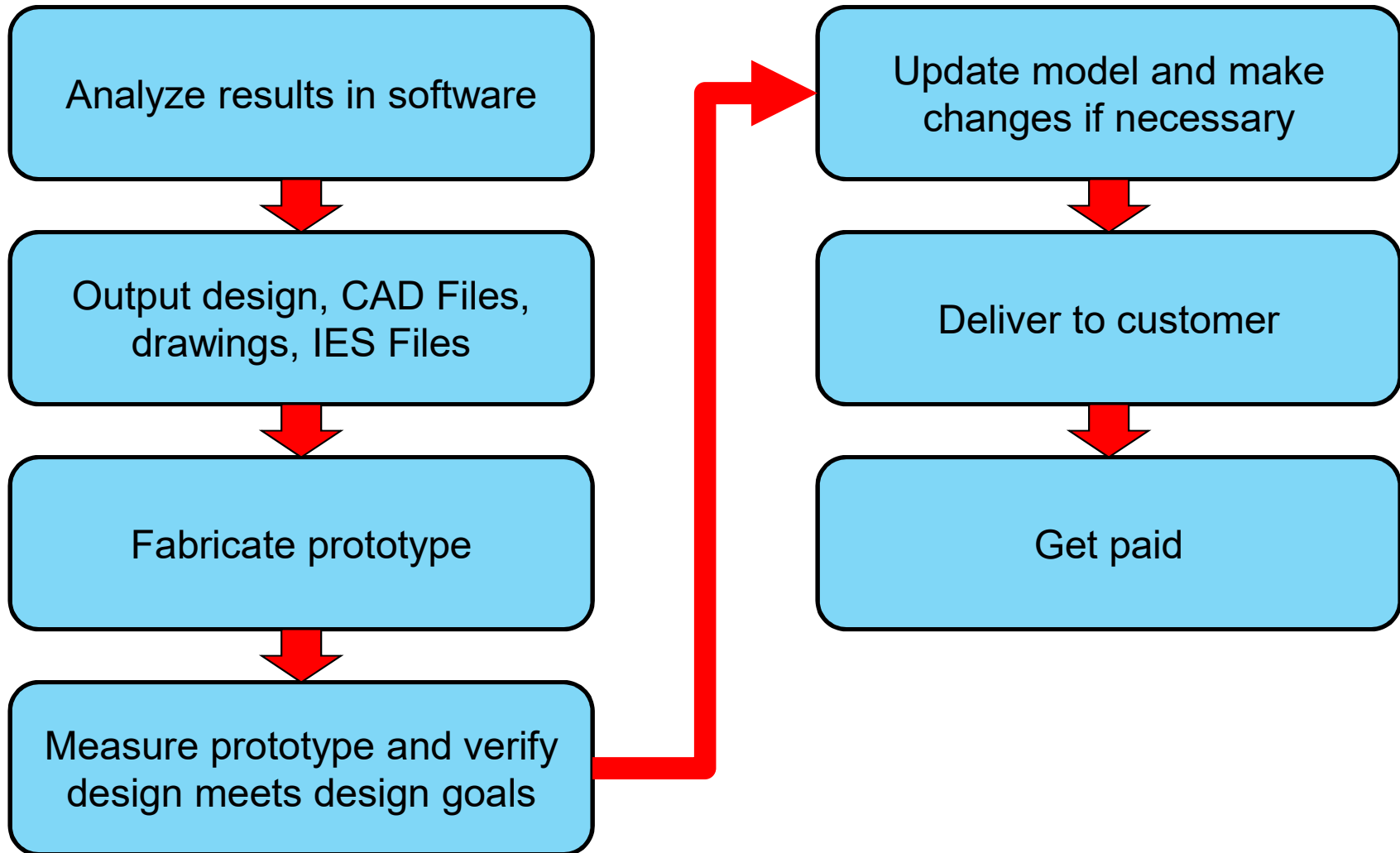
# Simplified workflow

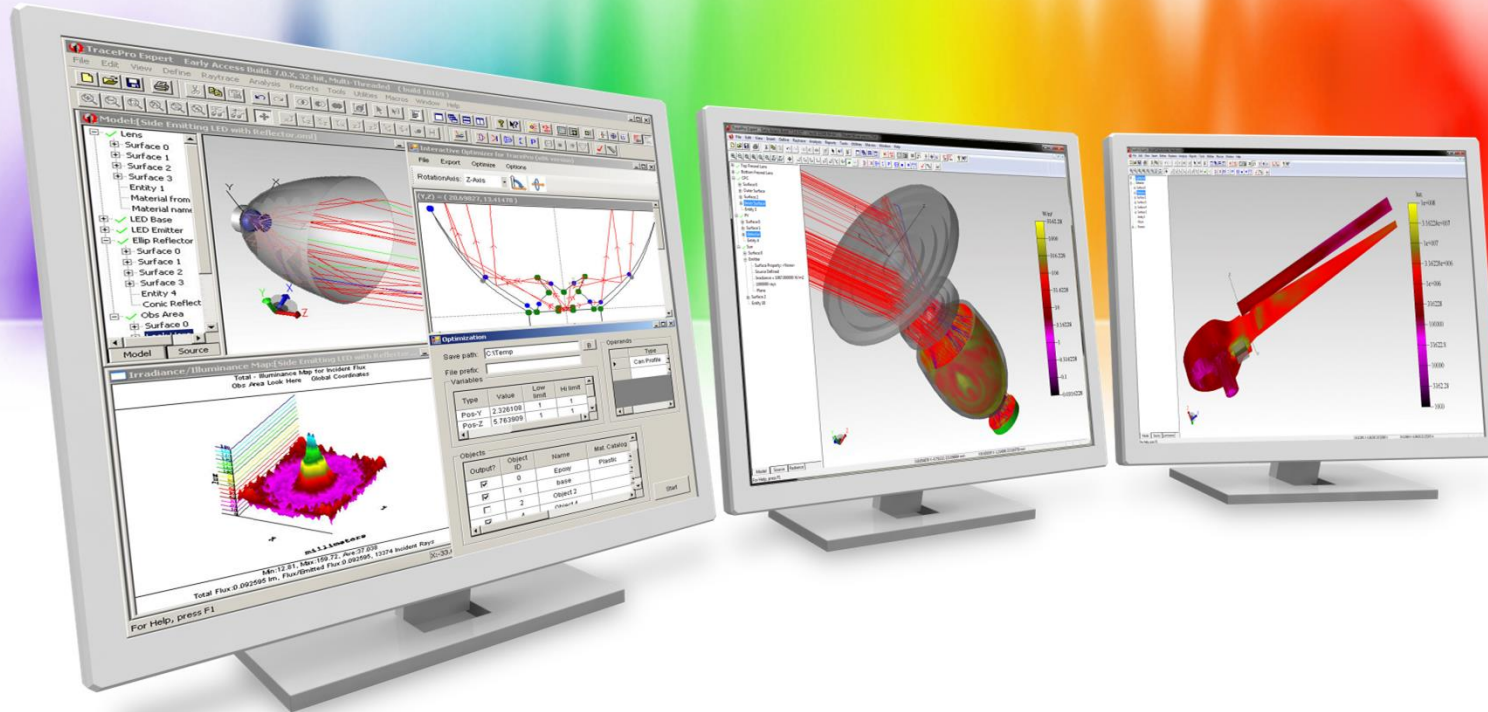


## Typical workflow



## Typical workflow





## Analysis Tools for Design Verification

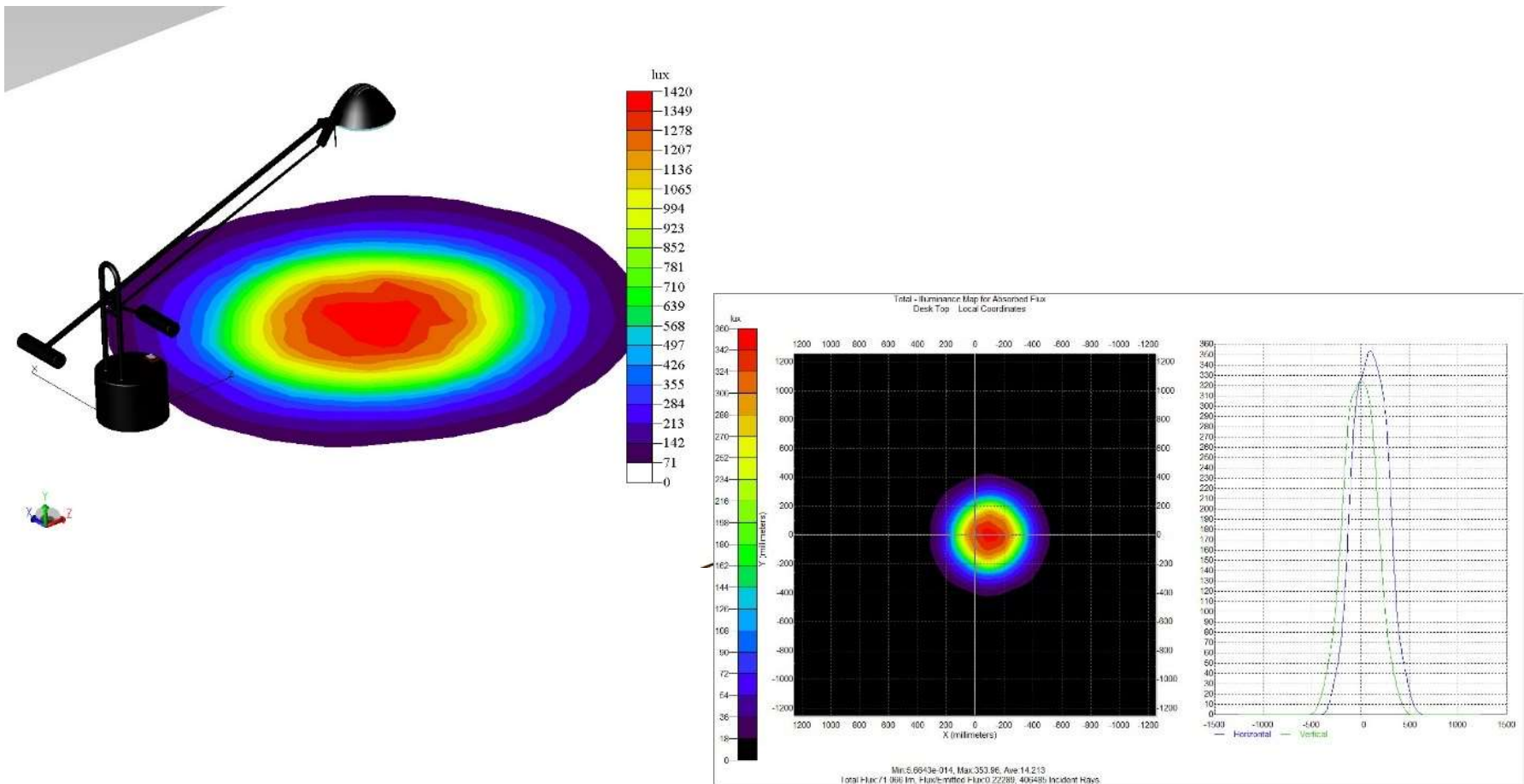
## Analysis Tools

- The analysis tools in optical design and analysis programs allow the users to test their designs in a virtual environment
- This can be accomplished much faster than setting up a prototype for measurement in an optical laboratory.
- Multiple types of measurements can be easily made
  - Illuminance, intensity (candela), luminance, total flux, efficiency, uniformity, colorimetry, photorealistic rendering
- Results can be saved as IES and LDT files
- Lighting reports can be generated using the data from the analysis
- Photometric and radiometric measurement units can be used



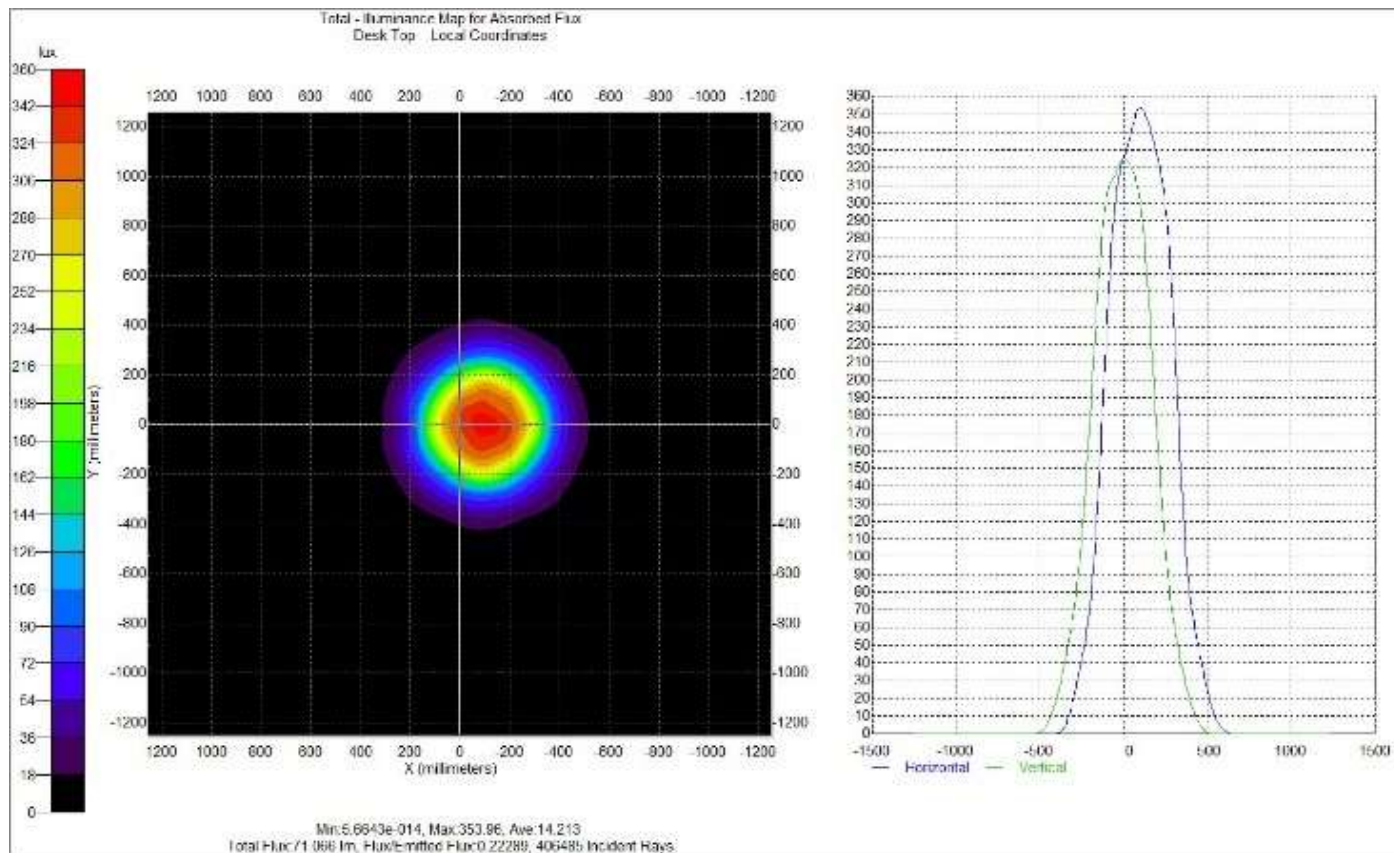
# Illuminance Map

- The Illuminance Map displays the spatial distribution of the light on a selected surface or surfaces.



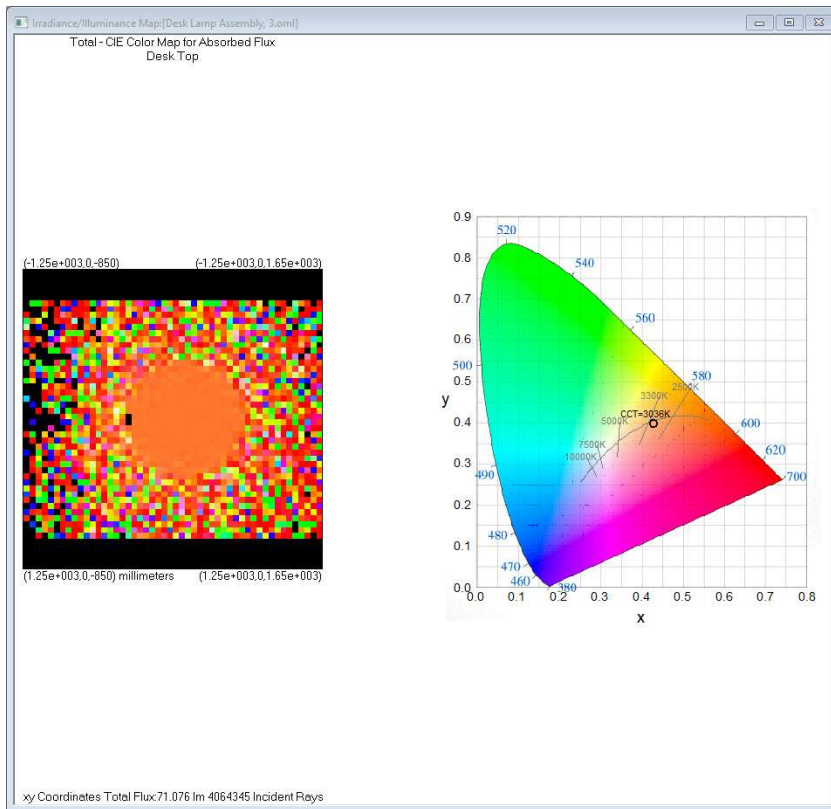
# Illuminance Map

- The Illuminance Map also displays total flux, minimum, maximum, and average illuminance values, flux received vs flux emitted (efficiency), and profile plots.

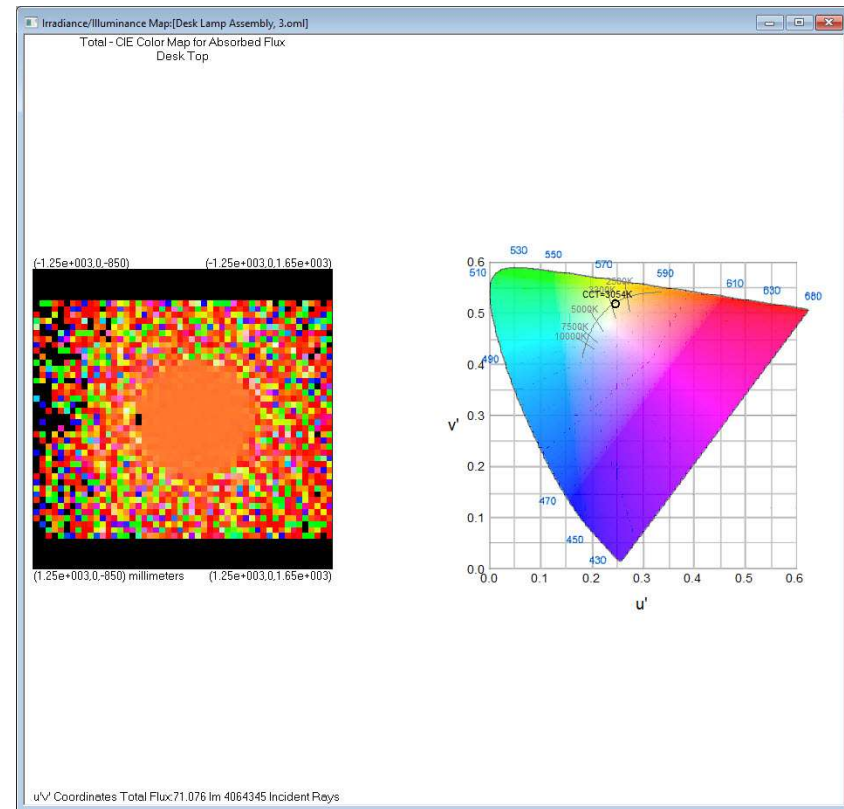


# Illuminance Map

- The Illuminance Map can also display the CCT, correlated color temperature, and CIE color coordinates, CIE xy and CIE u'v', of the light hitting a selected surface.



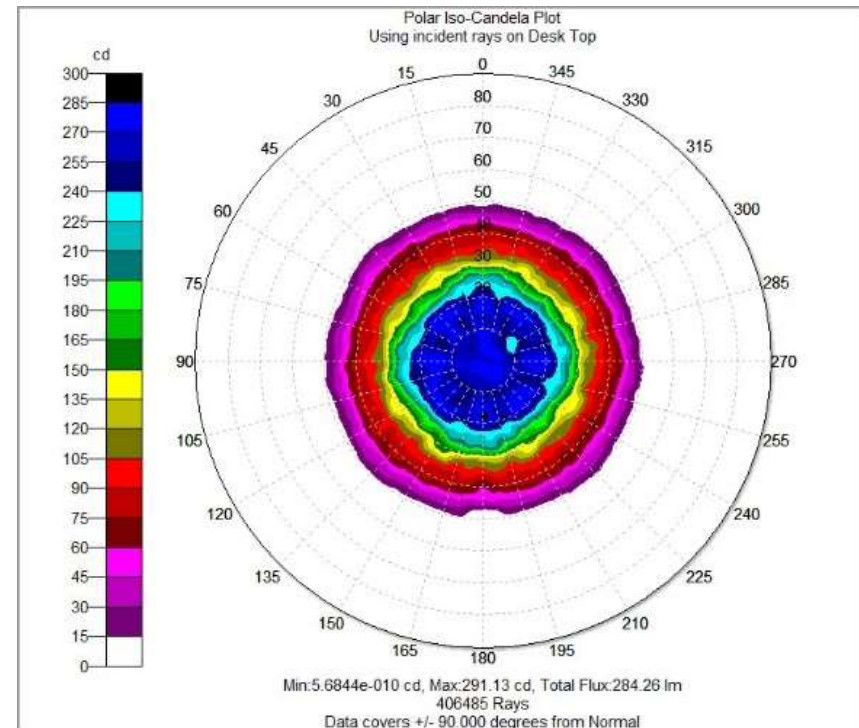
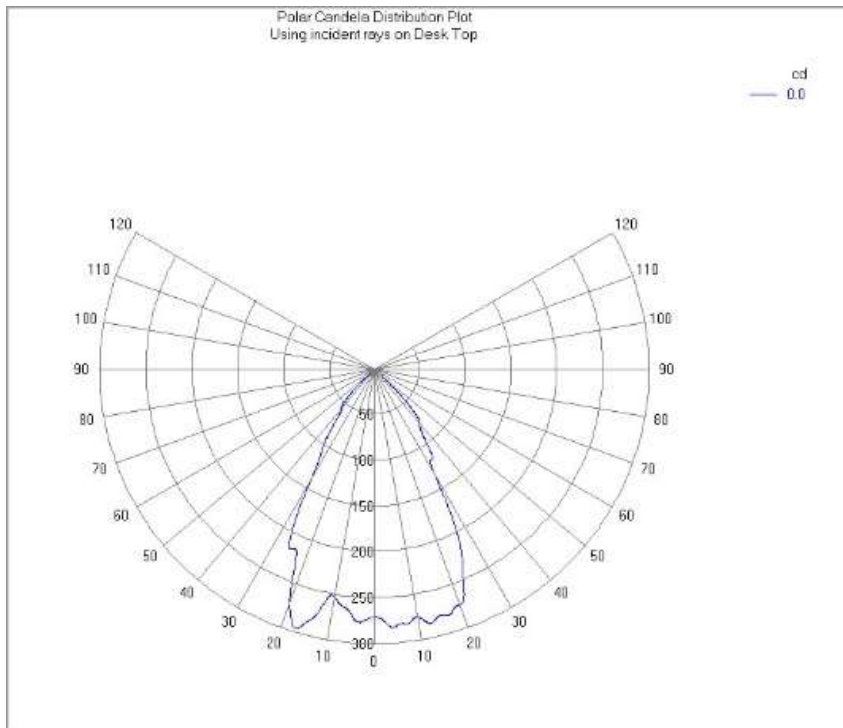
CIE xy



CIE u'v'

# Illuminance Map

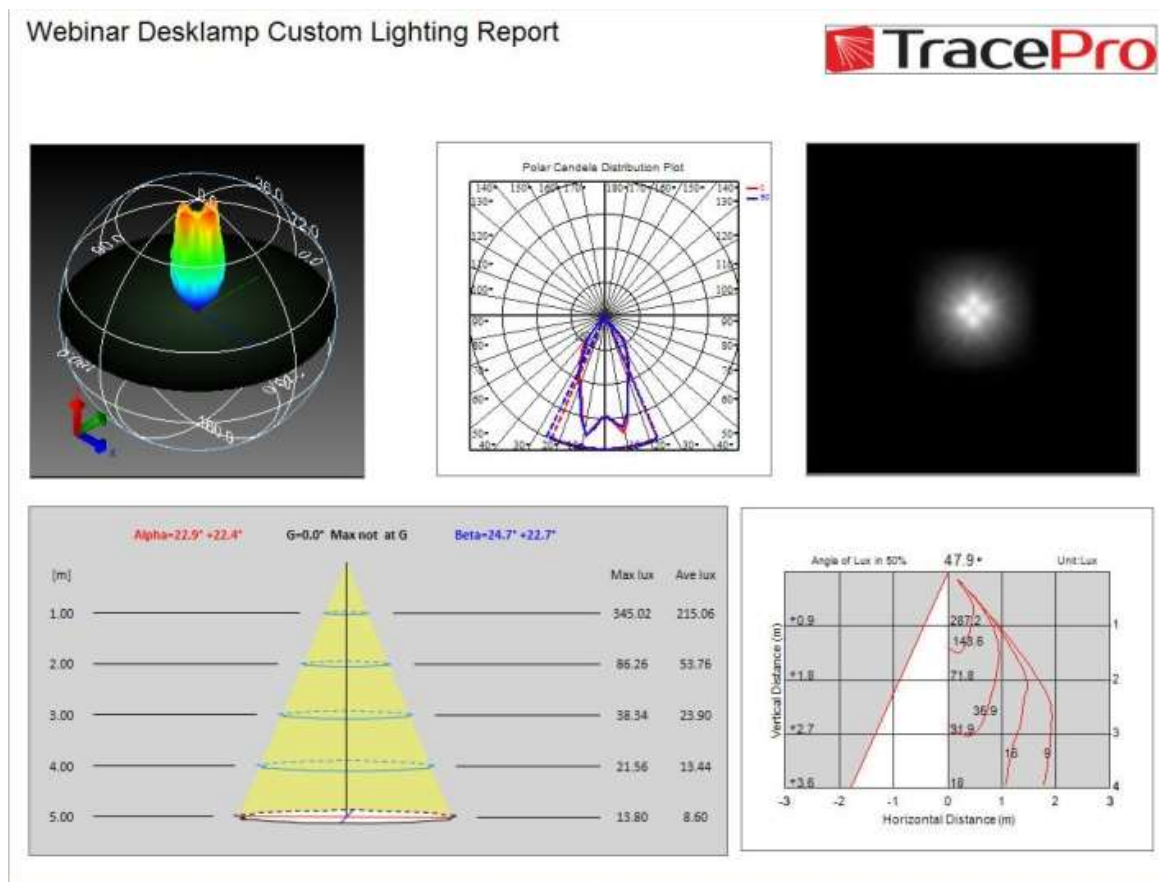
- The Candela or Intensity plots show the intensity of the light as a function of angle. IES and LDT files can be generated from Candela Plots.





# Illuminance Map

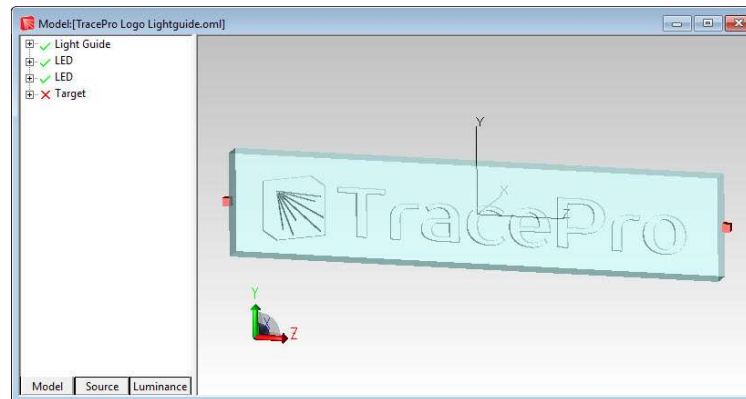
- The IES and LDT files can be used to generate custom light reports or export the photometric data to architectural lighting design software

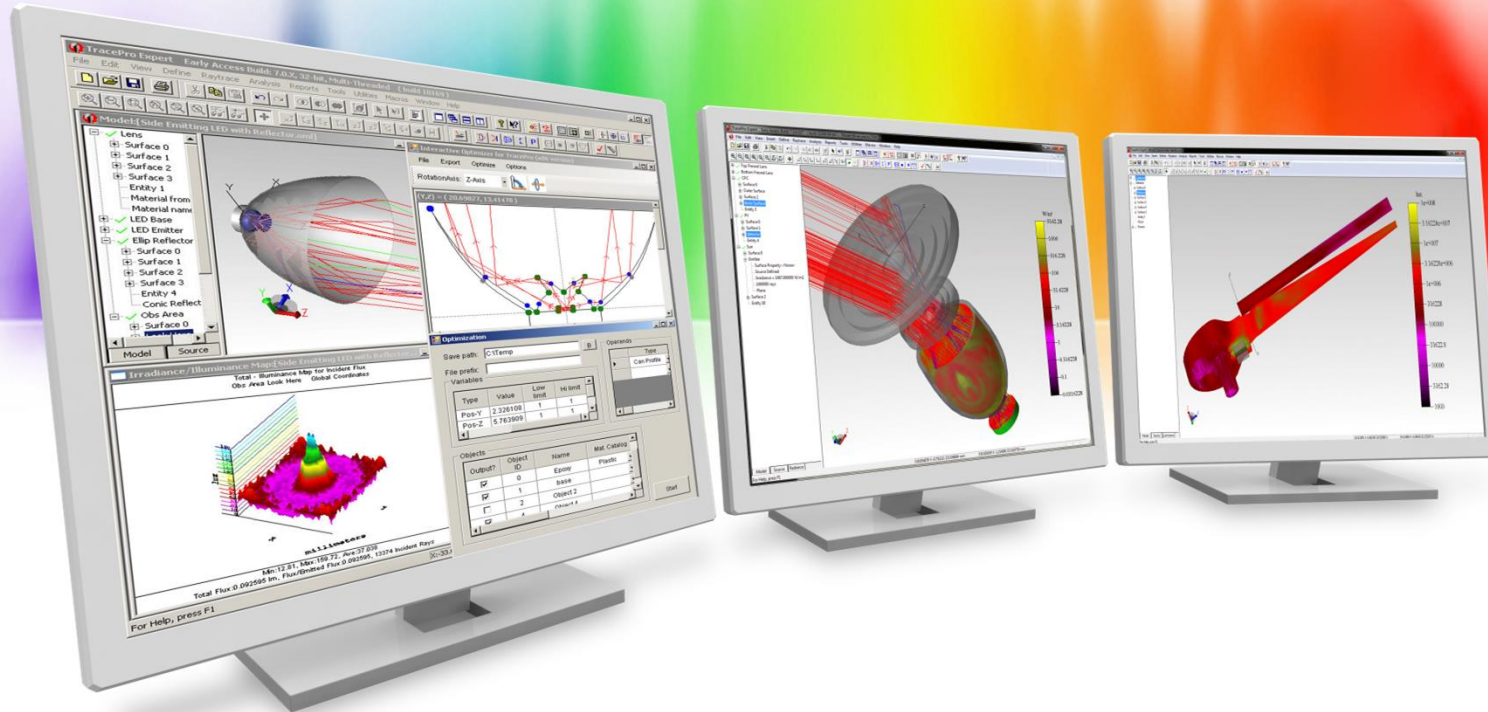




# Illuminance Map

- Luminance Maps and Photorealistic Rendering show the luminance of the luminaire or light source and a lit appearance display of how it looks to a viewer.





# Optimization

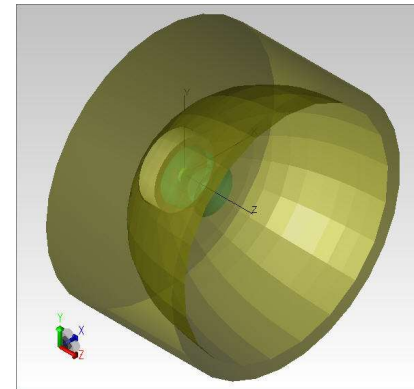
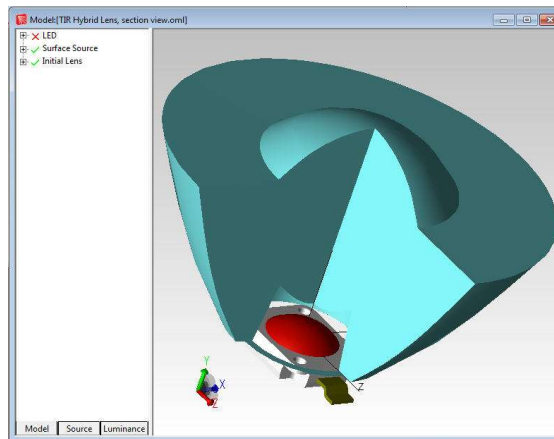
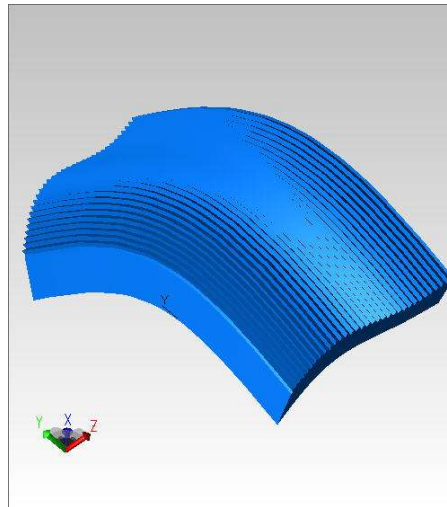
## What is optimization?

- An act, process, or methodology of making something (as a design, system, or decision) as fully perfect, functional, or effective as possible. (*Source: Merriam-Webster online dictionary*)

# What is optimization?

- What are some of the parameters that can be optimized?

- Geometry
- Curvature
- Facets
- Position
- Angle
- Spacing
- Thickness
- Properties



## What is optimization?

- What many people would like to see...





## What is optimization?

- Or....



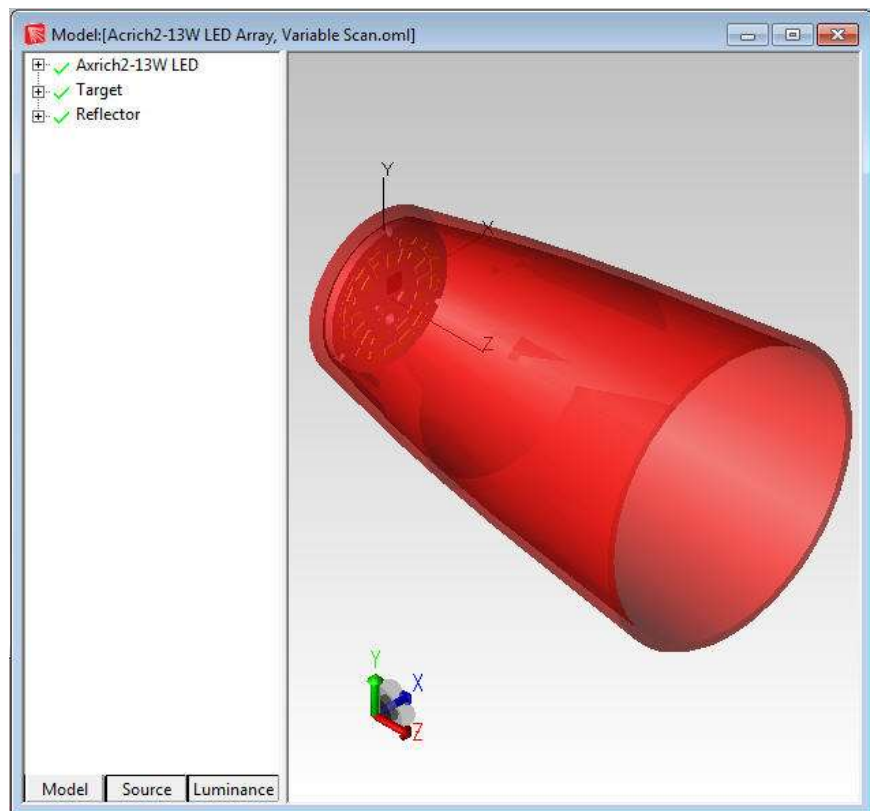
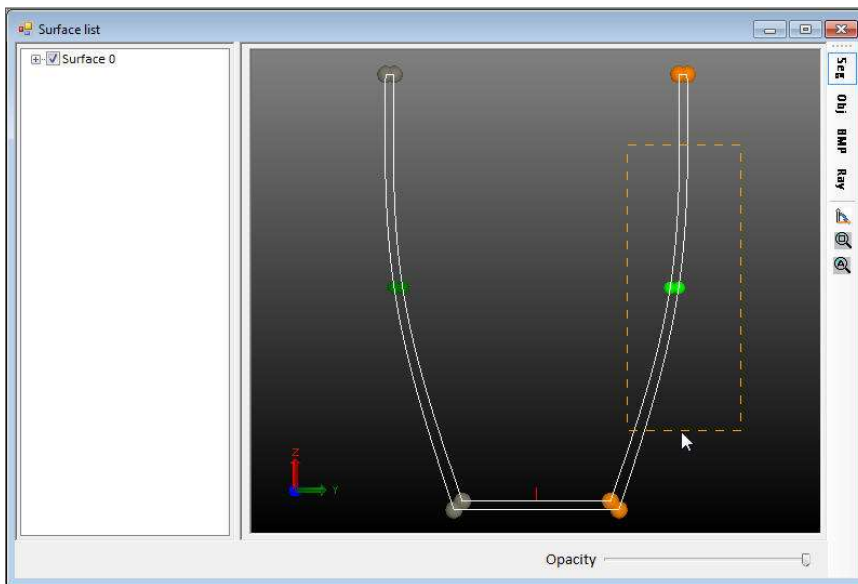
## What is optimization?

- What we can try to do with optimization....



# Why do we need optimization?

- Brute force vs. Optimization algorithm – The goal is to optimize the reflector shown below



# Why do we need optimization? The brute force approach.

- Optimization goal – even illumination in the central 2/3 of the target

The screenshot displays the TracePro optimization interface. The main window is titled "Optimization dialog" and shows the following settings:

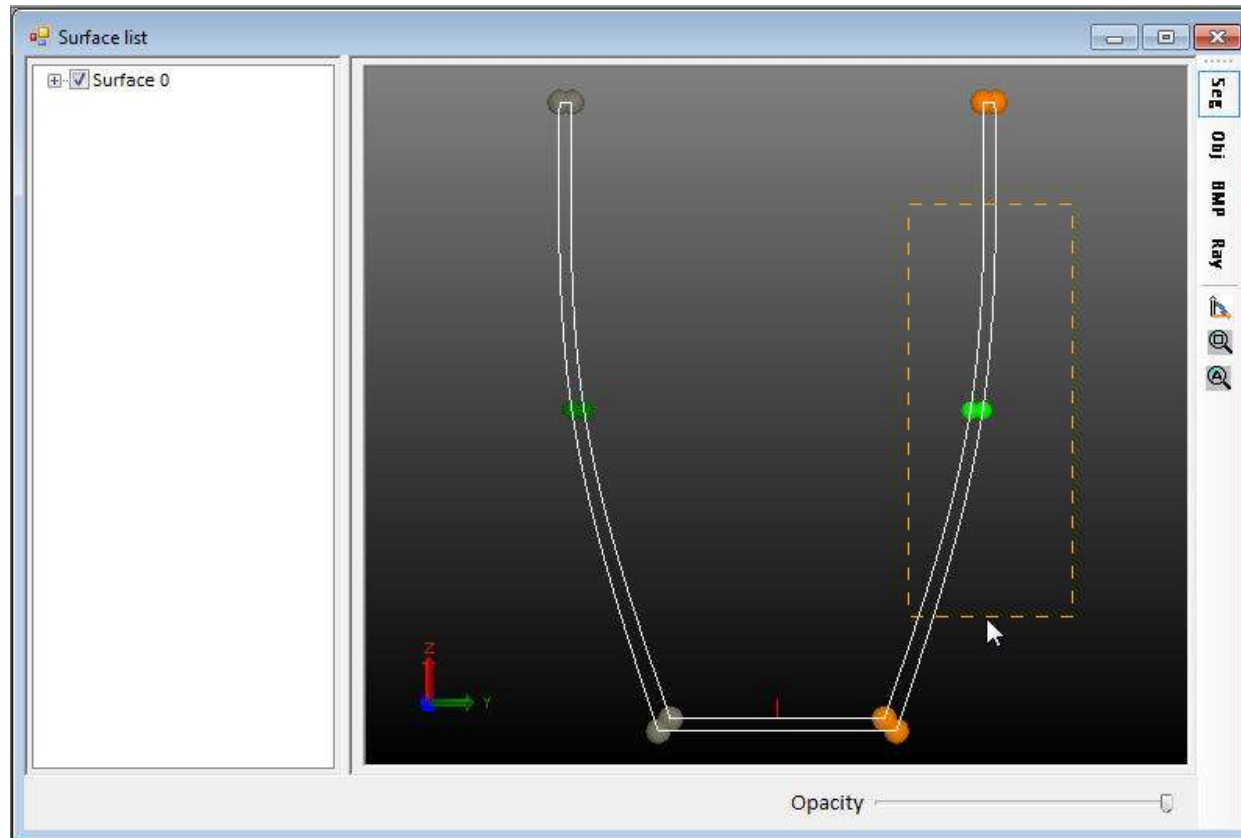
- Path: C:\3D Optimizer
- Prefix: LEDPro
- Operation mode: Variable Scan
- Variable list: Includes Position-Y and Position-Z.
- Object list: Includes a Reflector.
- Operand list: Shows an operand for Irr Profile Similarity on the Receiver surface.

An "Irradiance target profile definer" dialog is open, showing a graph of the target profile. The graph plots Relative Pos. (x-axis) against Value (y-axis). The profile is a trapezoid with a value of 1.0000 in the central region and 0.0000 at the edges.

Relative Pos.	Value
-0.5000	0.0000
-0.4500	0.0000
-0.3330	1.0000
0.3330	1.0000
0.4500	0.0000
0.5000	0.0000

## Why do we need optimization? The brute force approach.

- Control Point variable range - 40mm in Y-axis and 100mm in Z-axis





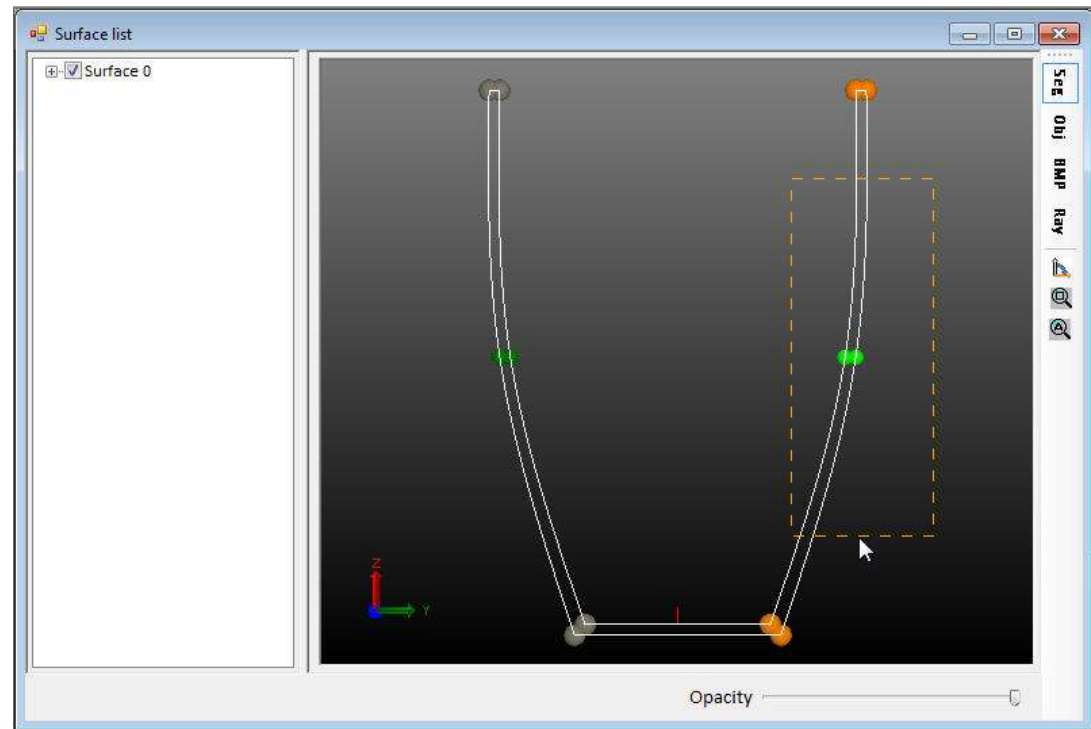
## Why do we need optimization? The brute force approach.

- Control Point variable range - 40mm in Y-axis and 100mm in Z-axis

Scanning the entire variable range in 1mm increments would take  $41 \times 101 = 4141$  increments.

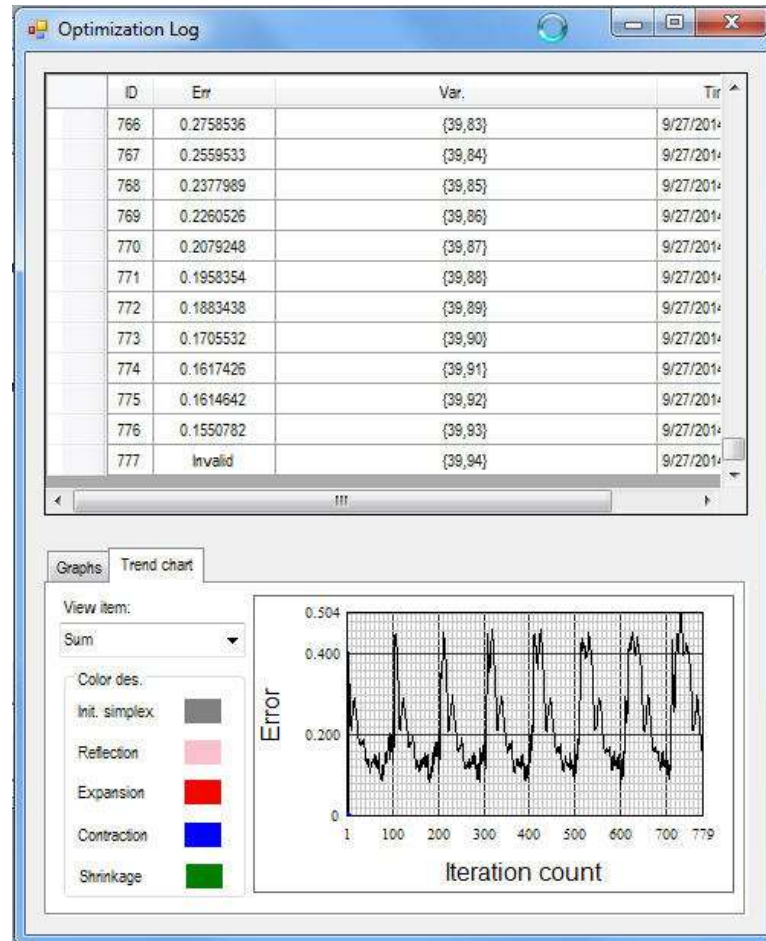
If the raytrace time is 1-minute per iteration, this would take around 70-hours to complete.

Scanning in 0.1mm increments would take around 6690 hours, or 279 days



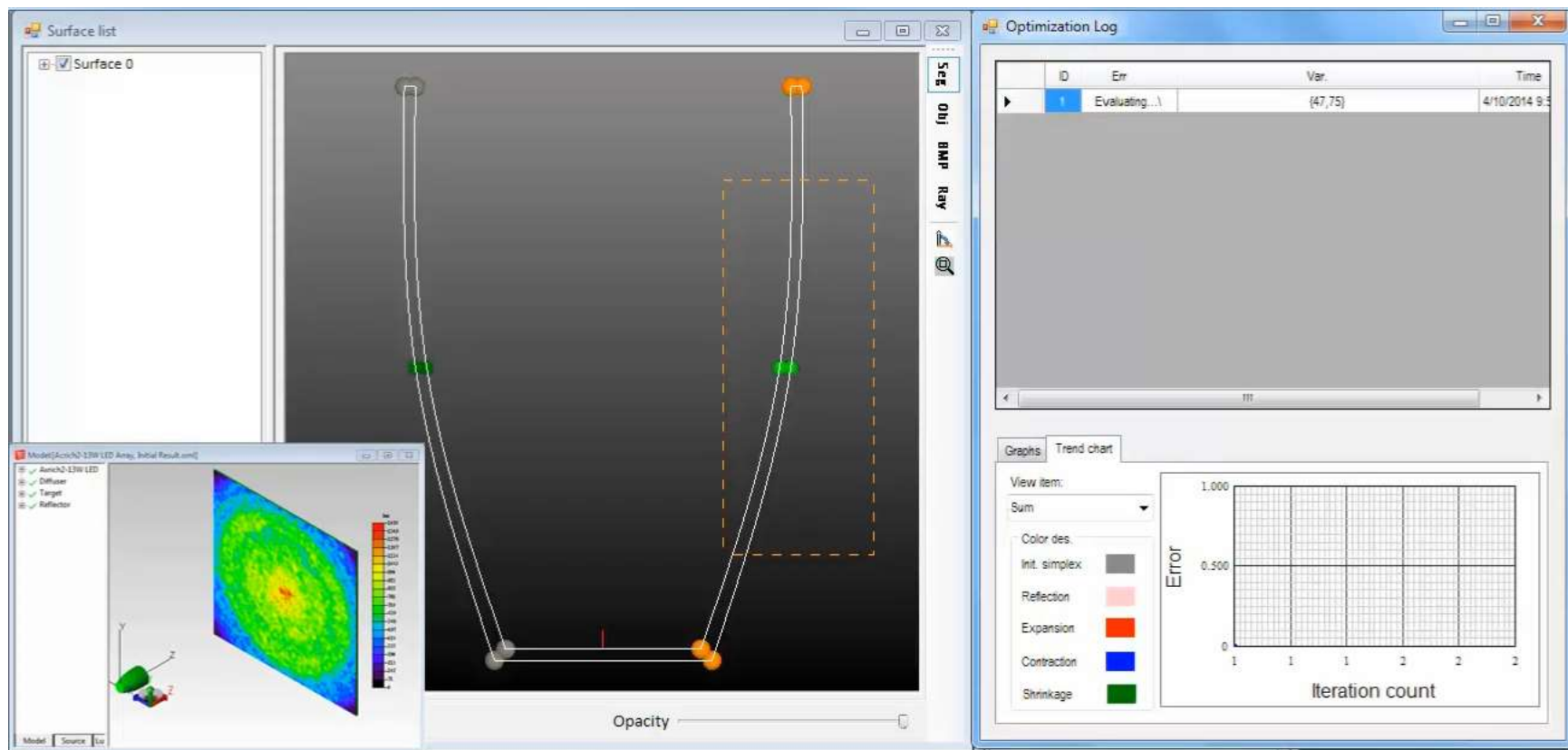
# Why do we need optimization?

- Optimization Log after 14 hours of raytracing



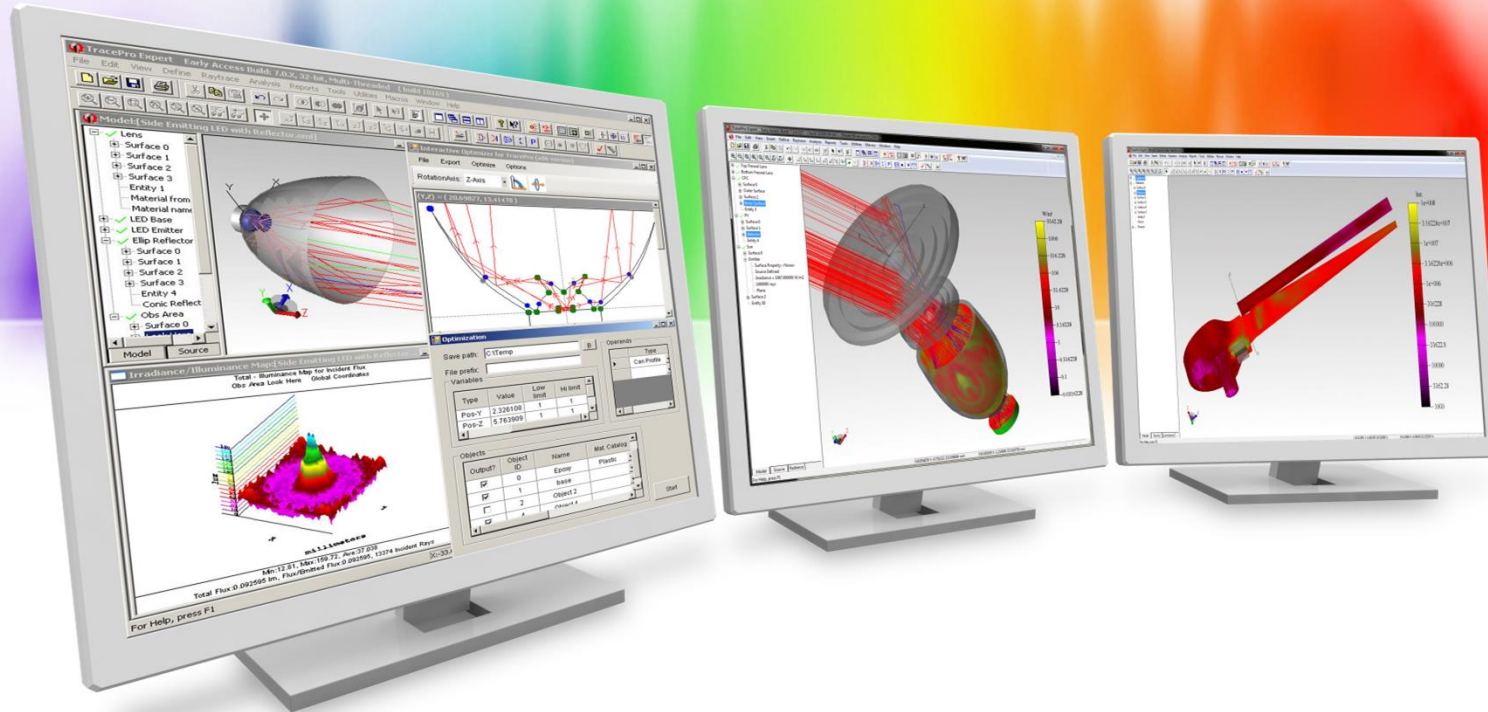
# Why do we need optimization? A better approach.

- Using an optimization algorithm the total time was reduced to about 2 hours 20 minutes, with more rays traced for each iteration - Video



## Optimization methods

- Generally there are 2 types of optimizers: Global and Local.
- Global optimizers will search the entire solution space to find the best solution based on the optimization goal or merit function. Typically used in lens design programs.
  - Global Explorer, Adaptive Simulated Annealing, Global Synthesis, Hammer Optimization
- Local optimizers will find the solution closest to the starting point of the optimization process. Changing the starting conditions can change the results of the optimization process. Typically used in illumination design programs.
  - Downhill Simplex or Nelder-Mead, Damped least squares, Powell's Method



## Examples

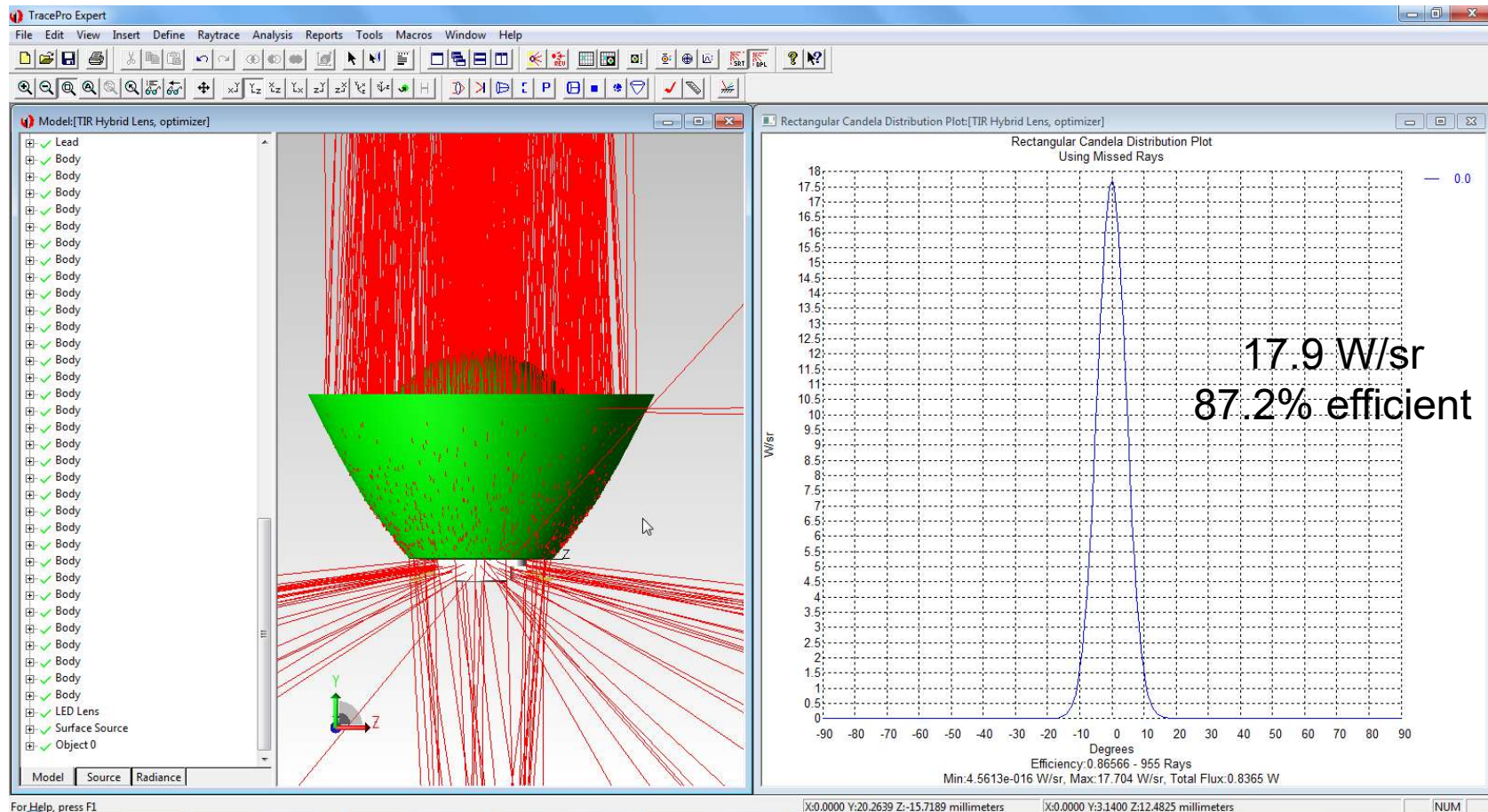


## Examples

- TIR Hybrid lens – manual vs automatic optimization
- Side emitting LED lens and reflector combination
  - One part at a time
  - Both parts at same time
- Curved Facet Reflector

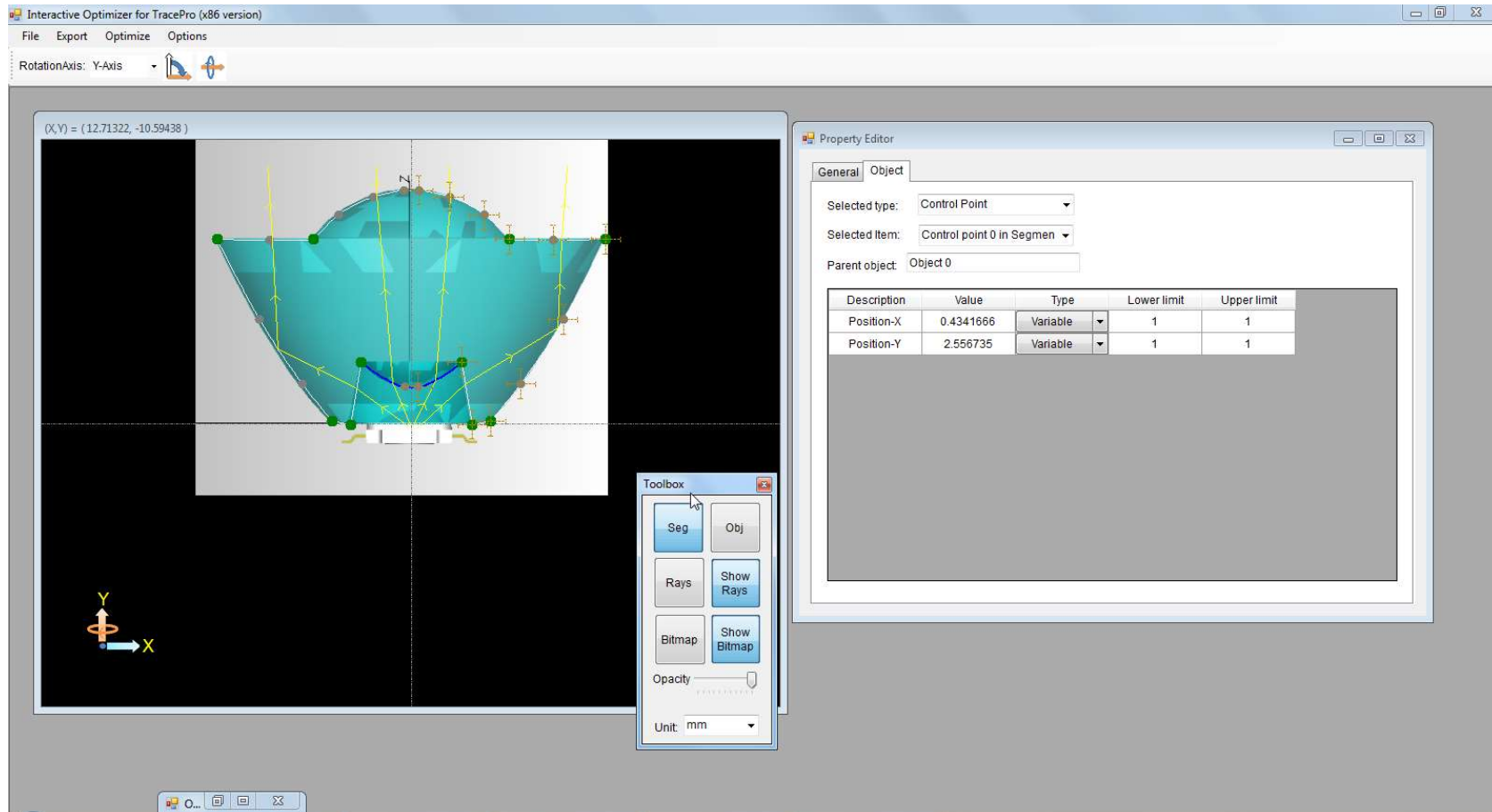
# TIR hybrid LED lens

- TIR Hybrid lens – Initially optimized by a trial and error process. Total time spent optimizing, about 3 days.



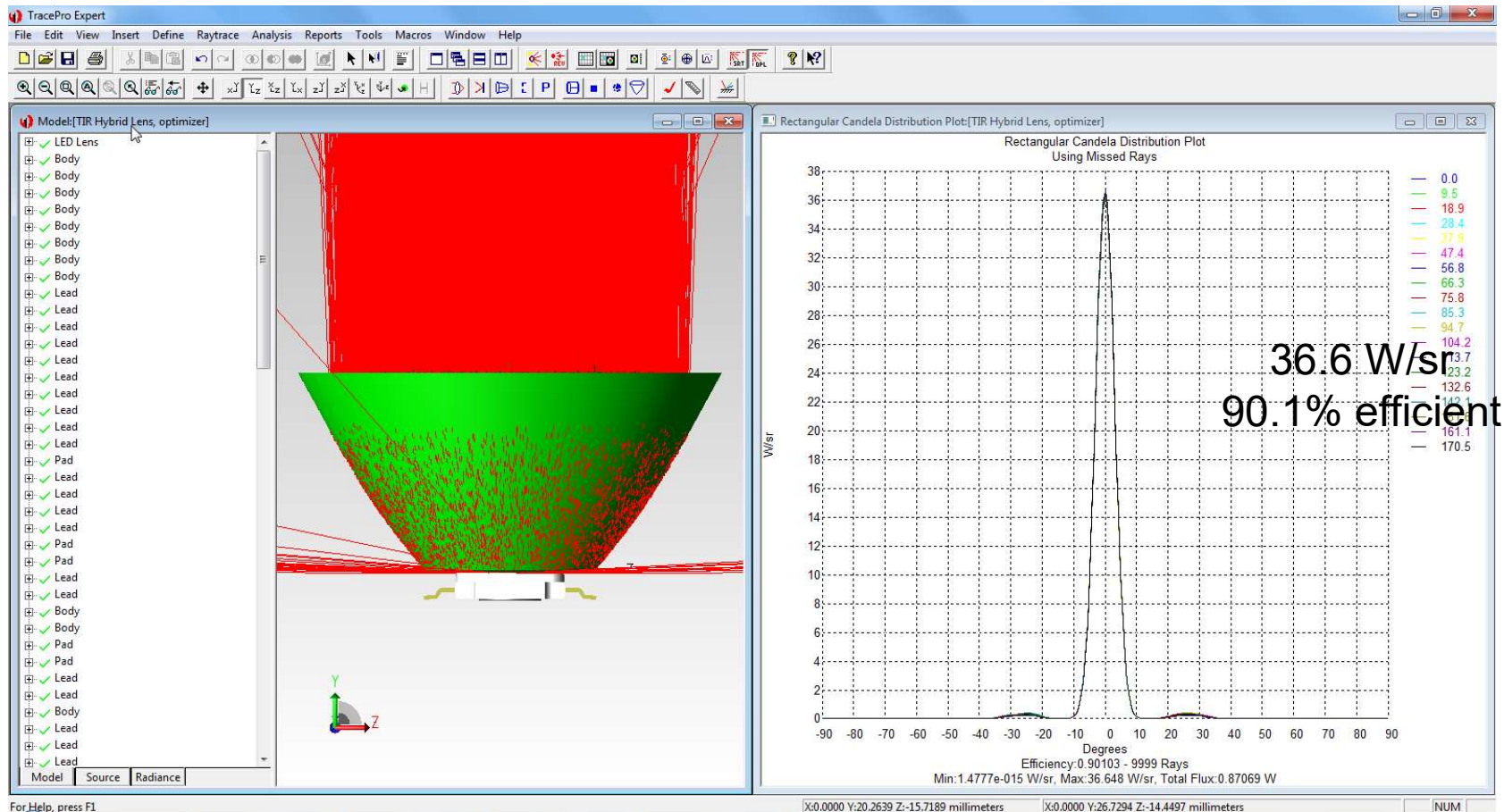
# TIR hybrid LED lens

- TIR Hybrid lens – Optimized using optimizer in TracePro – 12 variables in 2 axes each.



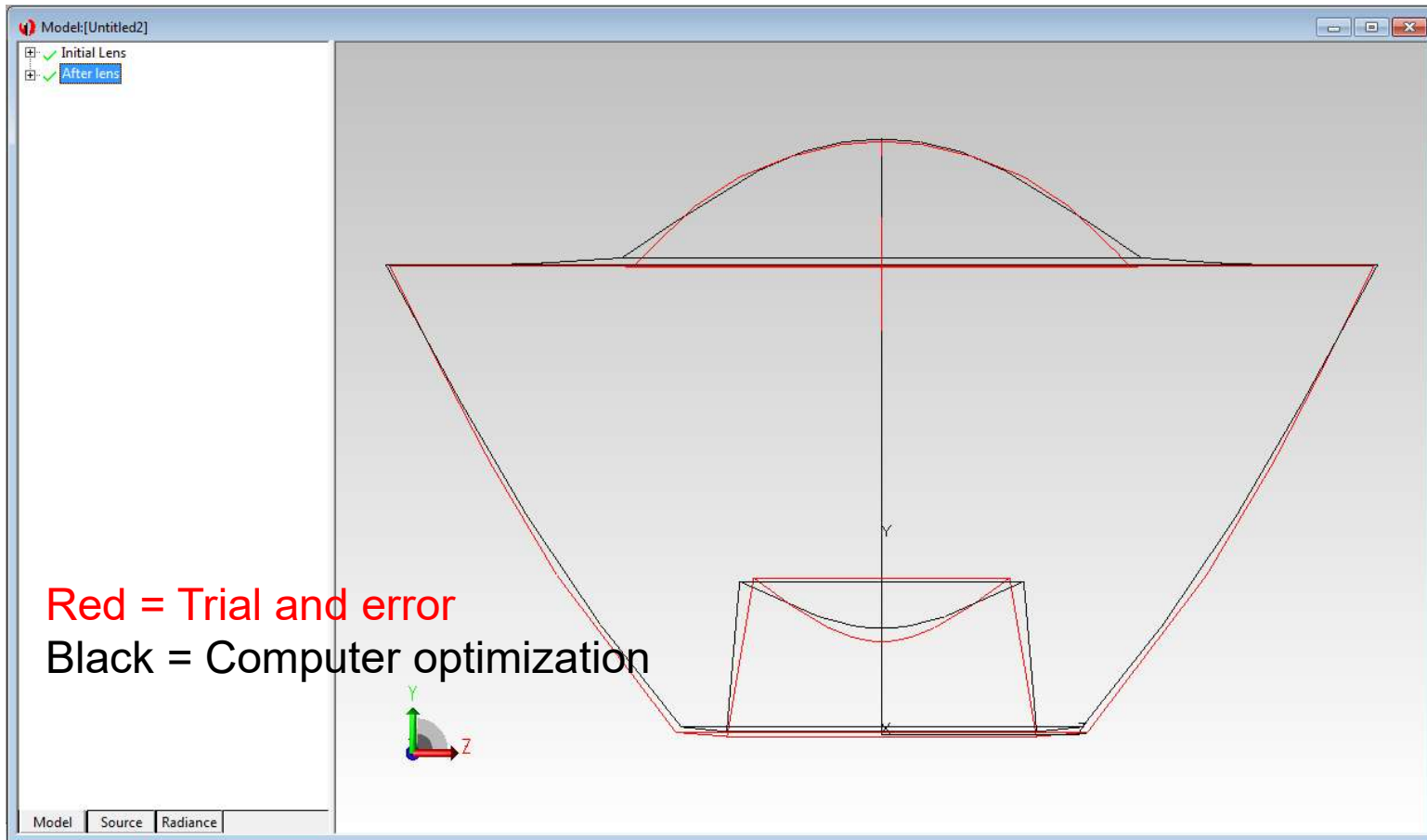
# TIR hybrid LED lens

- TIR Hybrid lens – Optimized using optimizer in TracePro. Total time spent optimizing, about 1 ½ hours.



# TIR hybrid LED lens

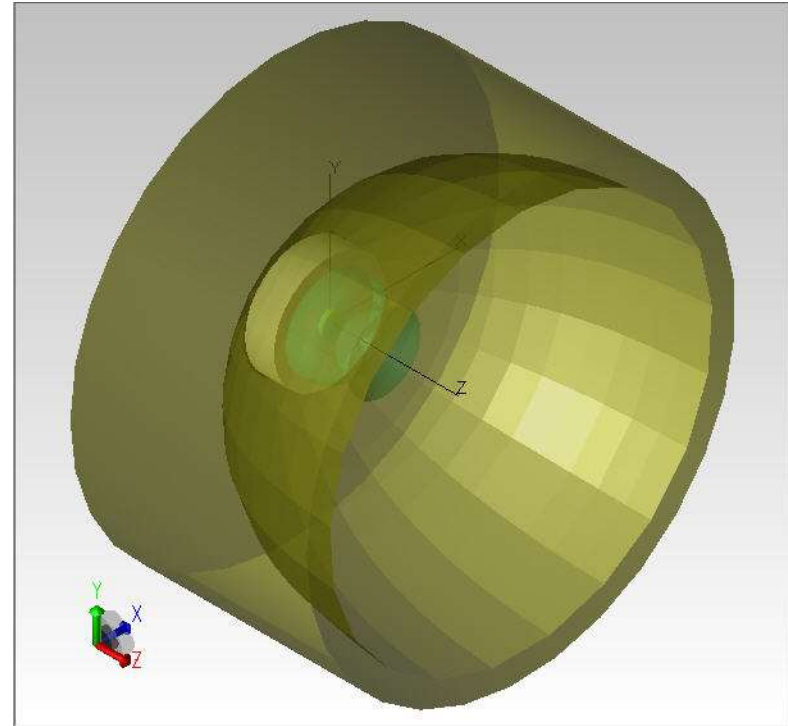
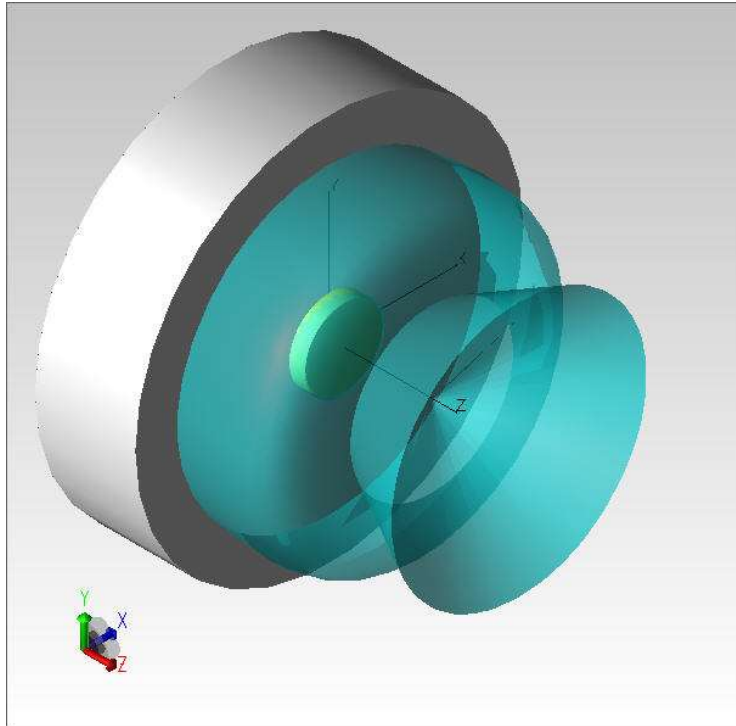
- TIR Hybrid lens – Trial and error vs. computerized optimization





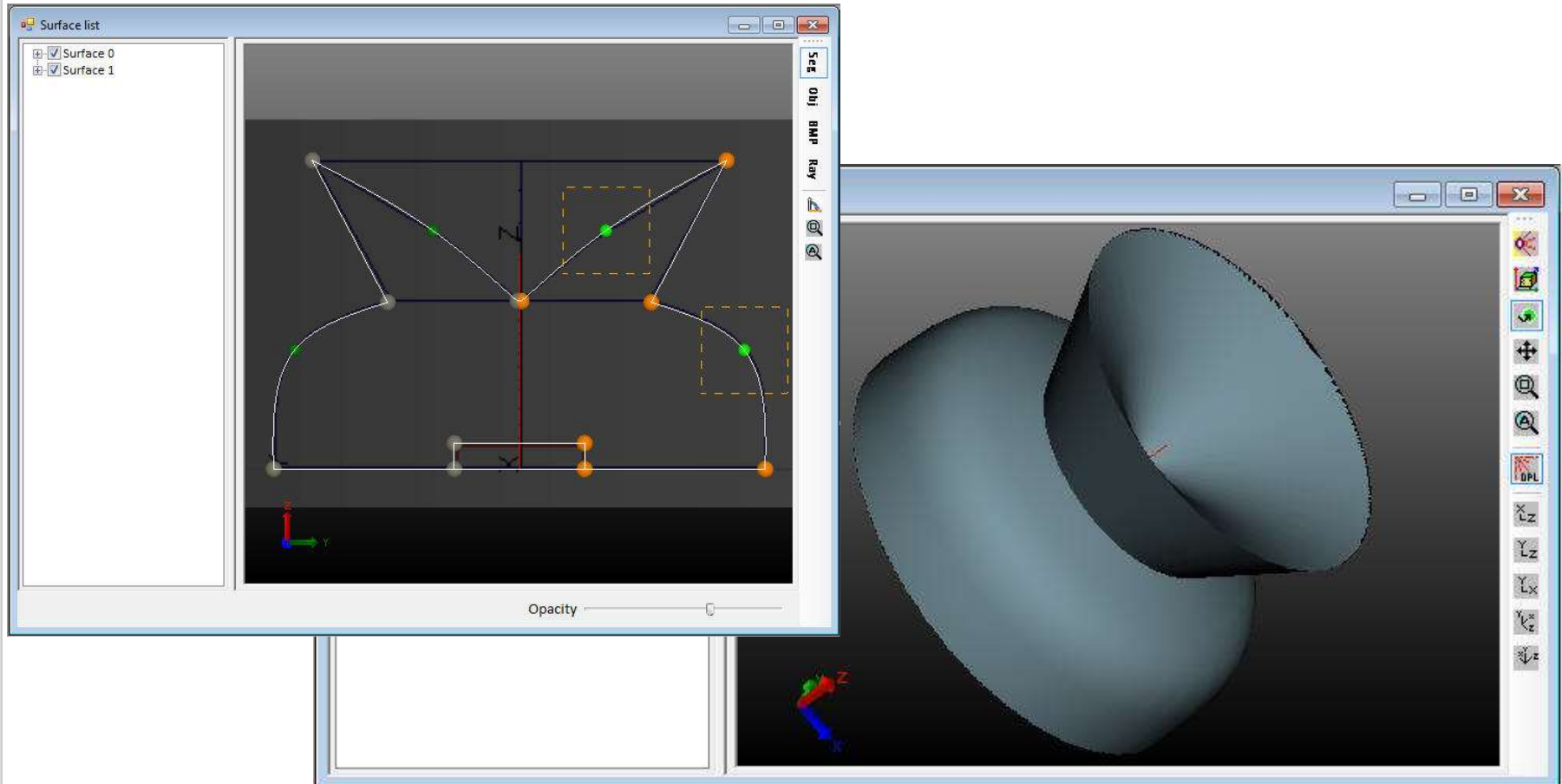
## Side emitting LED lens and reflector combination

- Side emitting LED lens and reflector combination
  - Is it better to optimize each part separately, or to optimize both parts at the same time?



# Side emitting LED lens and reflector combination

- Optimizing the optical elements separately – Setting up the LED side emitting lens – 2 control points in 2 axes each



# Side emitting LED lens and reflector combination

- Optimization Goal – Candela profile from 45 to 80 degrees and from -45 to -80 degrees with as little output between those lobes as possible

The screenshot displays the TracePro software interface during an optimization process. The main window is titled "Optimization dialog" and shows the following details:

- Path: C:\3D Optimizer
- Prefix: SEL
- Operation mode: Optimization
- Variable list table:

Included?	Item	Object
<input checked="" type="checkbox"/>	Position-Y	Ctrl Pnt:0@S
<input checked="" type="checkbox"/>	Position-Z	Ctrl Pnt:0@S
<input checked="" type="checkbox"/>	Position-Y	Ctrl Pnt:1@S
<input checked="" type="checkbox"/>	Position-Z	Ctrl Pnt:1@S

The "Operand list" table is also visible:

ID	Type	Opt.	Surface	Range	Weight	Target value
01	Can Profile	Similarity		Exiting ray	1.0	{{-180,-90,-80,-70,-45,45,7...

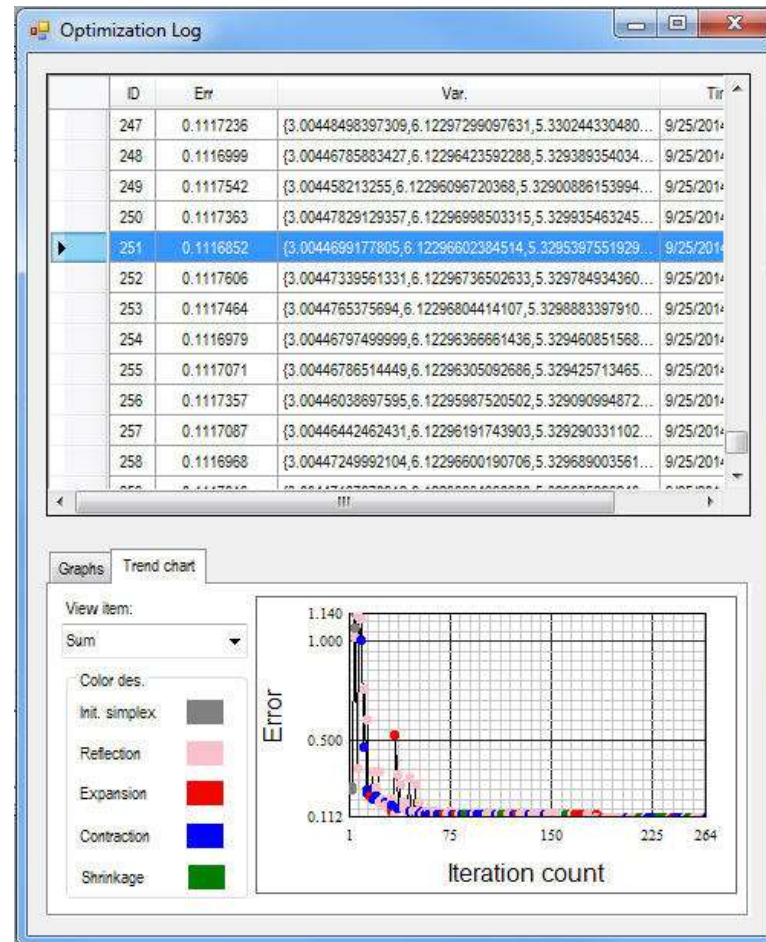
The "Candela target definer" window is open, showing a "Profile chooser" with a polar plot and a "Symmetric input" checkbox checked. The main plot is a rectangular graph with the following data table:

Angle	Value
-180.0000	0.0000
-90.0000	0.0000
-80.0000	1.0000
-70.0000	1.0000
-45.0000	0.0000
45.0000	0.0000
70.0000	1.0000
80.0000	1.0000
90.0000	0.0000
180.0000	0.0000

The graph shows two distinct lobes of light output, one centered around -75 degrees and another around 75 degrees, with zero output in between. The "Plot type" is set to "Rectangular".

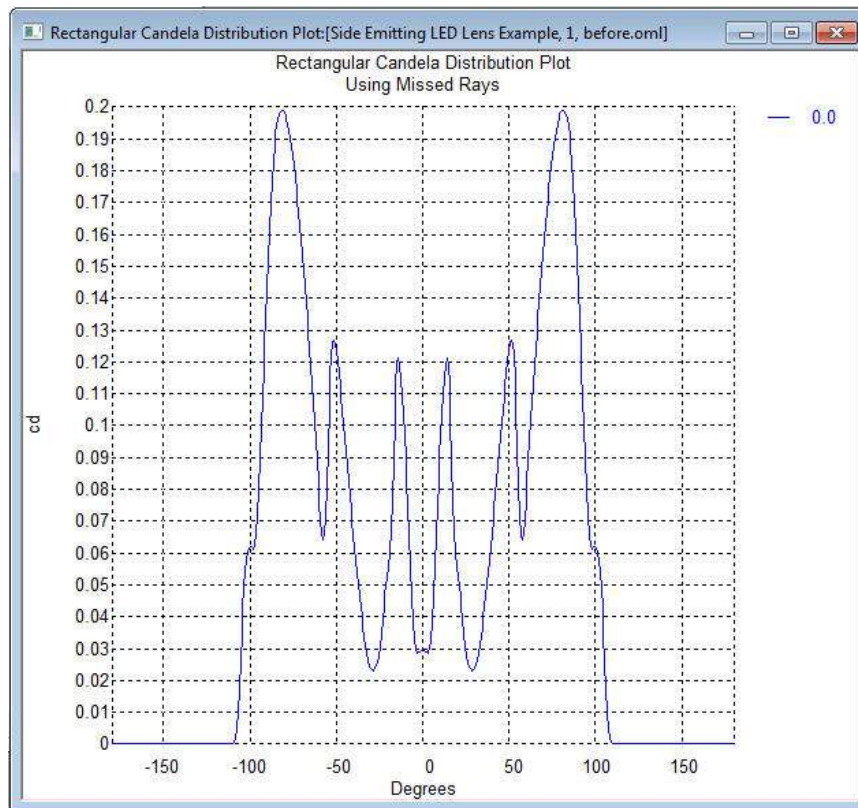
# Side emitting LED lens and reflector combination

- Optimization Log – 264 iterations

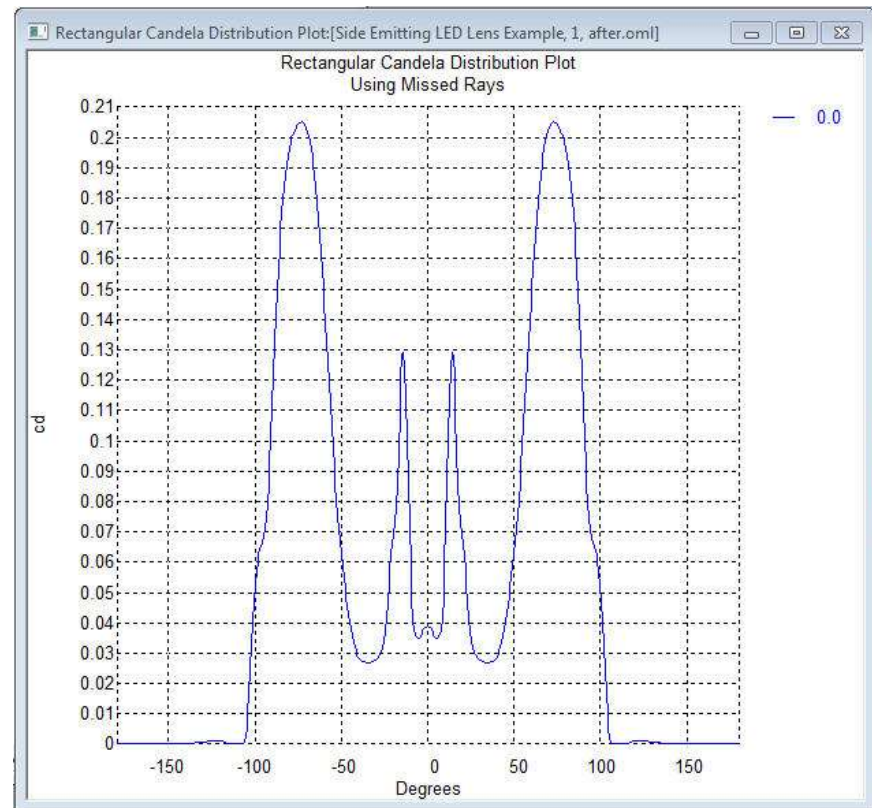


# Side emitting LED lens and reflector combination

- Candela Profile– Before and after optimization



Before optimization

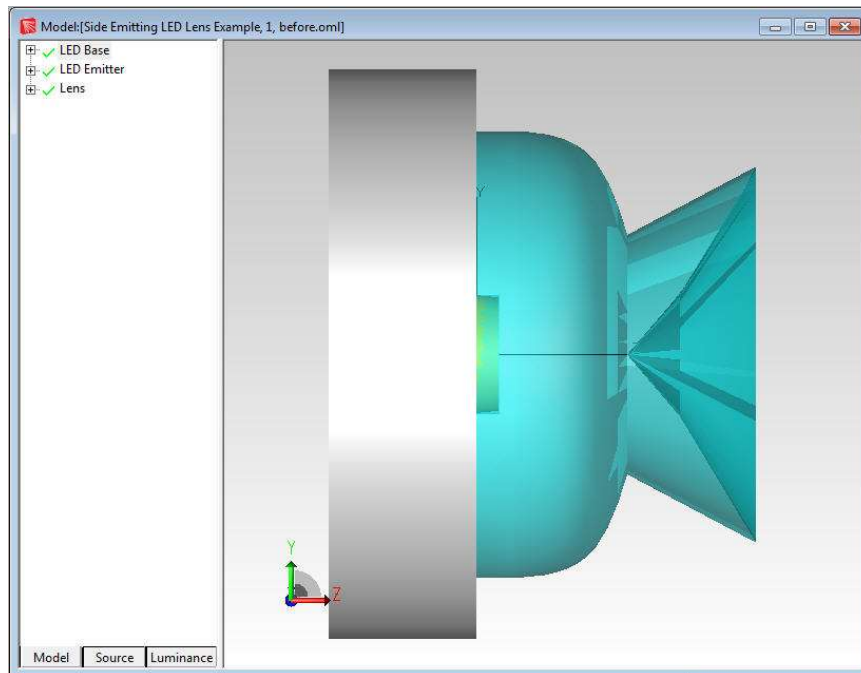


After optimization

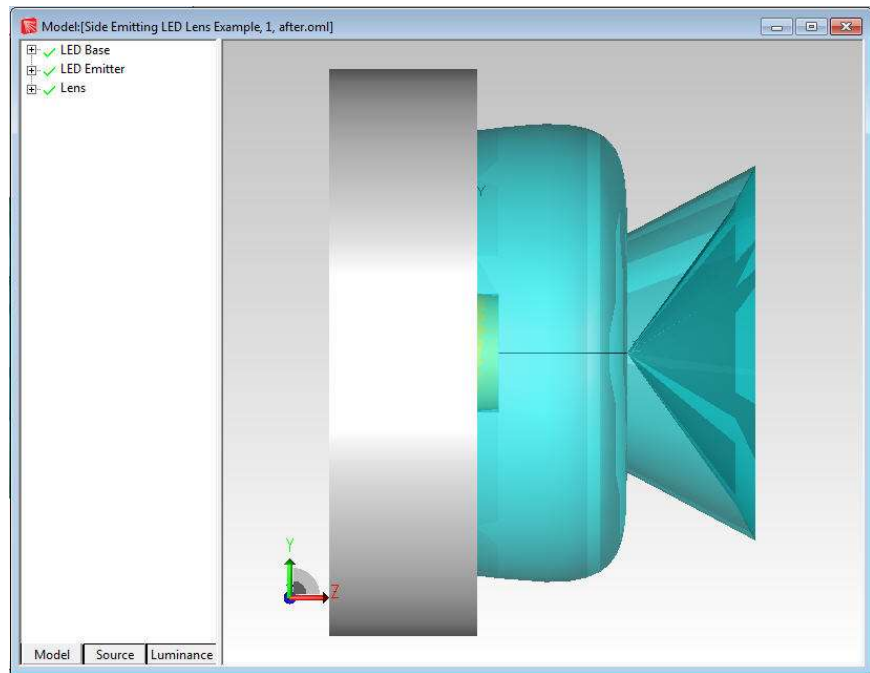


# Side emitting LED lens and reflector combination

- Lens Profile – Before and after optimization



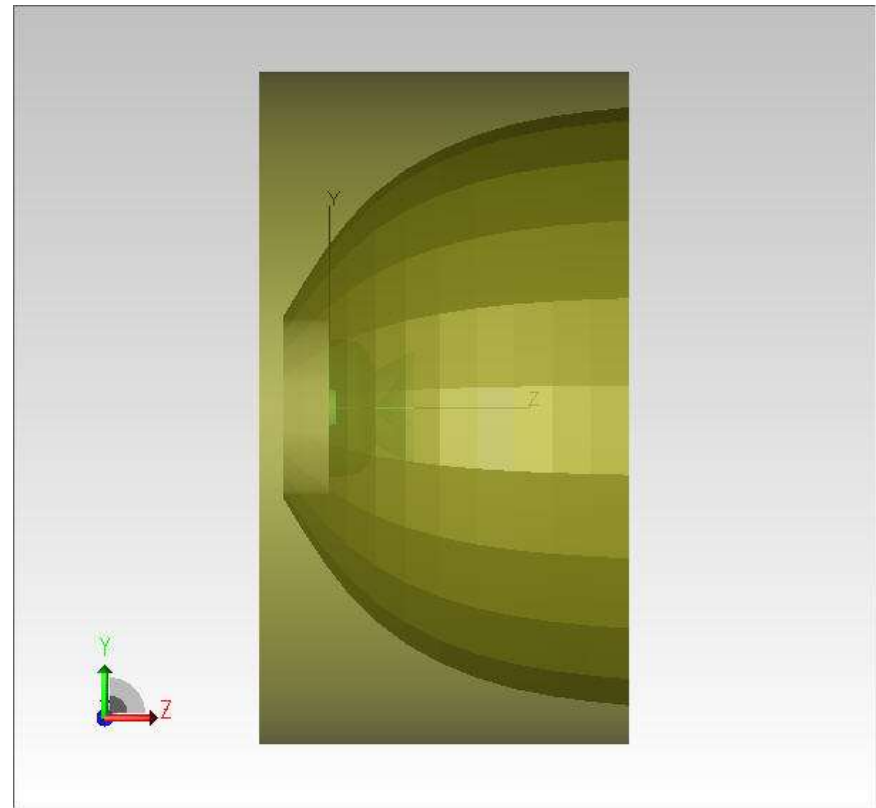
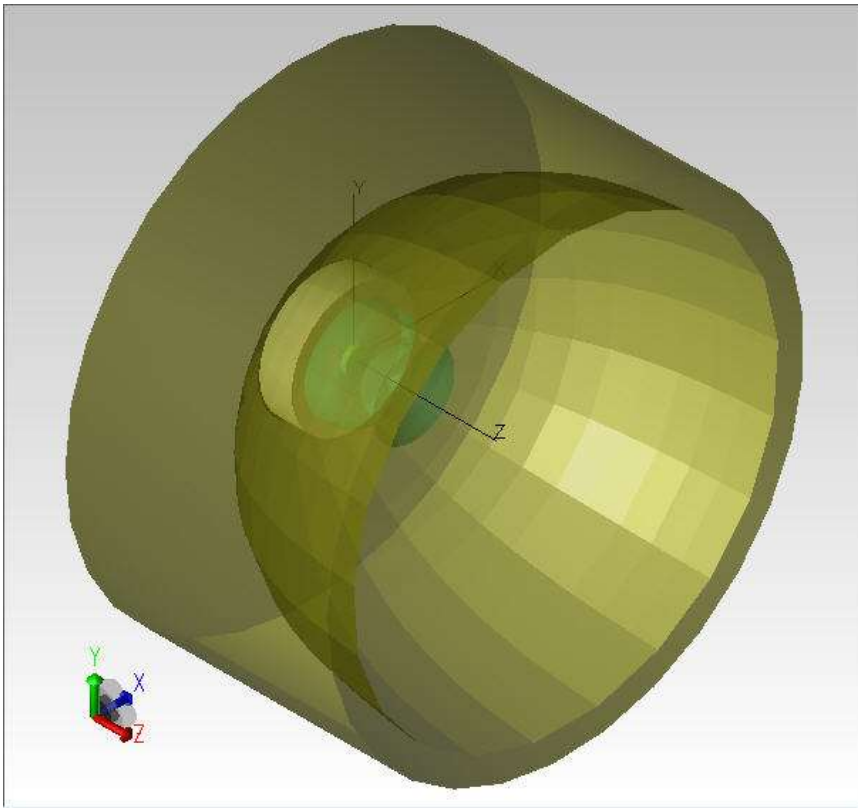
Before optimization



After optimization

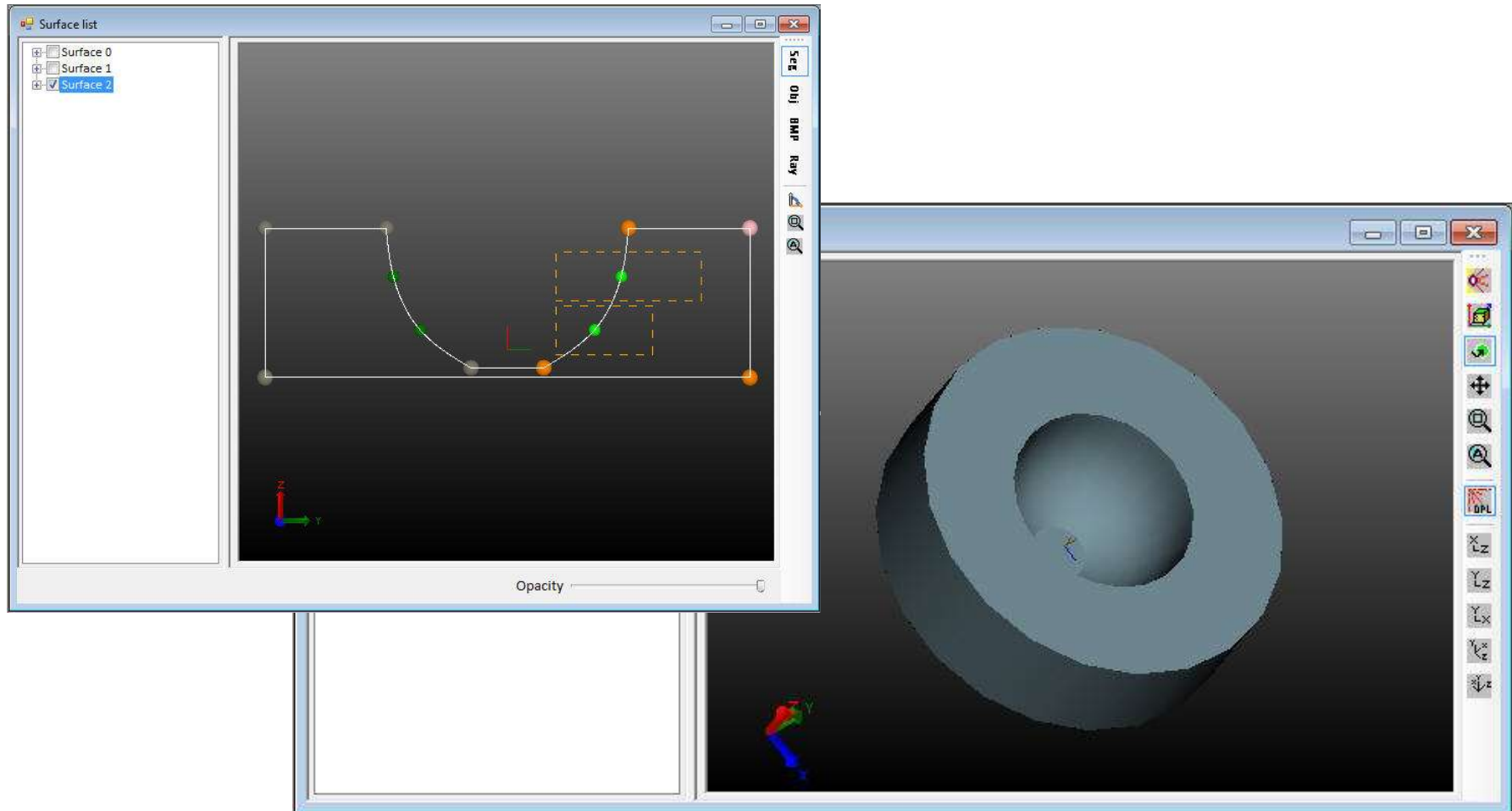
## Side emitting LED lens and reflector combination

- Add a reflector to the lens assembly



# Side emitting LED lens and reflector combination

- Reflector set-up for optimization – 2 control points in 2 axes each



# Side emitting LED lens and reflector combination

- Optimization Goal – Uniform Candela Profile from +/- 20-degrees falling to zero at +/- 25-degrees

The screenshot displays the TracePro optimization interface. The main window is titled "Optimization dialog" and shows the path "C:\3D Optimizer", prefix "SEL Reflector", and operation mode "Optimization". The "Variable list" table is as follows:

Included?	Item	Object
<input checked="" type="checkbox"/>	Position-Y	Ctrl Pnt:0@Seg.
<input checked="" type="checkbox"/>	Position-Z	Ctrl Pnt:0@Seg.
<input checked="" type="checkbox"/>	Position-Y	Ctrl Pnt:1@Seg.
<input checked="" type="checkbox"/>	Position-Z	Ctrl Pnt:1@Seg.
<input checked="" type="checkbox"/>	Position-Y	Ctrl Pnt:0@Seg.
<input checked="" type="checkbox"/>	Position-Z	Ctrl Pnt:0@Seg.
<input checked="" type="checkbox"/>	Position-Y	Ctrl Pnt:1@Seg.
<input checked="" type="checkbox"/>	Position-Z	Ctrl Pnt:1@Seg.

The "Object list" table is:

Output?	ID	Object name	Obj
<input type="checkbox"/>		Pre-processor	
<input type="checkbox"/>	2	Lens	cRa
<input checked="" type="checkbox"/>	3	Object 3	cRa
<input checked="" type="checkbox"/>	4	Object 4	cRa

The "Candela target definer" dialog box is open, showing a "Profile chooser" with a polar plot and a "Rectangular" plot type. The "Symmetric input" checkbox is checked. The "Selected azimuth" is 0. The "Plot type" is set to "Rectangular". The "Discard" and "Apply" buttons are visible.

The "Operand list" table in the background is:

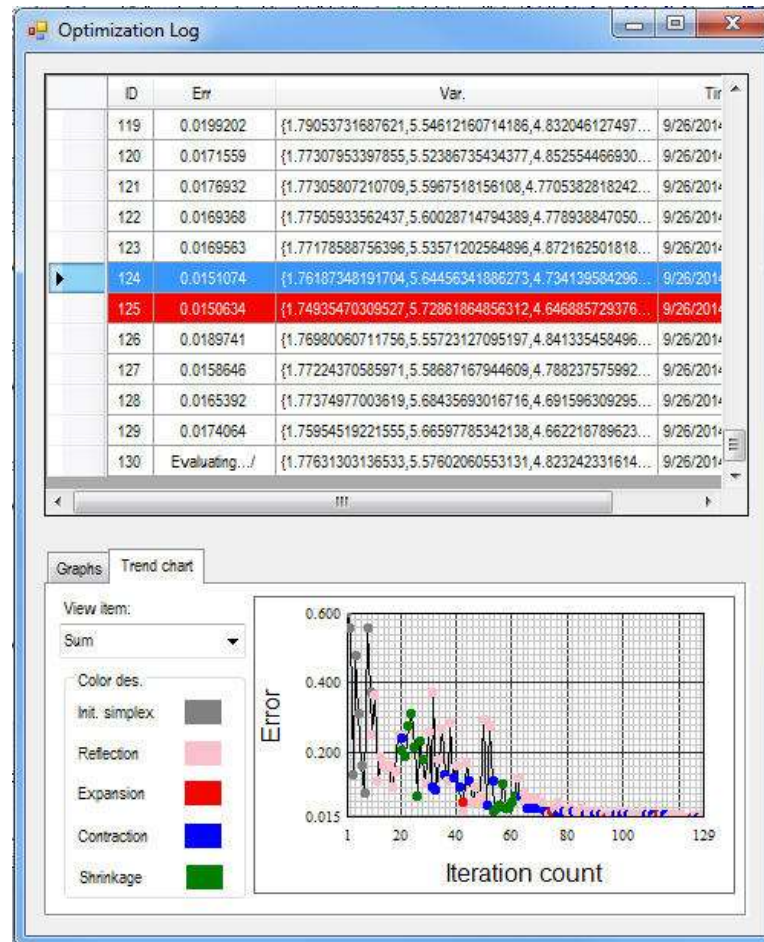
ID	Type	Opt.	Surface	Range	Weight	Target value
01	Can Profile	Similarity		Exiting ray	1.0	{{-180,-25,-20,20,25,180}{...

The "Candela target definer" dialog box also contains a table with the following data:

Angle	Value
-180.0000	0.0000
-25.0000	0.0000
-20.0000	1.0000
20.0000	1.0000
25.0000	0.0000
180.0000	0.0000

# Side emitting LED lens and reflector combination

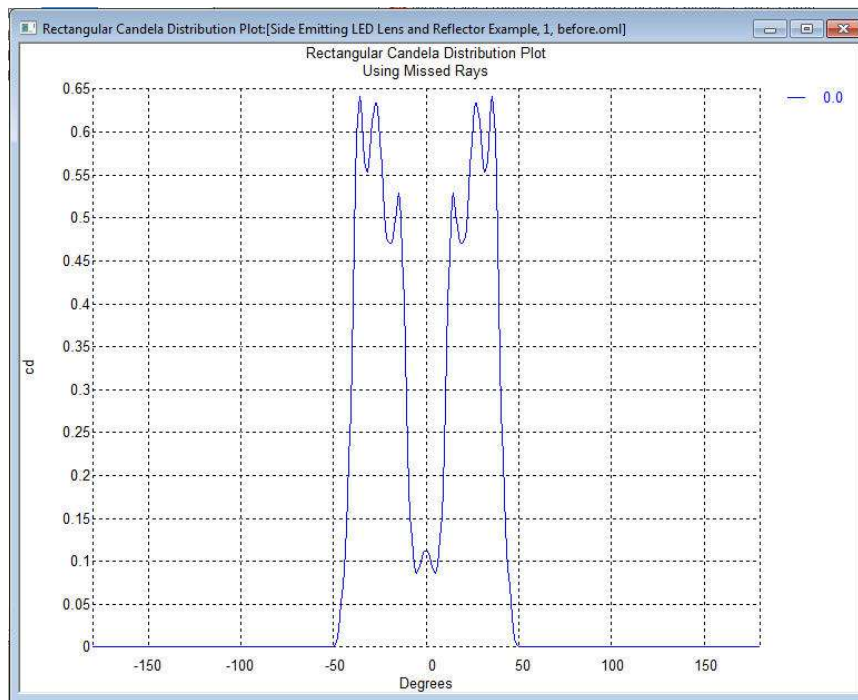
- Optimization Log – 129 iteration



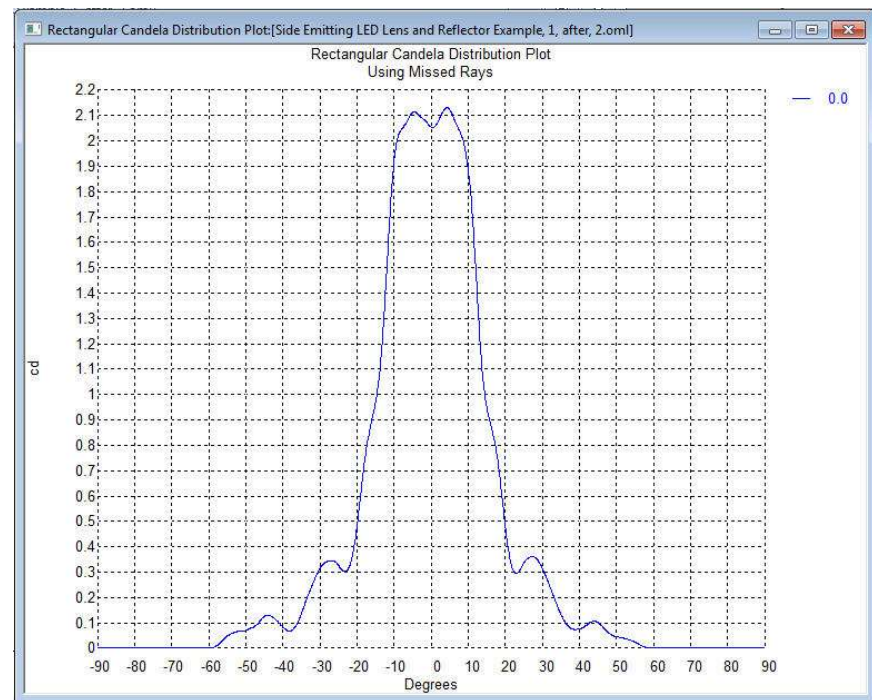


# Side emitting LED lens and reflector combination

- Candela Profile – before and after optimization



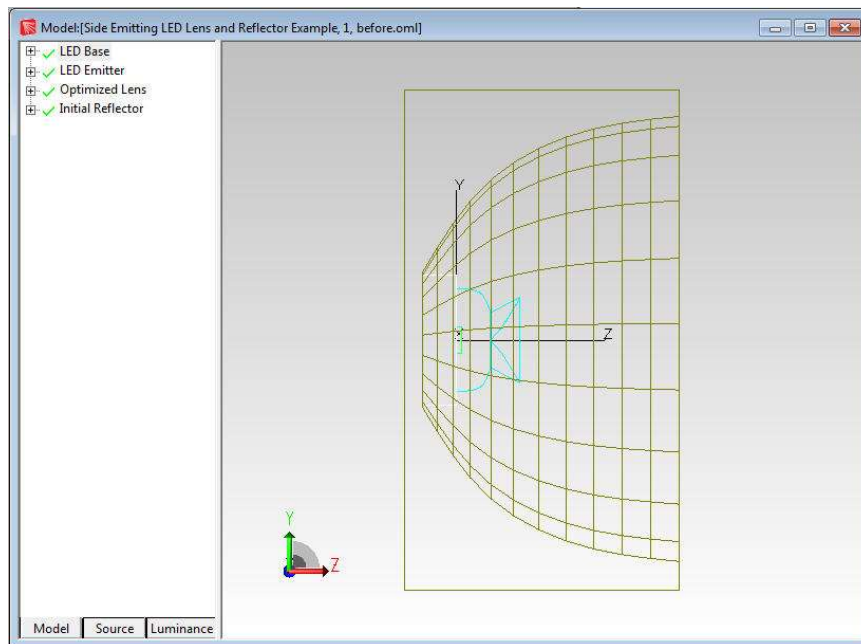
Before optimization



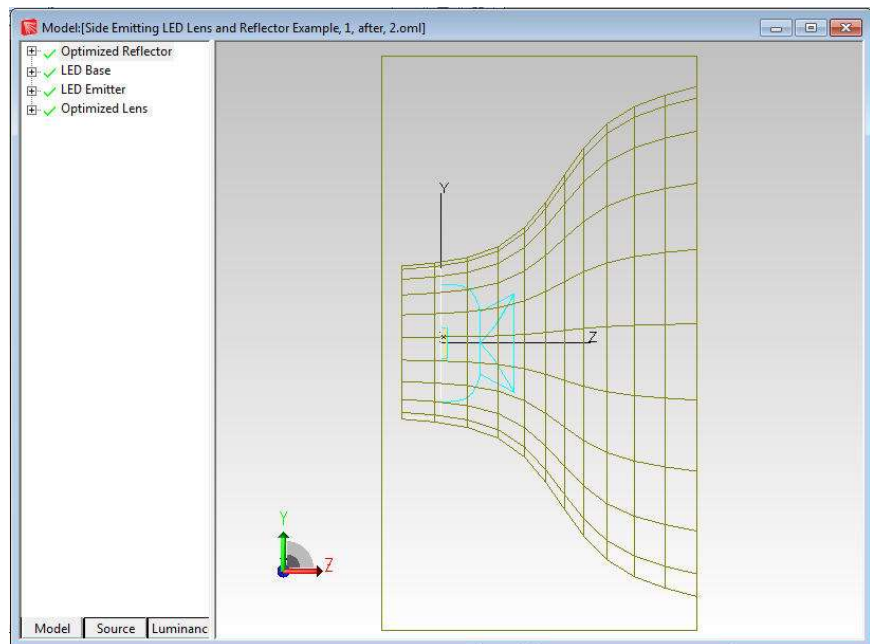
After optimization

# Side emitting LED lens and reflector combination

- Reflector Profile – before and after optimization



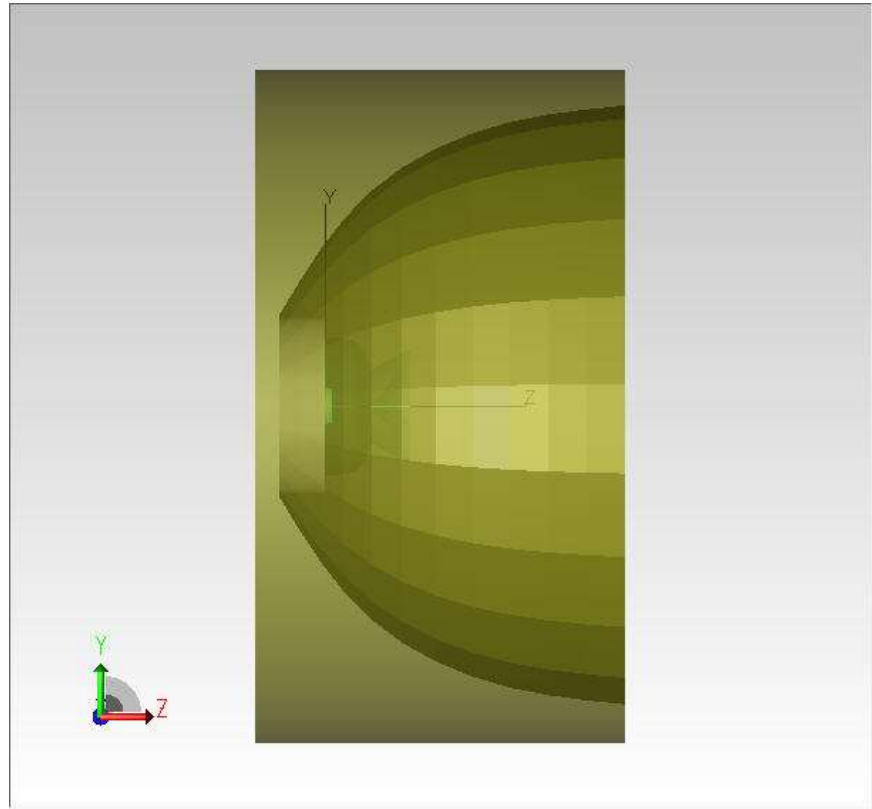
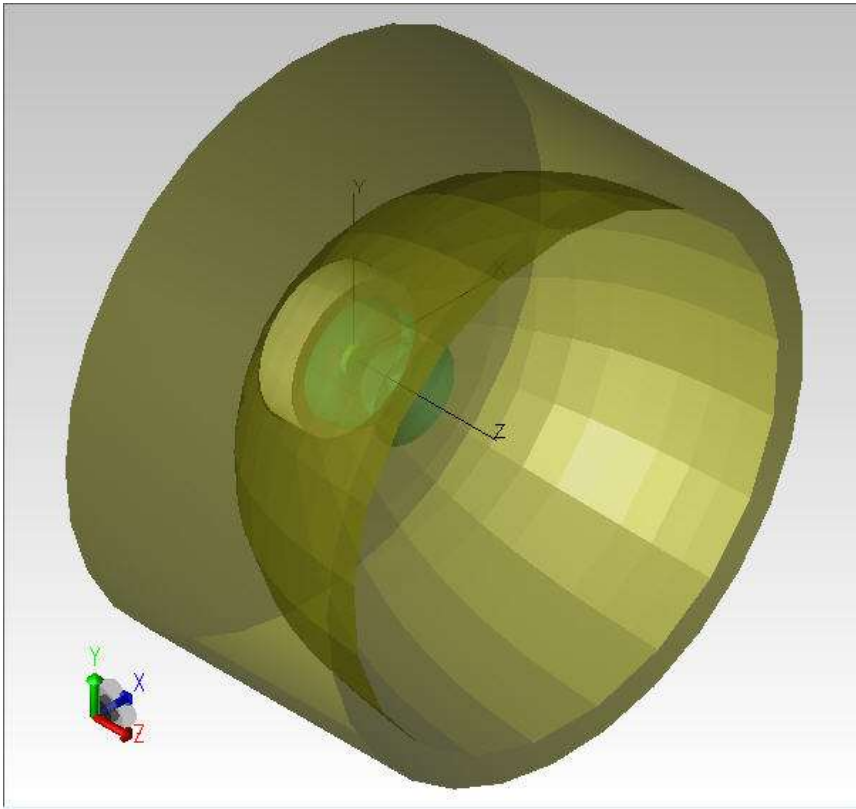
Before optimization



After optimization

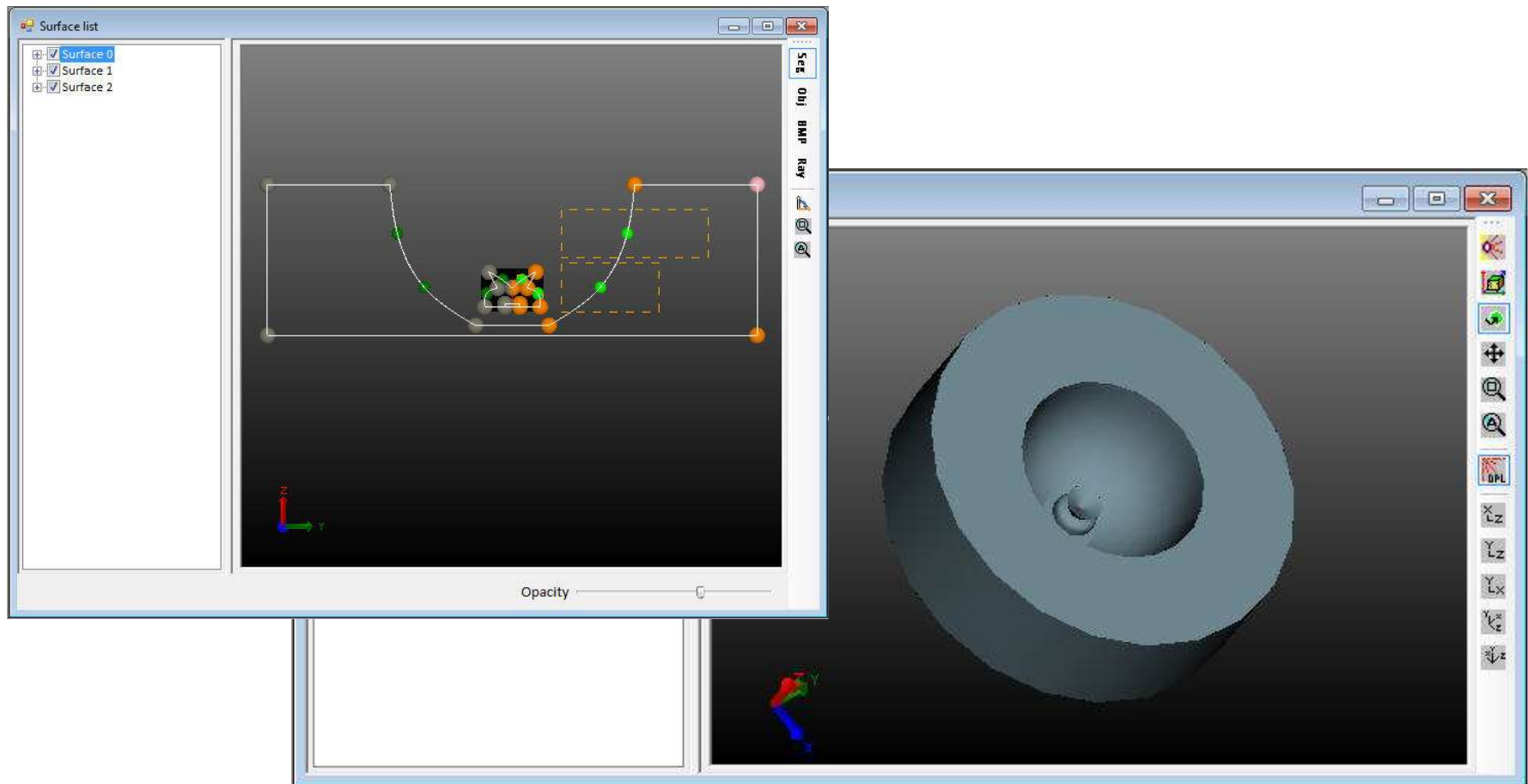
## Side emitting LED lens and reflector combination

- What about optimizing the lens and reflector at the same time?



# Side emitting LED lens and reflector combination

- Setting up the lens and reflector for optimization – 4 control points in 2 axes each



# Side emitting LED lens and reflector combination

- Optimization Goal – Uniform Candela Profile from +/- 20-degrees falling to zero at +/- 25-degrees

The screenshot displays the TracePro optimization interface. The main window is titled "Optimization dialog" and shows the following settings:

- Path: C:\3D Optimizer
- Prefix: SEL Reflector
- Operation mode: Optimization
- Variable list: A table with columns "Included?", "Item", and "Object". It lists various position variables (Position-Y and Position-Z) for different segments (Ctrl Pnt:0@Seg. and Ctrl Pnt:1@Seg.), all of which are checked.
- Object list: A table with columns "Output?", "ID", "Object name", and "Object type". It lists "Pre-processor", "Lens", "Object 3", and "Object 4".
- Operand list: A table with columns "ID", "Type", "Opt.", "Surface", "Range", "Weight", and "Target value". It shows a single operand: ID 01, Type Can Profile, Opt. Similarity, Surface (empty), Range Exiting ray, Weight 1.0, and Target value {{-180,-25,-20,20,25,180}}{...}

The "Candela target definer" dialog box is open, showing a "Profile chooser" with a circular plot and a "Symmetric input" checkbox checked. The plot shows a uniform profile from -20 to 20 degrees and zero elsewhere. The "Selected azimuth" is 0. The "Plot type" is set to "Rectangular". A table on the right shows the target values:

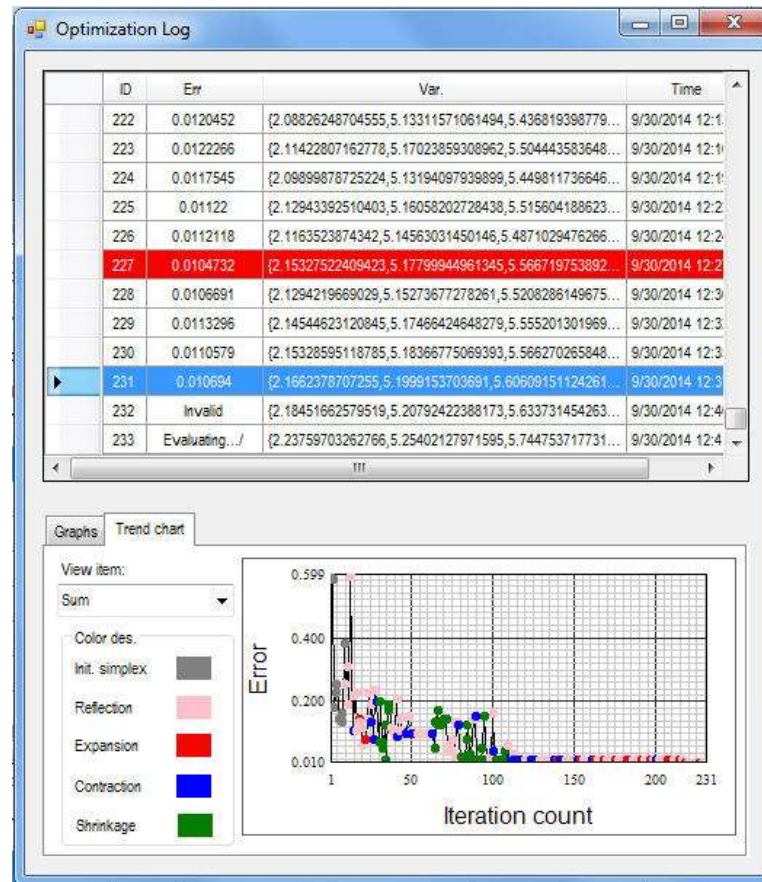
Angle	Value
-180.0000	0.0000
-25.0000	0.0000
-20.0000	1.0000
20.0000	1.0000
25.0000	0.0000
180.0000	0.0000

Buttons for "Discard", "Apply", and "Start" are visible at the bottom of the dialog.



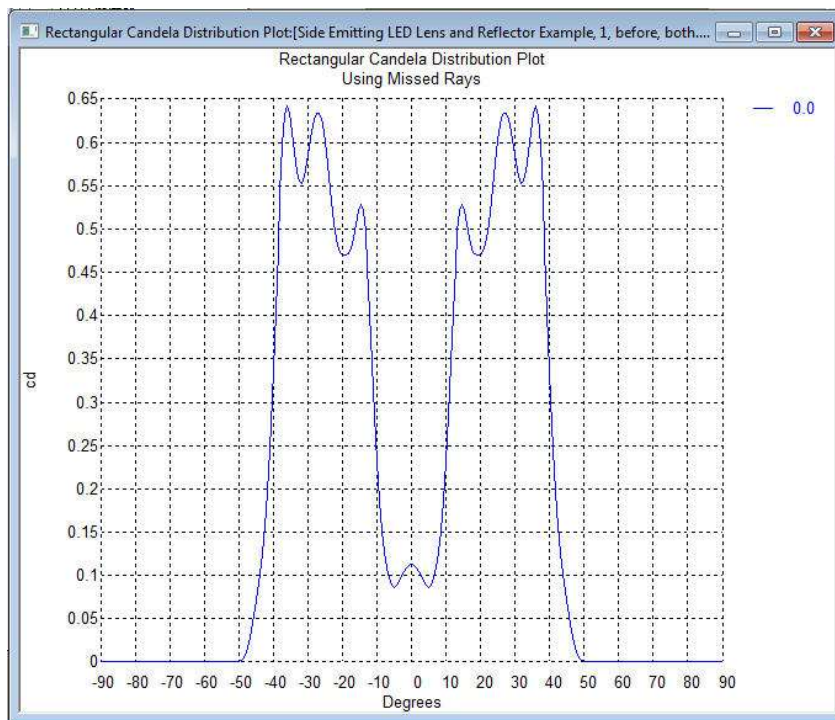
# Side emitting LED lens and reflector combination

- Optimization Log – combined optimization – 231 iterations

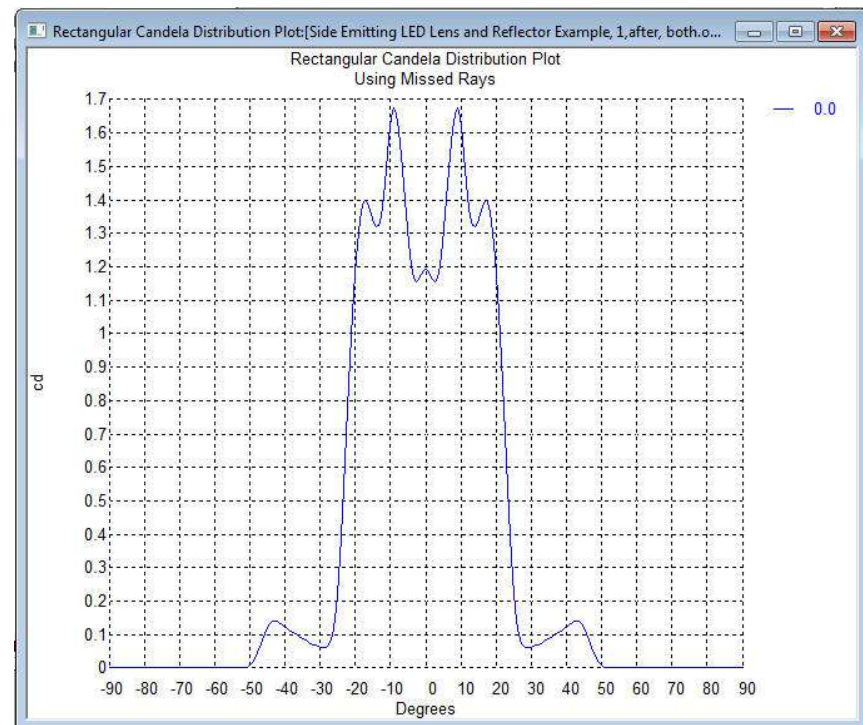


# Side emitting LED lens and reflector combination

- Candela Profile – before and after combined optimization



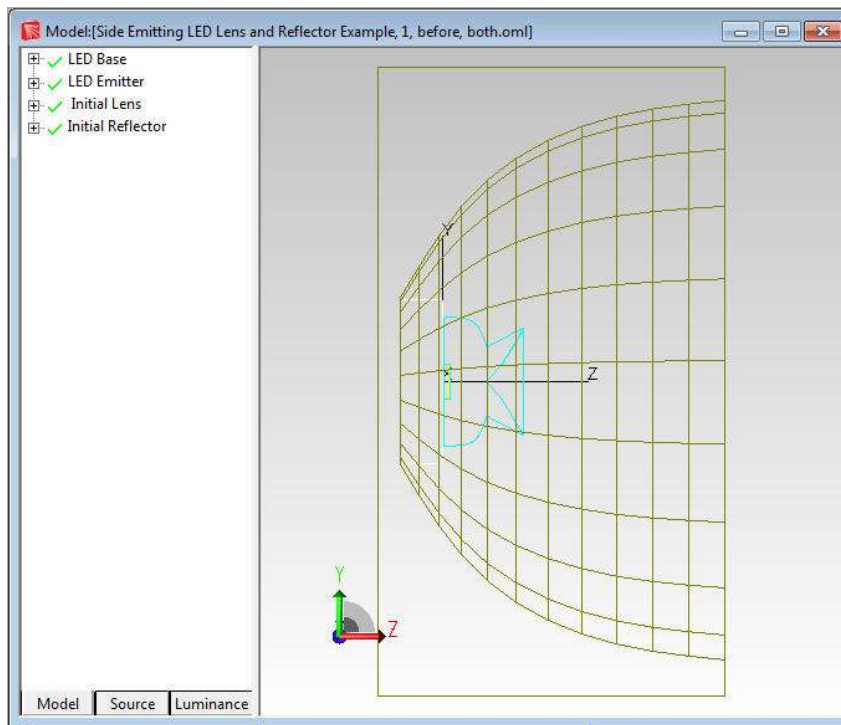
Before optimization



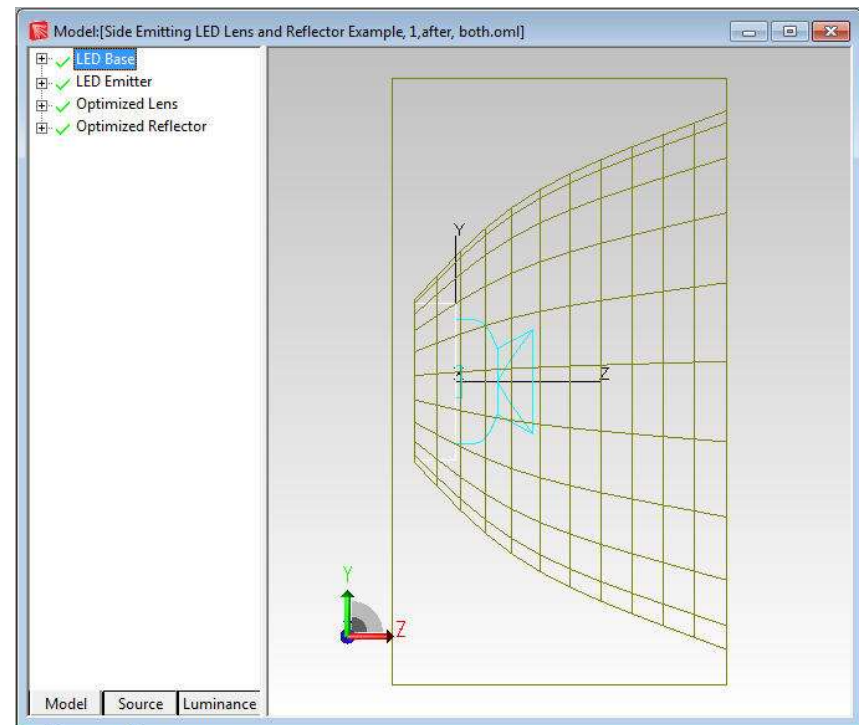
After optimization

# Side emitting LED lens and reflector combination

- Lens and Reflector Profiles – before and after combined optimization



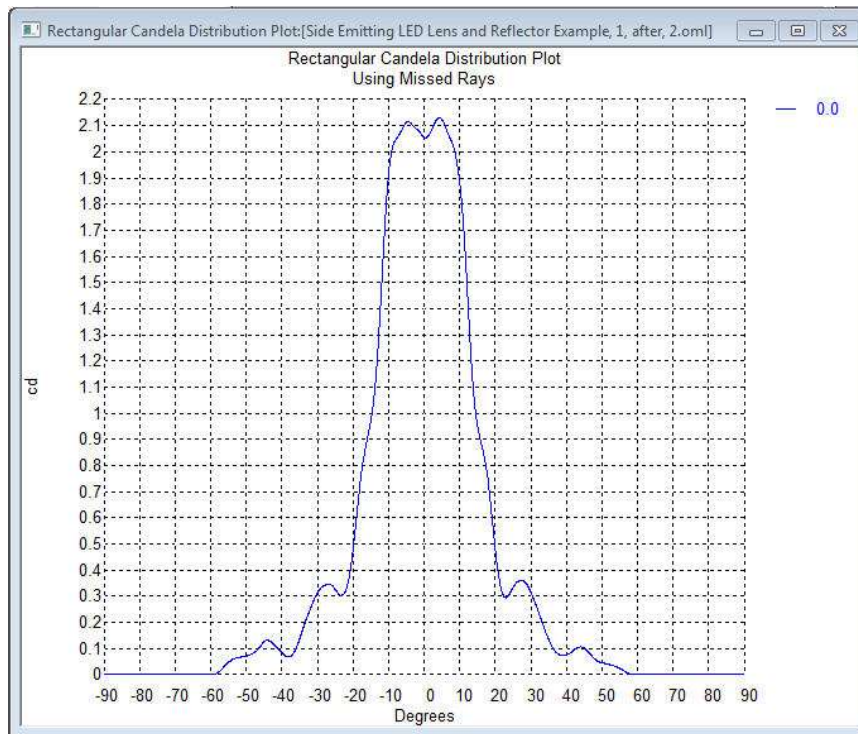
Before optimization



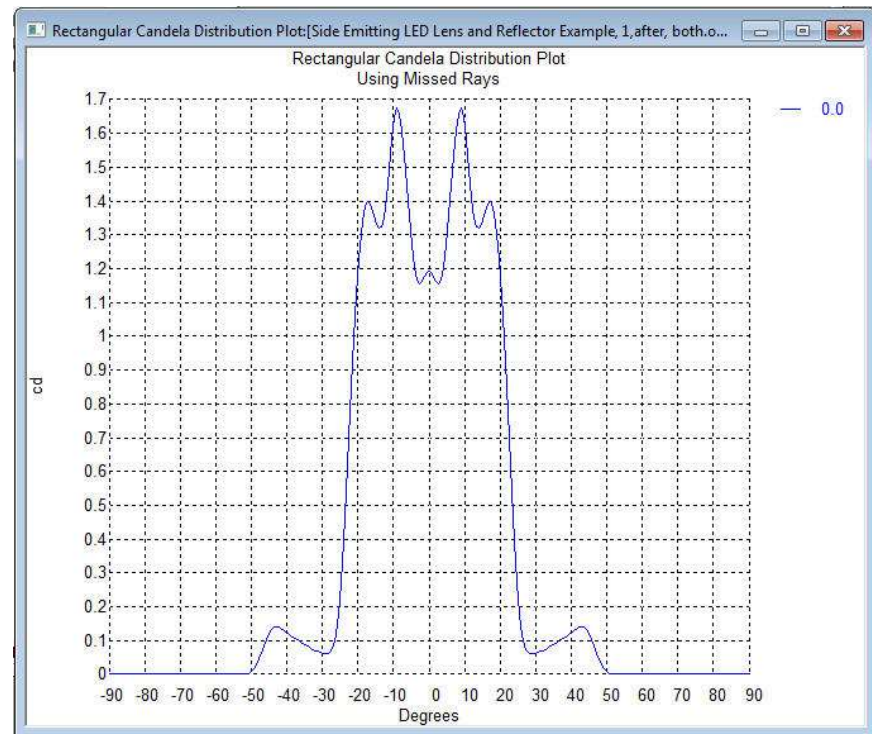
After optimization

# Side emitting LED lens and reflector combination

- Candela Profile – 2 different optimization procedures



Separate optimization

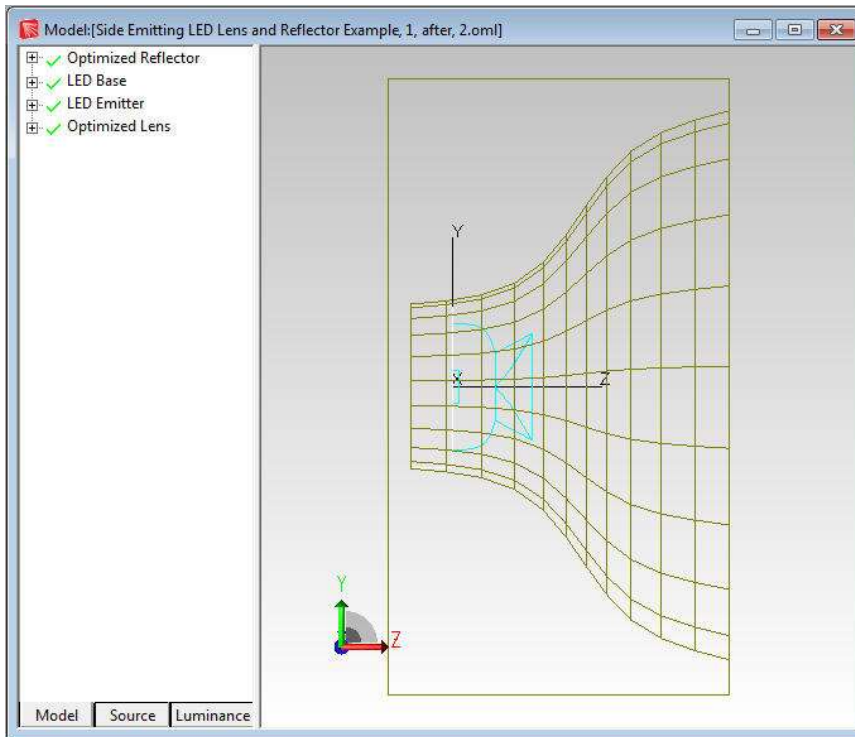


Combined optimization

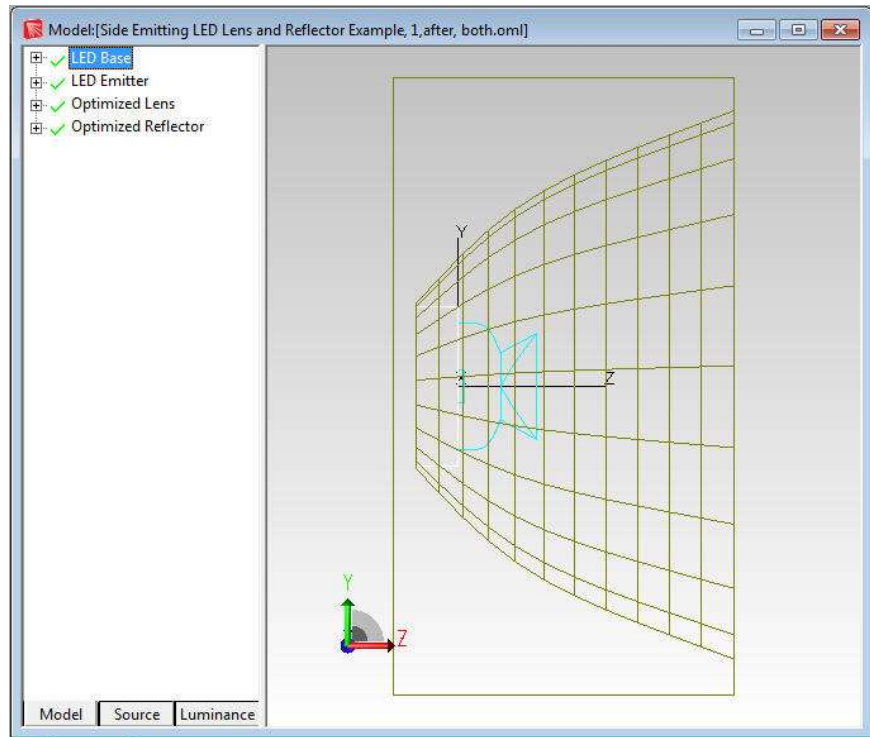


# Side emitting LED lens and reflector combination

- Lens and Reflector Profiles – 2 different optimization procedures



Separate optimization

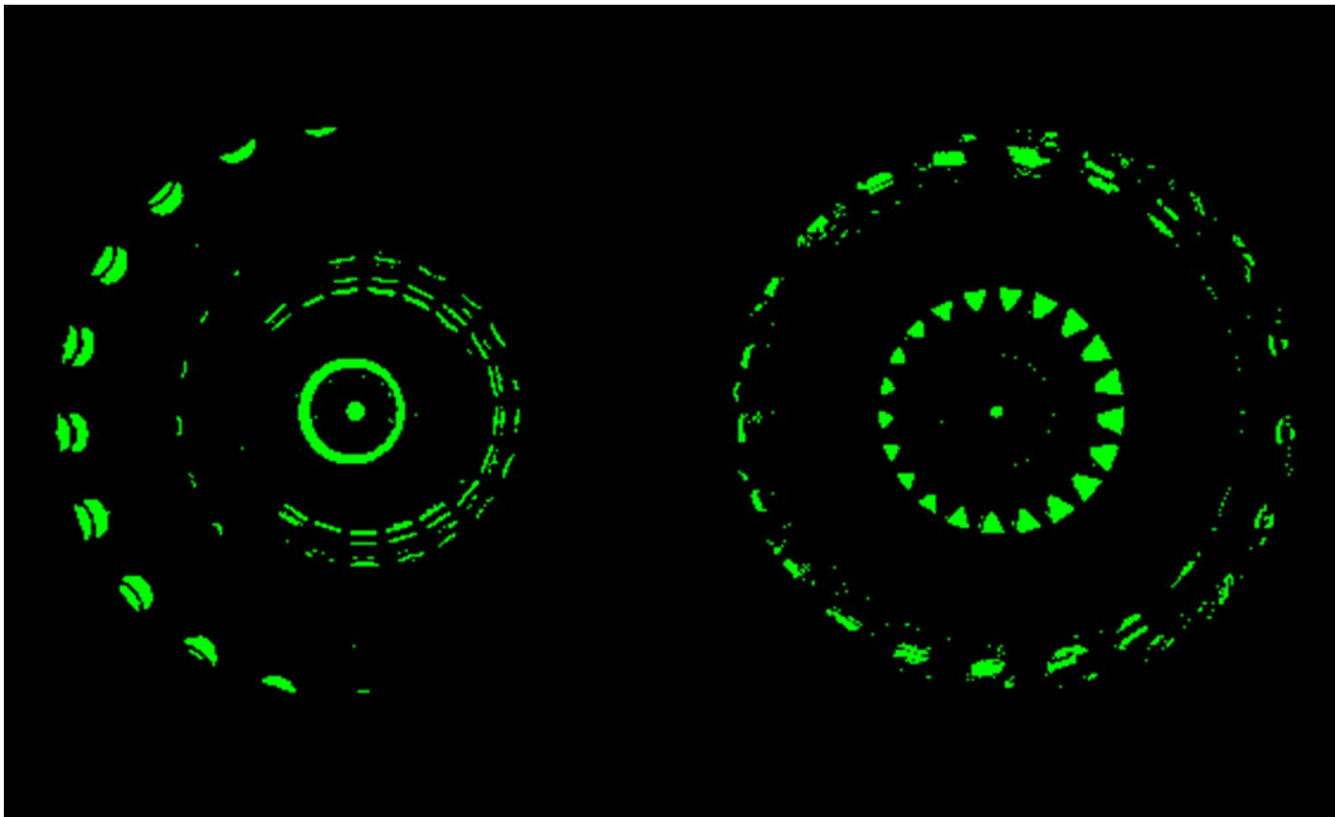


Combined optimization



## Side emitting LED lens and reflector combination

- Photorealistic Rendering – 2 different optimization procedures

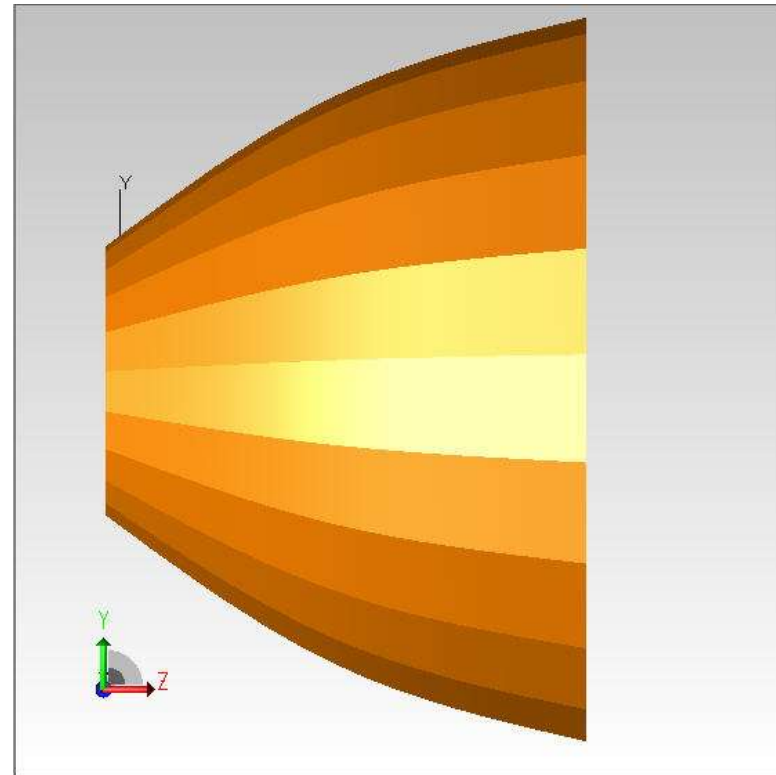
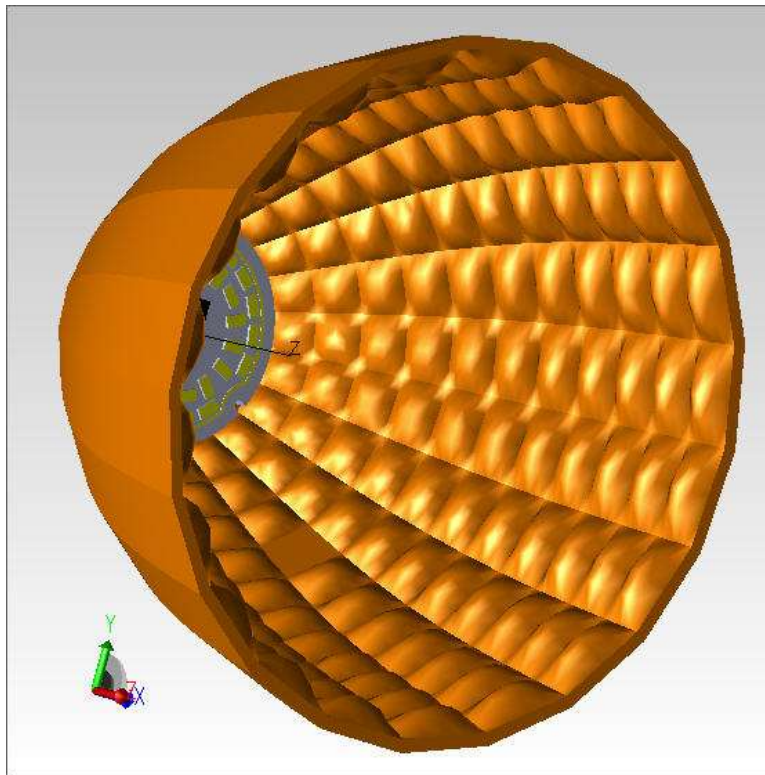


Combined optimization

Separate optimization

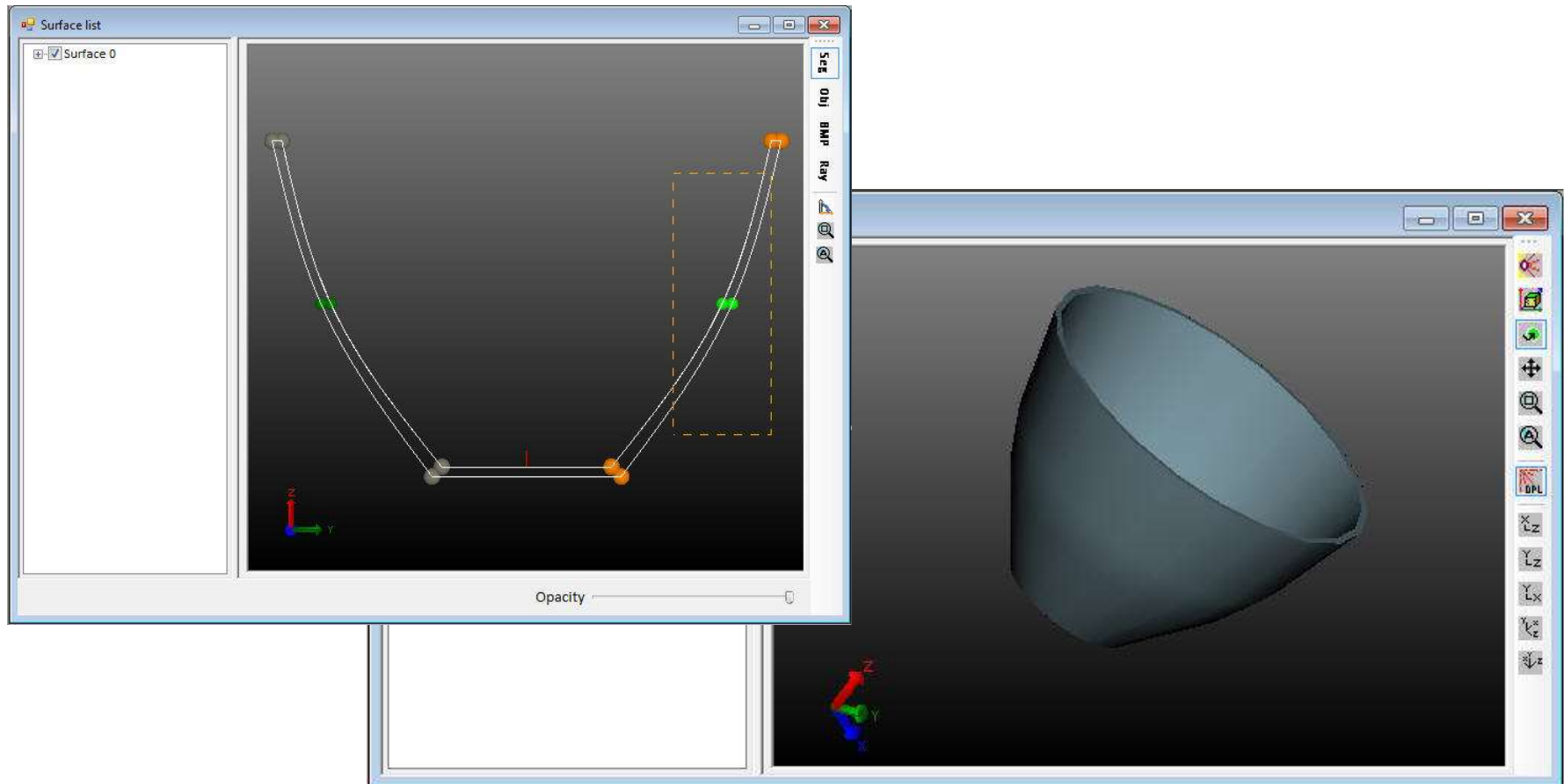
## Curved facet reflector

- Reflector with curved facet optimization. Making multiple prototypes of a reflector like this could be quite expensive.



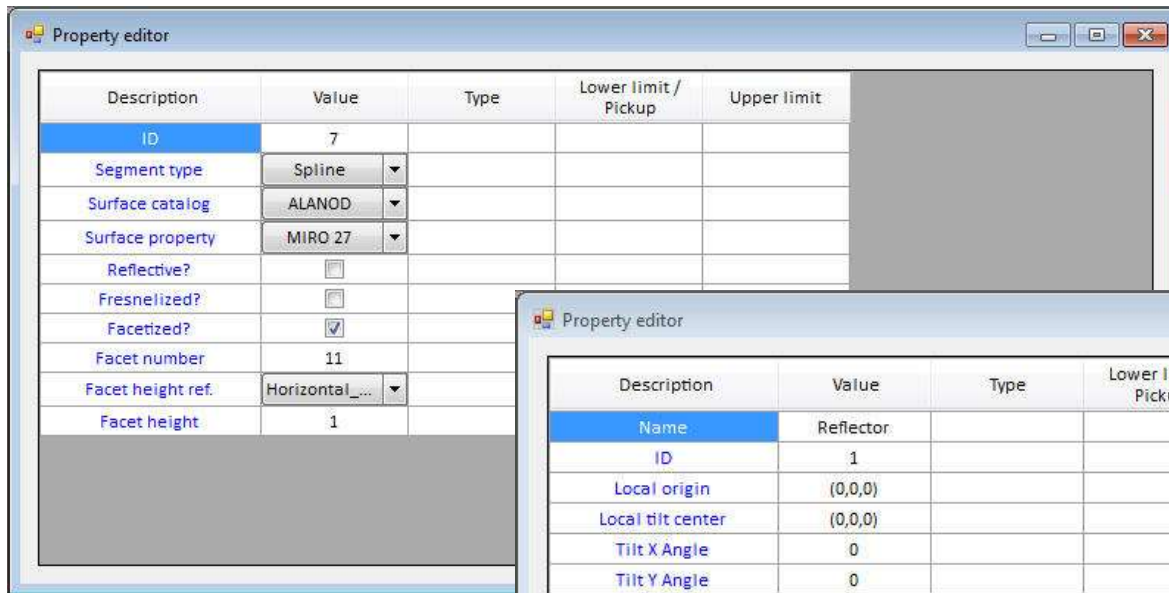
# Curved facet reflector

- Defining the initial reflector profile and the variables for the optimization process.



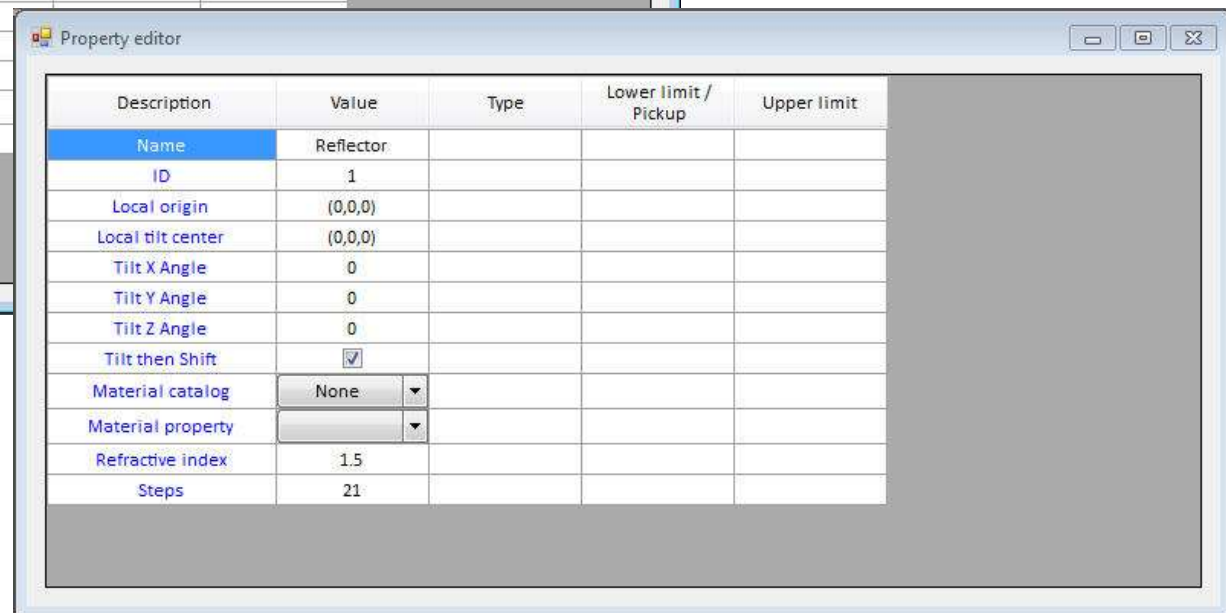
# Curved facet reflector

- Defining the curved facets. 11 vertical facets and 21 radial facets with a convex curvature.



Property editor

Description	Value	Type	Lower limit / Pickup	Upper limit
ID	7			
Segment type	Spline			
Surface catalog	ALANOD			
Surface property	MIRO 27			
Reflective?	<input type="checkbox"/>			
Fresnelized?	<input type="checkbox"/>			
Facetized?	<input checked="" type="checkbox"/>			
Facet number	11			
Facet height ref.	Horizontal_...			
Facet height	1			

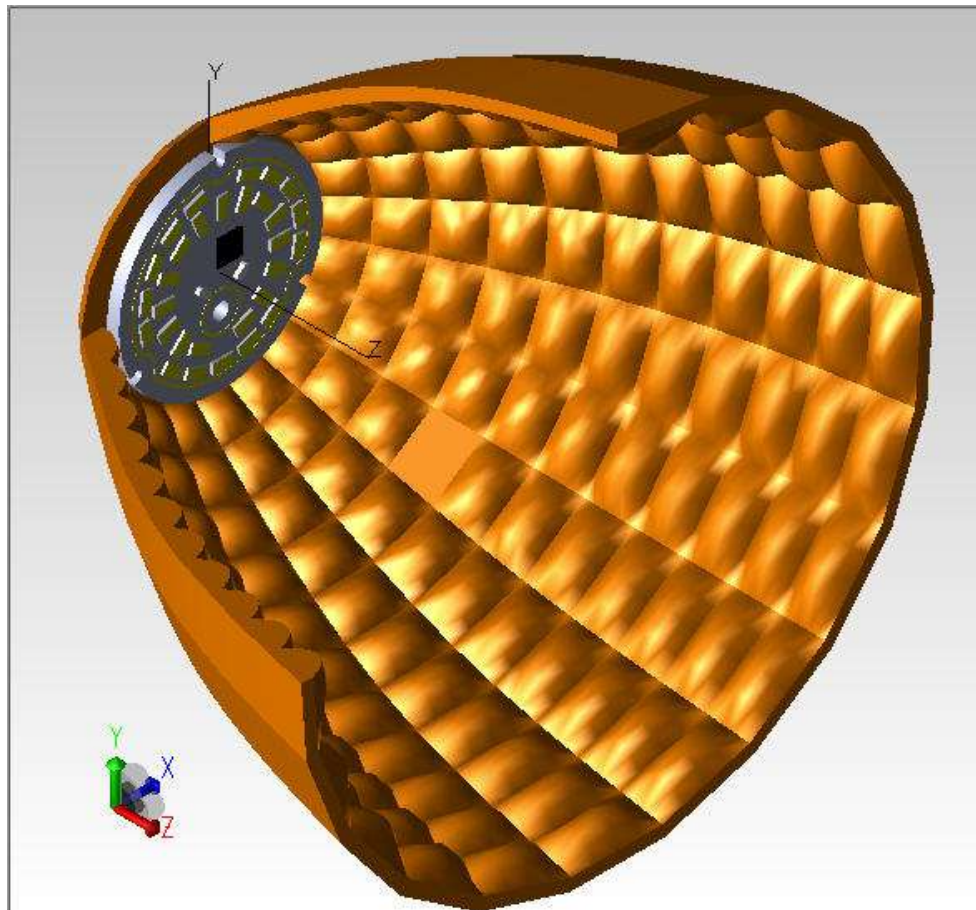


Property editor

Description	Value	Type	Lower limit / Pickup	Upper limit
Name	Reflector			
ID	1			
Local origin	(0,0,0)			
Local tilt center	(0,0,0)			
Tilt X Angle	0			
Tilt Y Angle	0			
Tilt Z Angle	0			
Tilt then Shift	<input checked="" type="checkbox"/>			
Material catalog	None			
Material property				
Refractive index	1.5			
Steps	21			

## Curved facet reflector

- LED source model – LED array modeled using a 3D solid model and a Surface Source Property





# Curved facet reflector

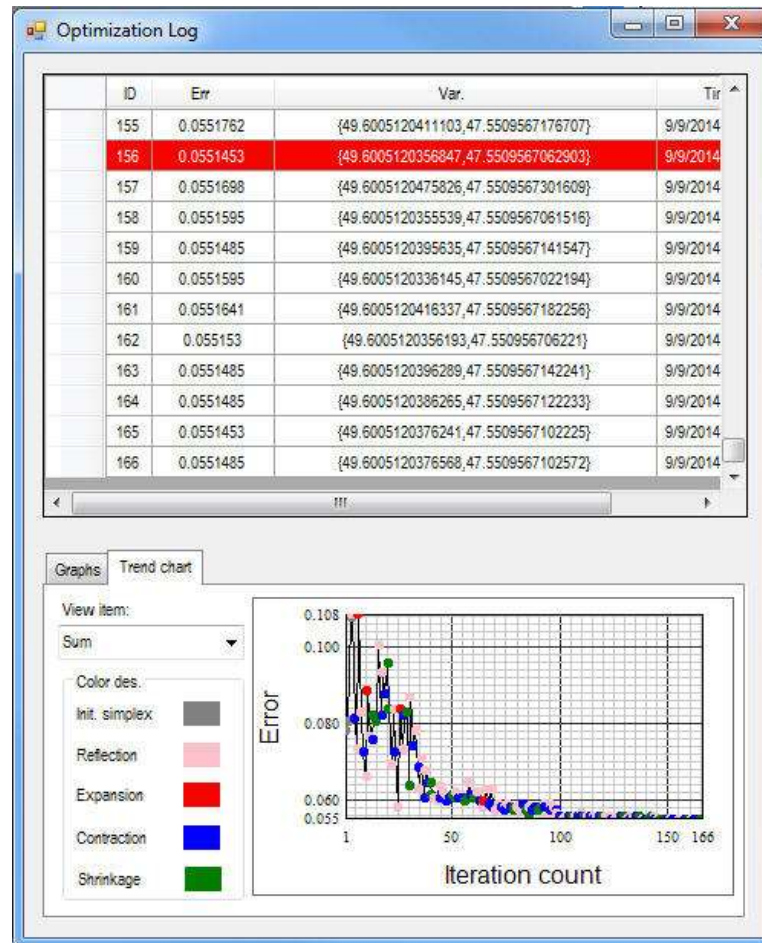
- Optimization Goal - flat irradiance profile across the central 2/3 portion of the target surface

The screenshot displays the TracePro optimization environment. The main window is titled "Optimization dialog" and contains fields for Path, Prefix, and Operation mode. A table lists optimization variables, including Position-Y and Position-Z. An "Operand list" table shows a single operand for Irr Profile Similarity on the Receiver surface. Overlaid on this is the "Irradiance target profile definer" dialog box, which features a 2D plot of irradiance vs. relative position. The plot shows a flat profile at 1.0 irradiance between -0.25 and 0.25 relative positions. A table on the right of the dialog lists the target values for these positions.

Relative Pos.	Value
-0.5000	0.0000
-0.3000	0.0000
-0.2500	1.0000
0.2500	1.0000
0.3000	0.0000
0.5000	0.0000

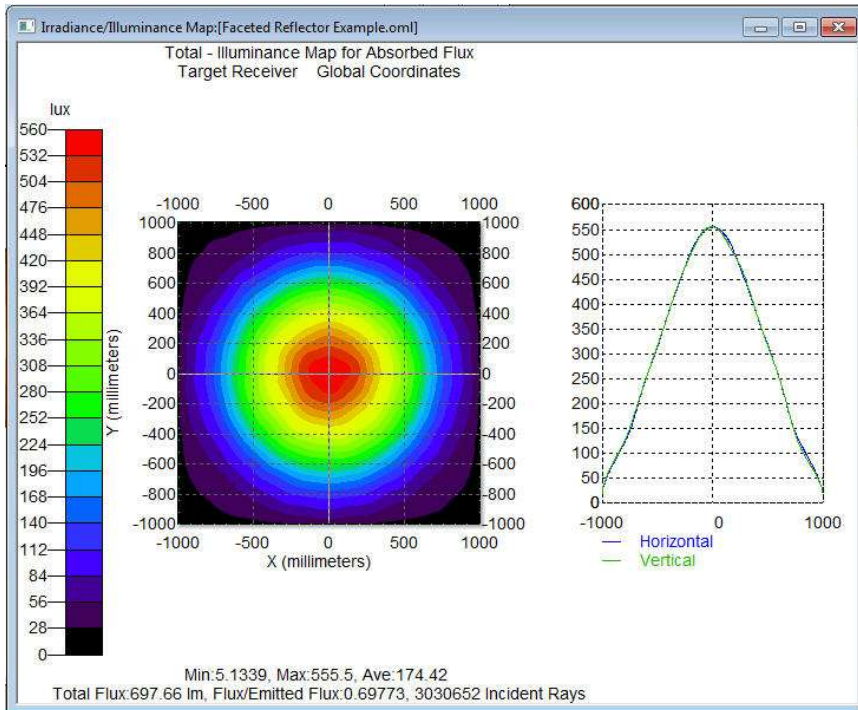
# Curved facet reflector

- Optimization Log – 166 iterations

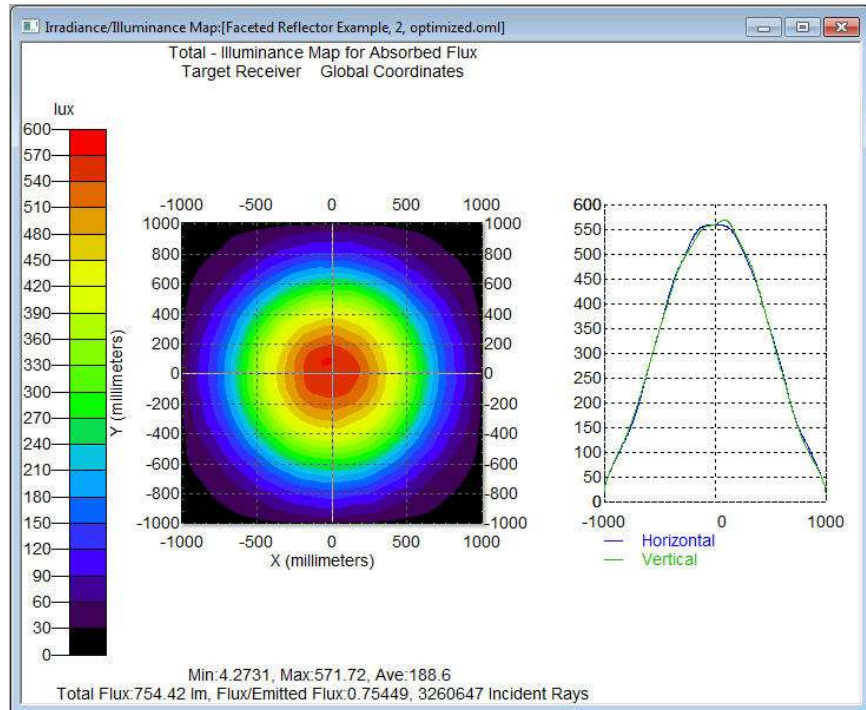


# Curved facet reflector

- Illuminance Map – Before and after optimization



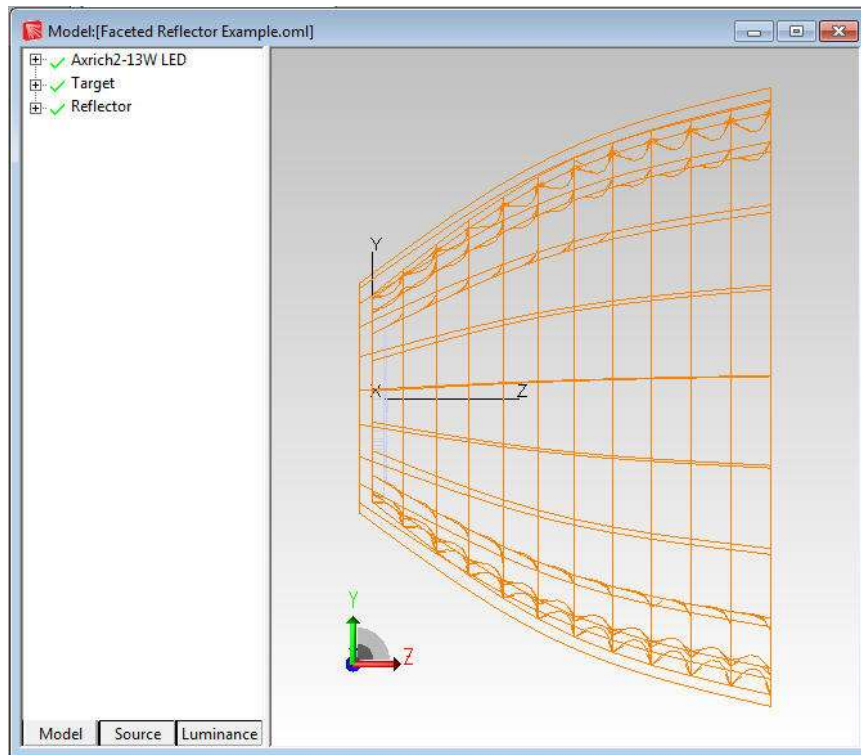
Before optimization



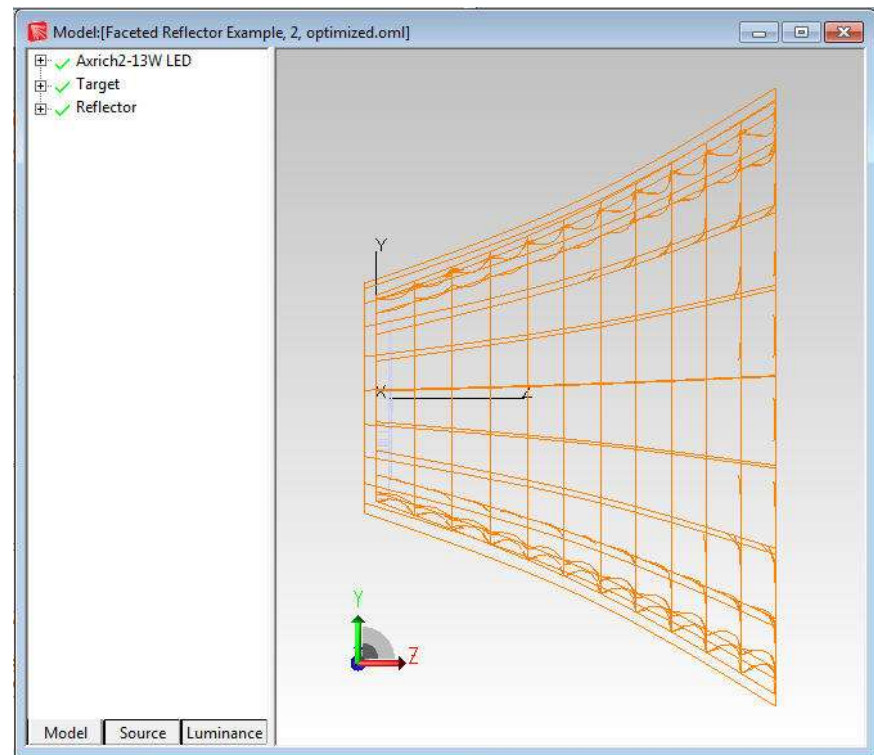
After optimization

# Curved facet reflector

- Reflector Profile – Before and after optimization

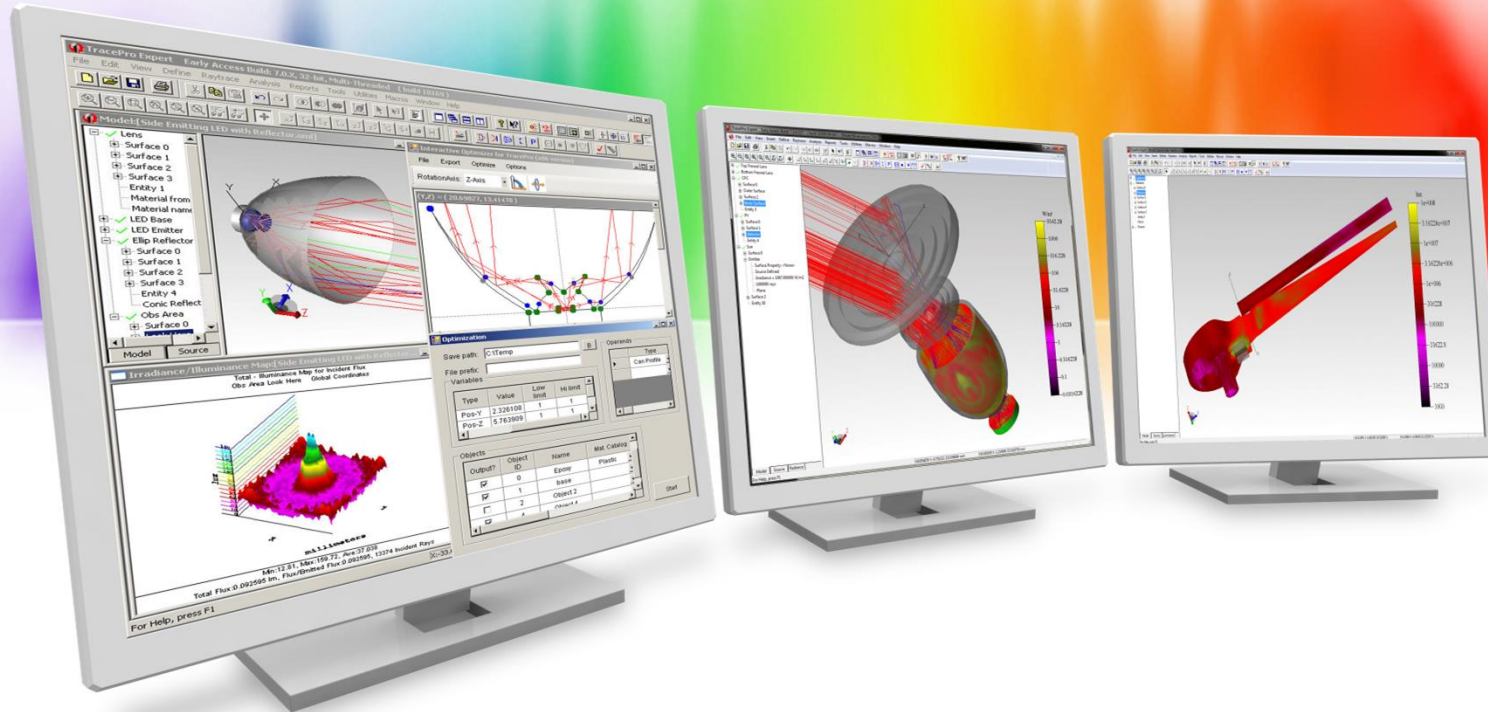


Before optimization



After optimization





## Summary and Questions



## Summary and Questions

Virtual prototyping of luminaire designs using optical design and analysis software allows for:

- ✓ Faster more efficient design process
- ✓ Better designs when compared with a trial and error process
- ✓ Ability to try multiple designs for minimal extra cost
- ✓ Fast and easy analysis of potential designs
- ✓ Lower development cost

For more information or to sign up for our free 30-day trial please visit us at:

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