SYNOPSYS®
Silicon to Software™

Illumination Optics IV

SPIE 9629-9

Jena, Germany

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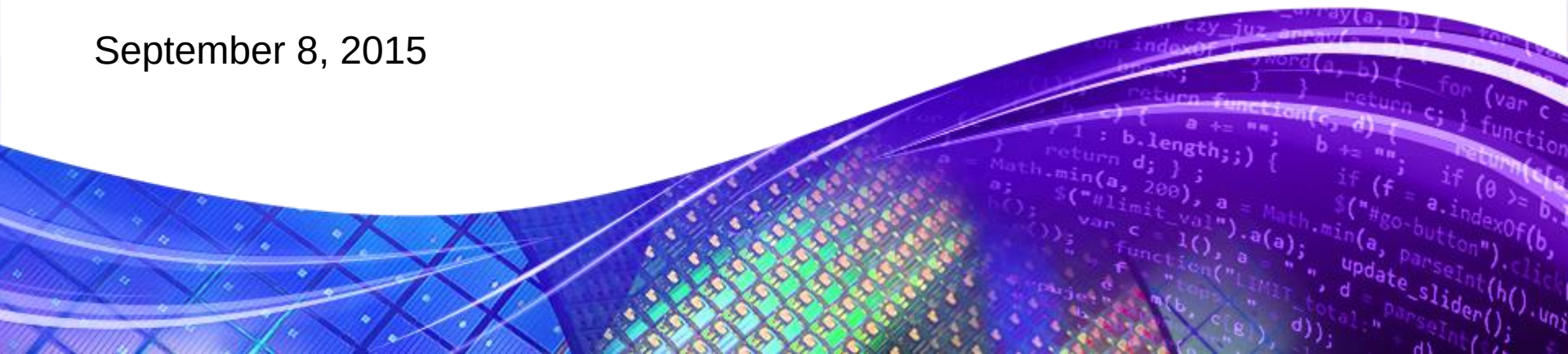
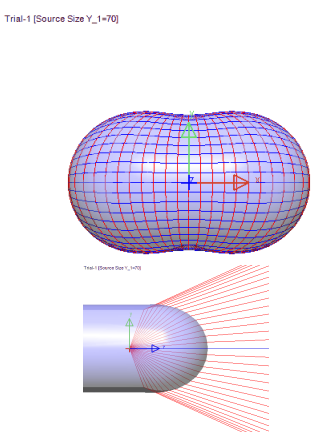
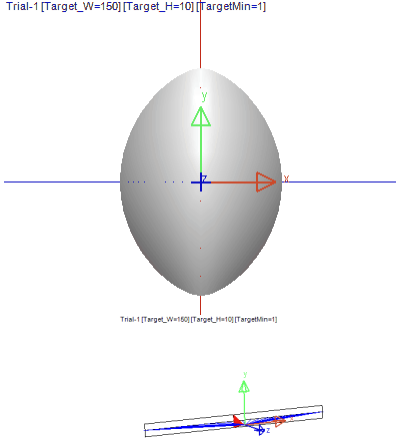
September 8, 2015

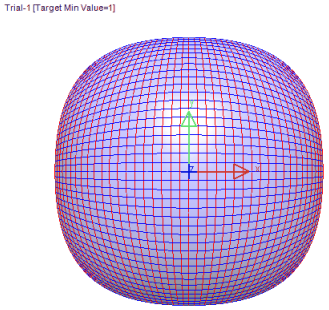


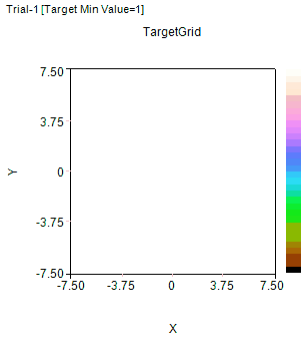
Agenda

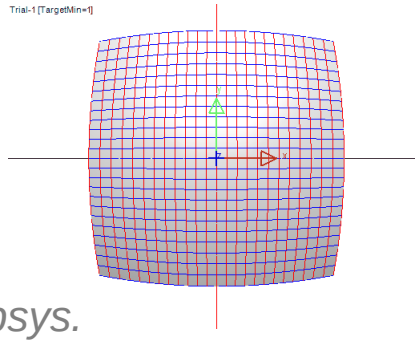
- Overview and Background
- Examples
  - Lens+Reflector cases which vary
    - source collection
    - target aspect ratio
    - target decenter
    - contrast ratio
  - Reflector cases which vary
    - distance to target
    - target size
    - source intensity
    - target rotation
  - Lens cases which vary
    - source tilt angle
- Summary

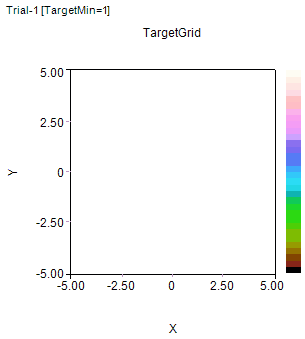












All examples in this talk use LightTools® from ORA/Synopsys.

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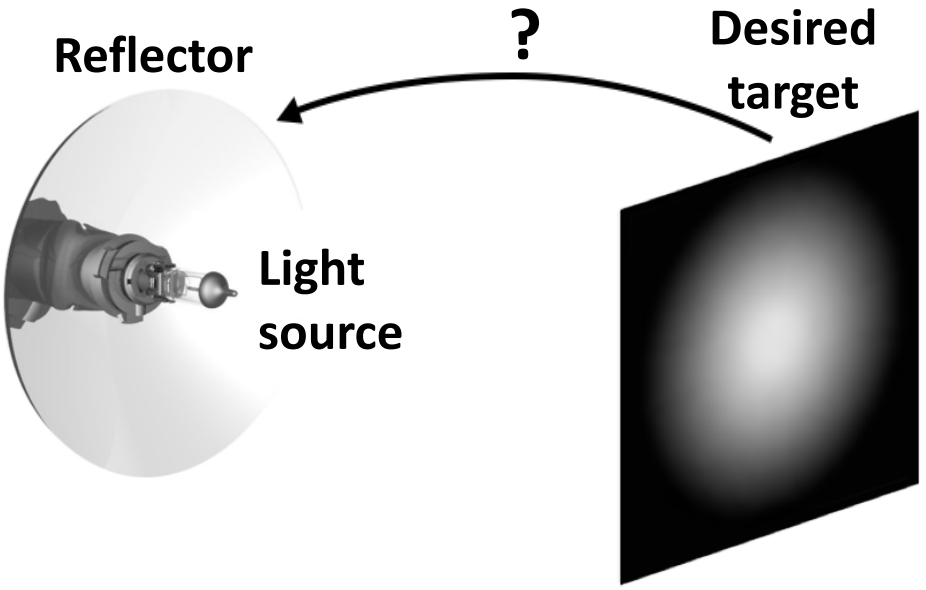
Background

Task: derive the shape to direct light from a given source to a desired target distribution



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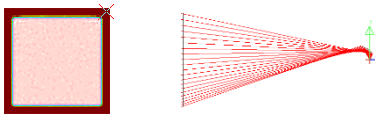
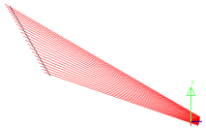
Freeform Design Algorithm

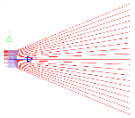
- In this talk, Freeform surfaces are computed assuming a point source
  - Robust and Fast
  - Refractive and Reflective
  - Illuminance and Intensity targets



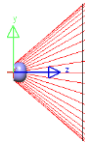
Crossed

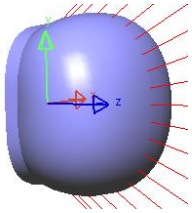
Tilted Target

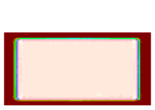
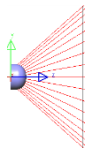



Collimated

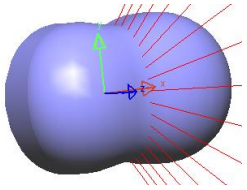



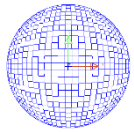
Refractive



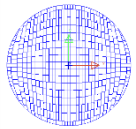



Refractive
'Peanut'

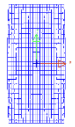


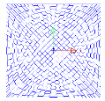
Non-uniform Target

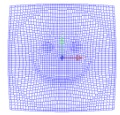
High Aspect Ratio Target

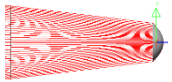
Rectangular Source Output

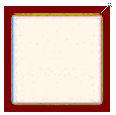
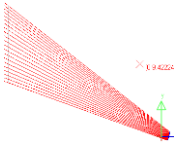
Square to Diamond

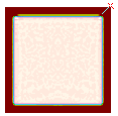
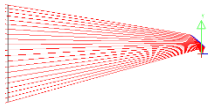
Binary Targets

Large Collection Angles

Off-Axis Target

Off-Axis Source Aim

All examples in this talk use LightTools® from ORA/Synopsys.

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Freeform design tradeoffs

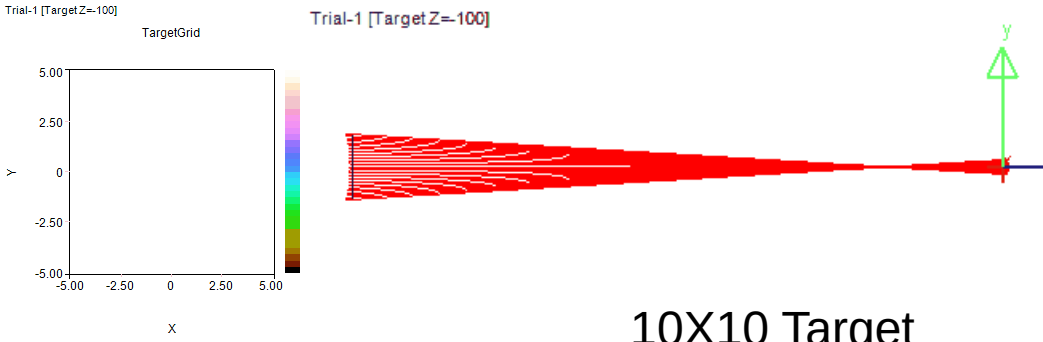
- Freeform illumination optics couple light from a source to a target using freeform surfaces. The designer has to balance performance criteria like collection efficiency and achieving an ideal target distribution with the way that the freeform surface(s) must change.

- Although the increasing power of freeform illumination design tools allows freeform surface to be computed automatically, the designer must still contend with how freeform surfaces change to achieve the desired performance.

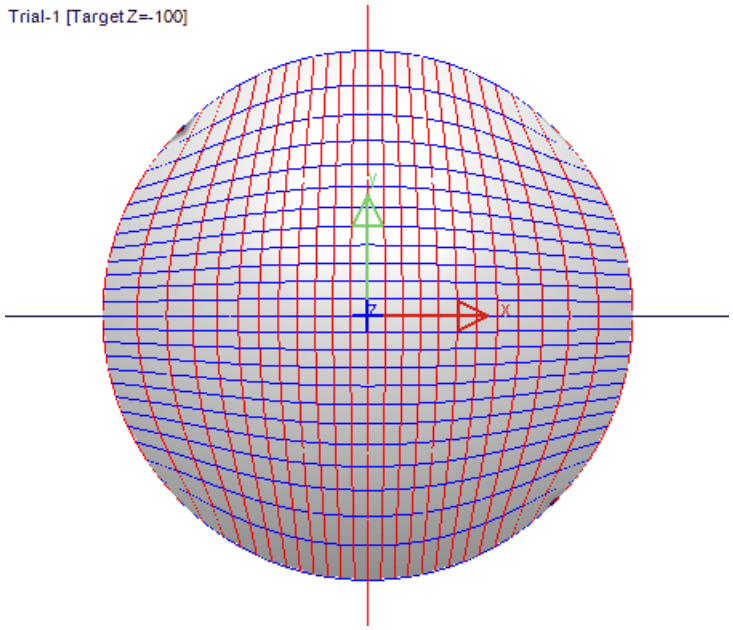
- This paper examines some of the common tradeoffs with special emphasis on how the shape of the freeform surfaces changes.

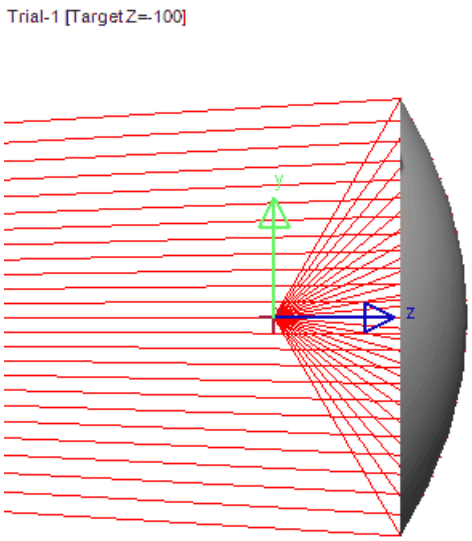
Reflector: Vary Distance to Target

- Reflector becomes flatter as distance to target increases
  - More like parabola
- Reflector can block reflected light with close targets



10X10 Target





+/-60° collection

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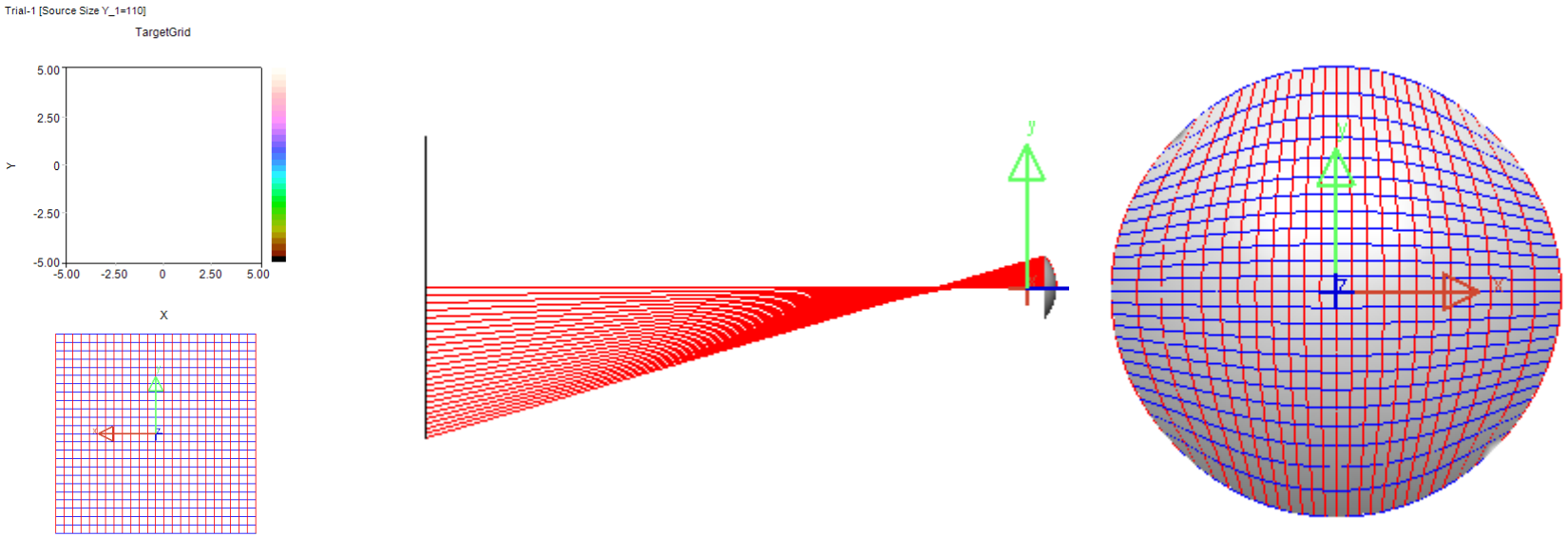
Clarification Slide:
Grid lines on optical surface



- Grid lines on optical surface match correspond to target grid lines.
  - To avoid complexity, the target always uses equi-spaced grid lines in this talk.

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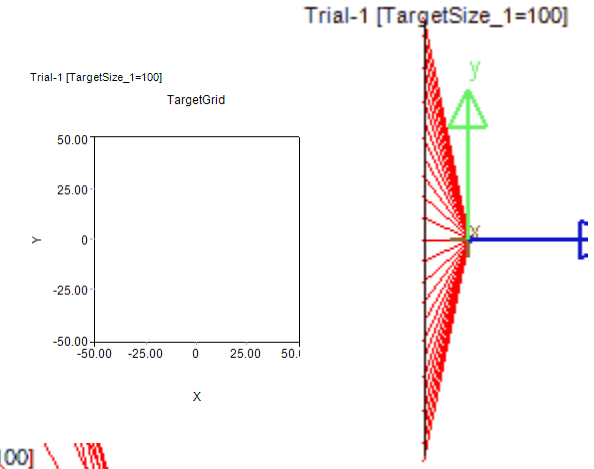
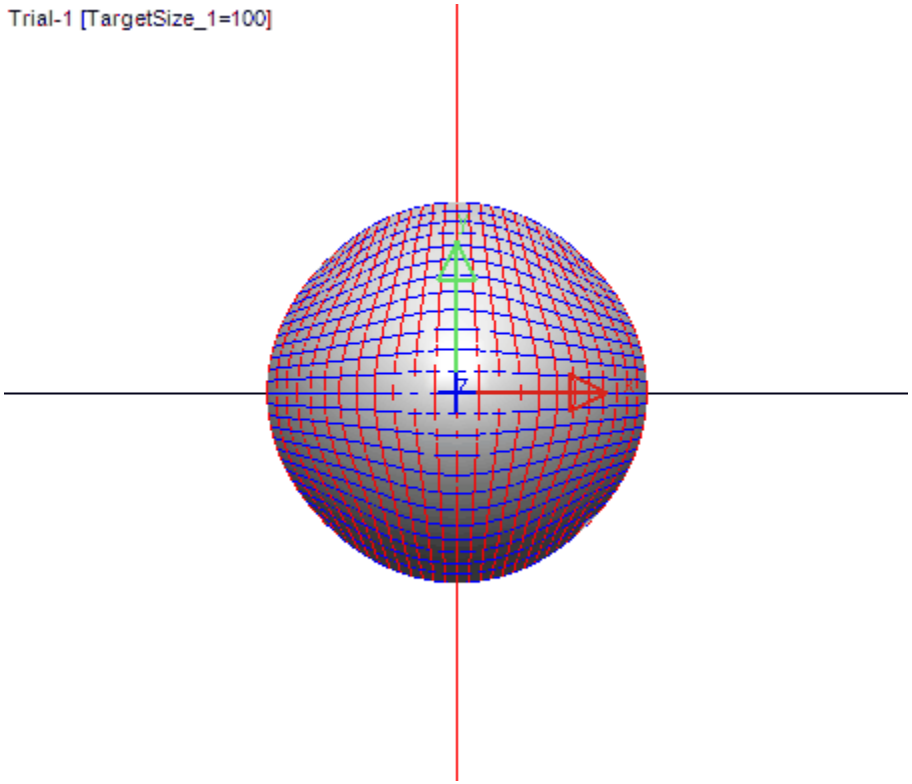
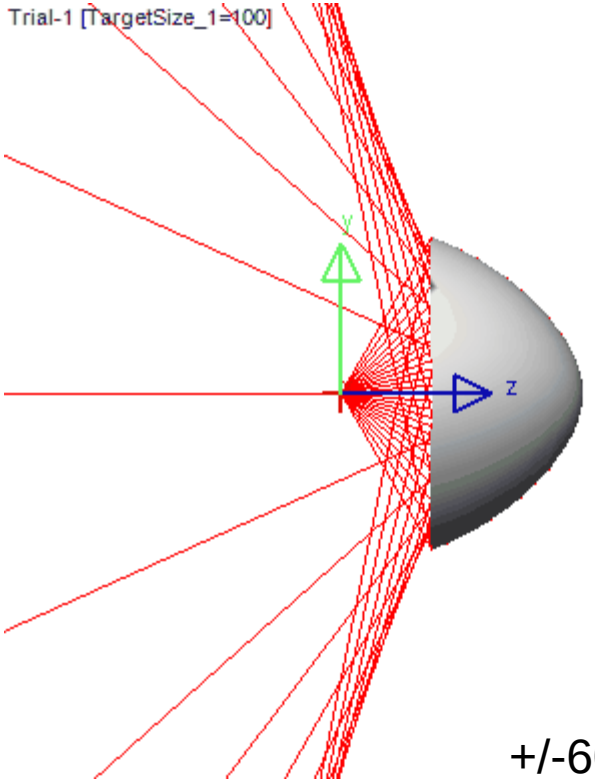
Reflector: Vary Target Size

- Reflector becomes flatter as target size decreases
- Reflector can block reflected light with large targets







+/-60° collection

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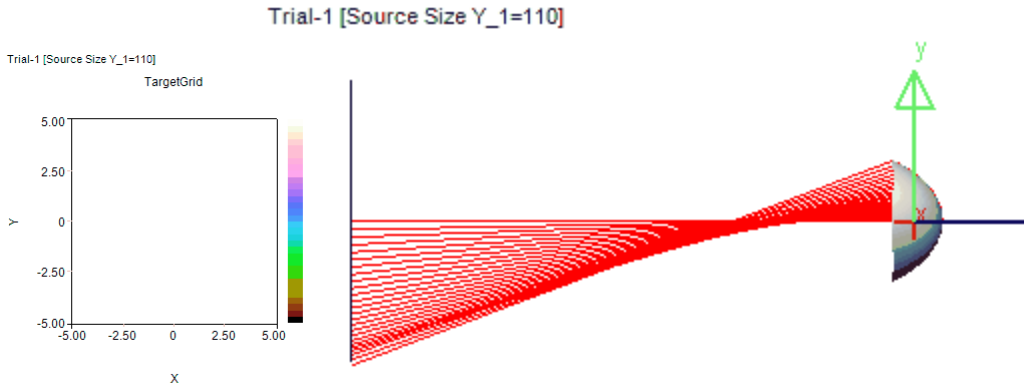
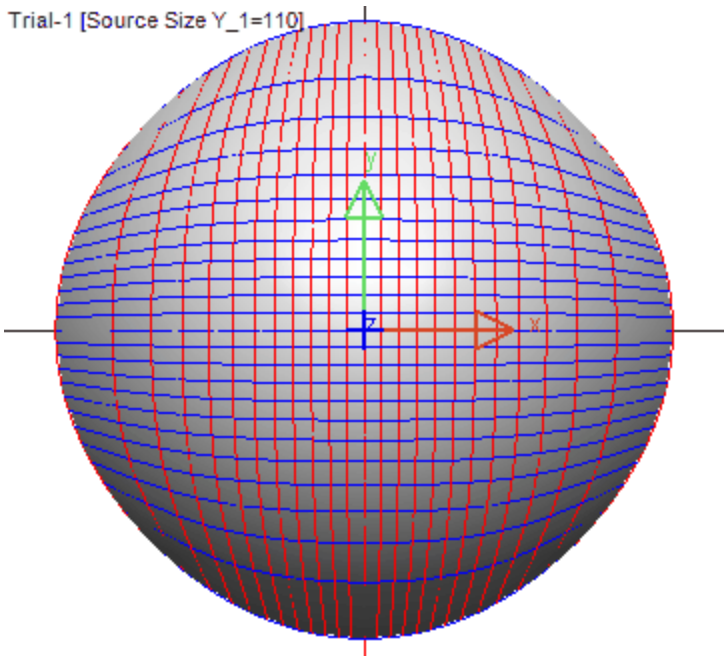
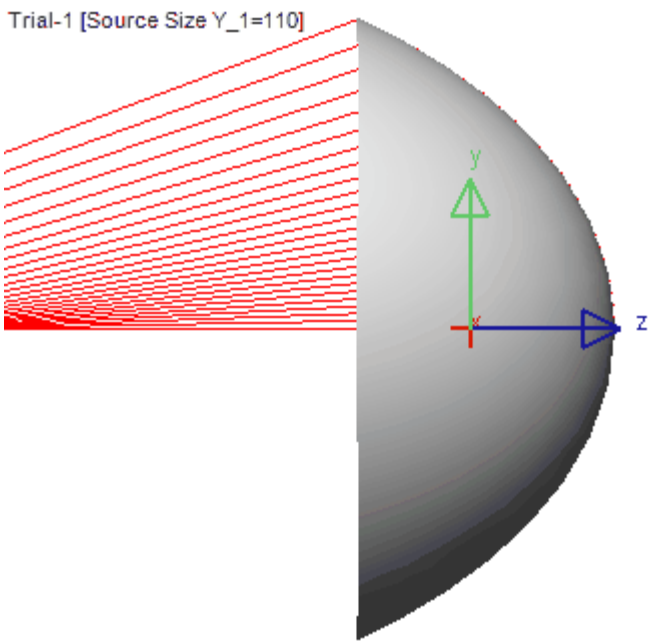
Reflector: Vary Source Collection Angle

- Reflector diameter decreases as collection angle decreases
- Reflector looks similar to a rotationally symmetric reflector.







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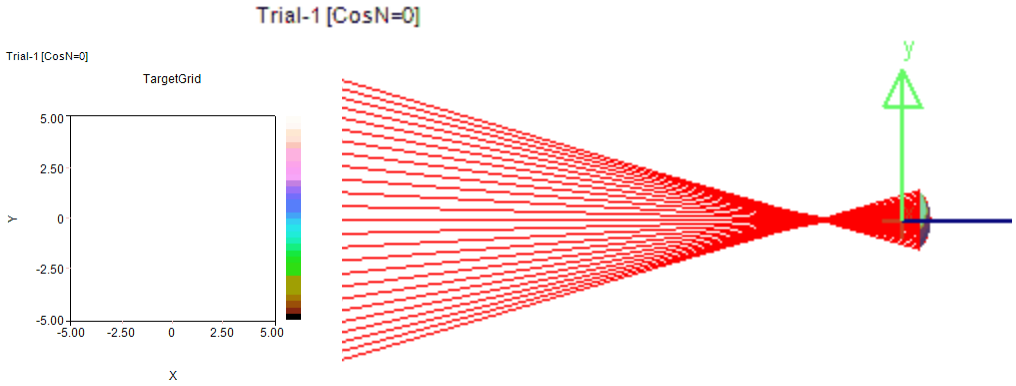
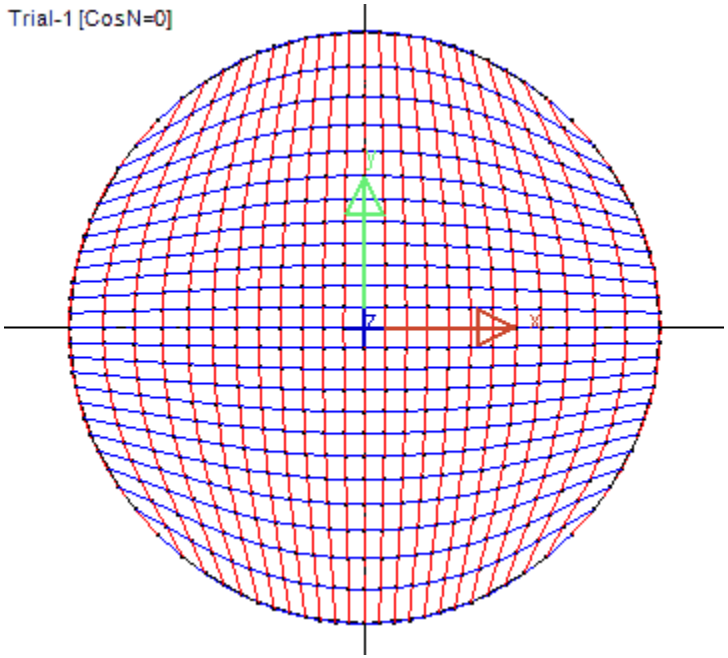
Reflector: Vary Source Intensity

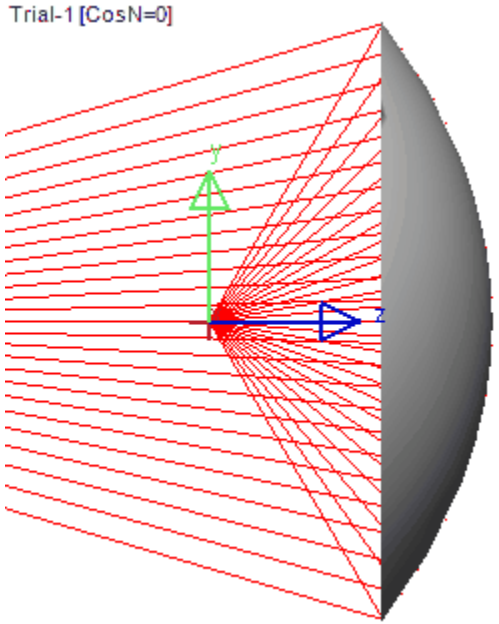
- Intensity=$Cos^N(\phi)$

  $Cos^4(60)$~0.06

- Small reflector shape change as source intensity becomes more peaked.
  - But, grid line spacing changes







+/-60° collection

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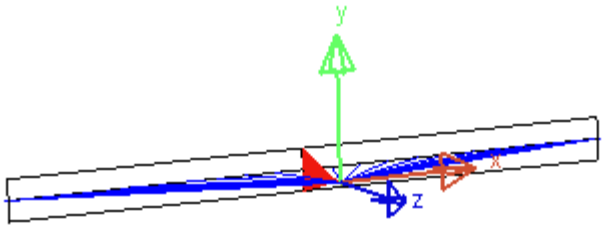
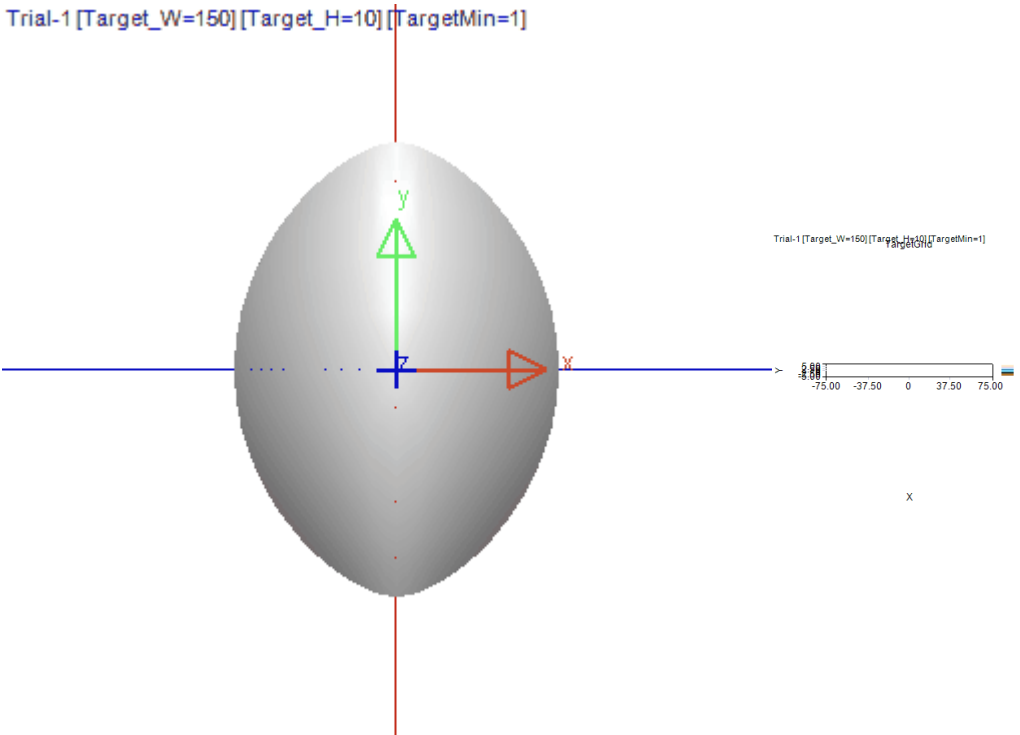
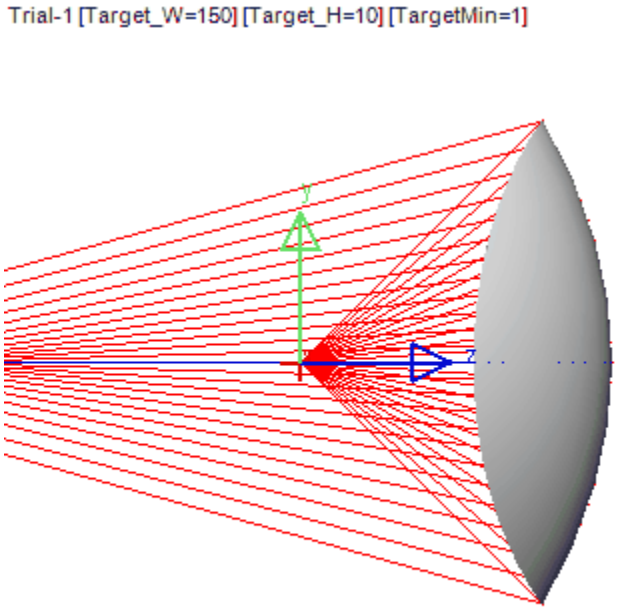
Reflector: Vary Target Aspect Ratio

- High aspect target results in ‘Football/Rugby’ shape.
- High aspect increases odds of rays hitting reflector twice.

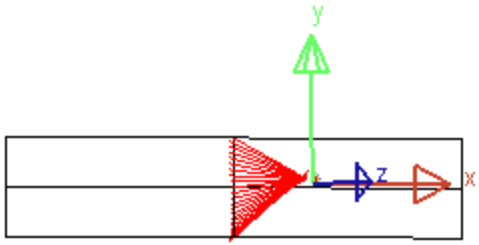


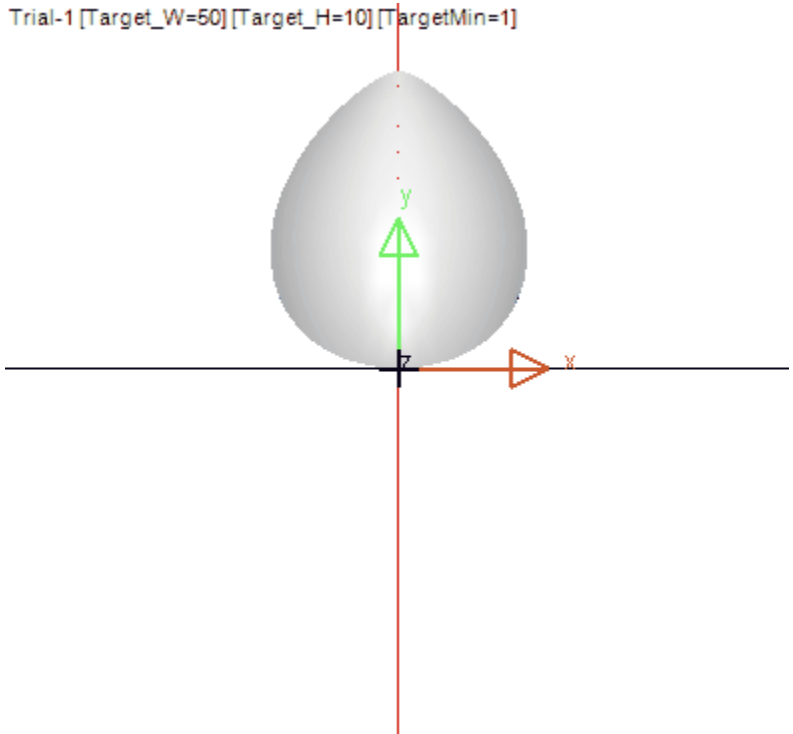


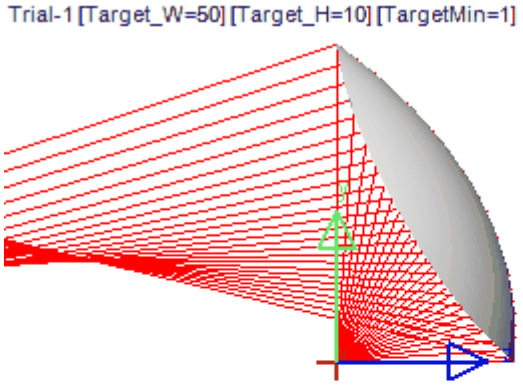


Off-Axis Reflector: Vary Target Aspect Ratio

- High aspect target results in ‘Football’ shape; albeit, one end.



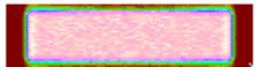


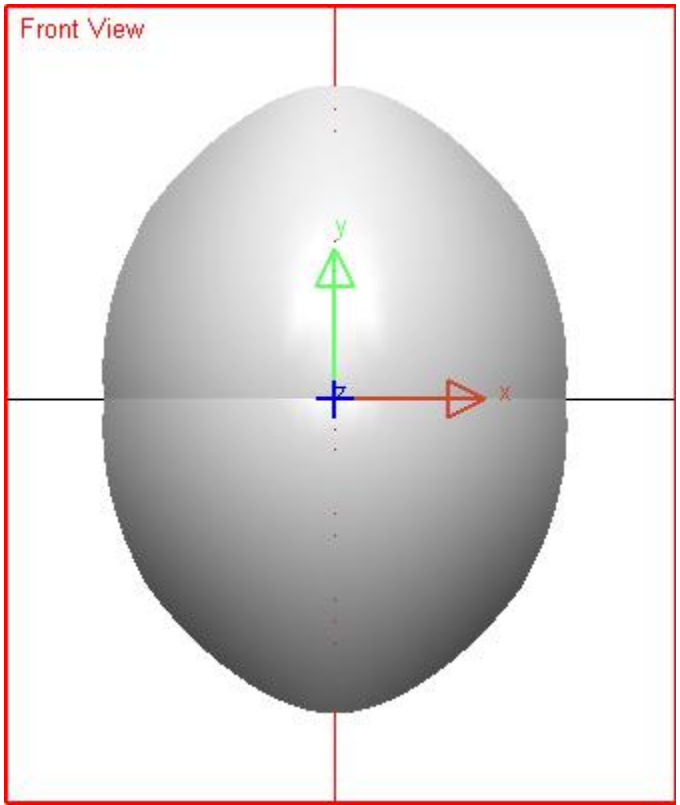


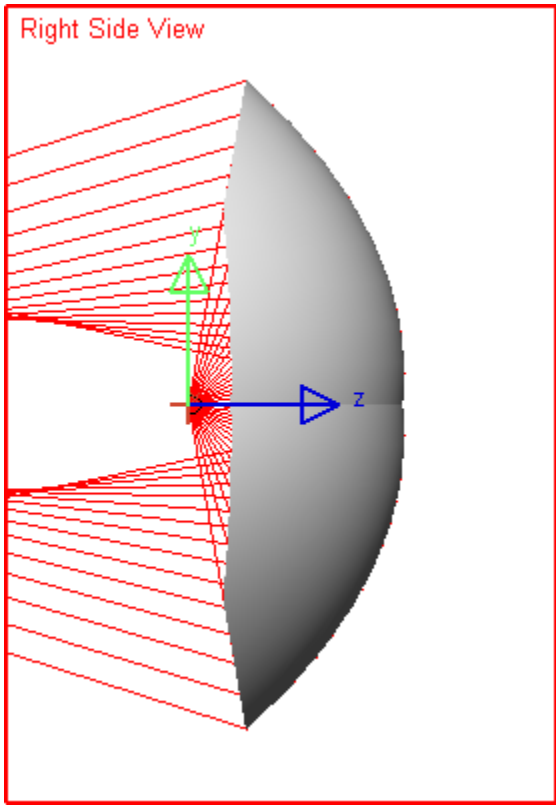
+/-45° collection
Tilted 45°

Reflector: Multiple Facets

- Multiple reflector segments.
  - Each providing same distribution.
- Allows light distribution to ‘clear’ the source!

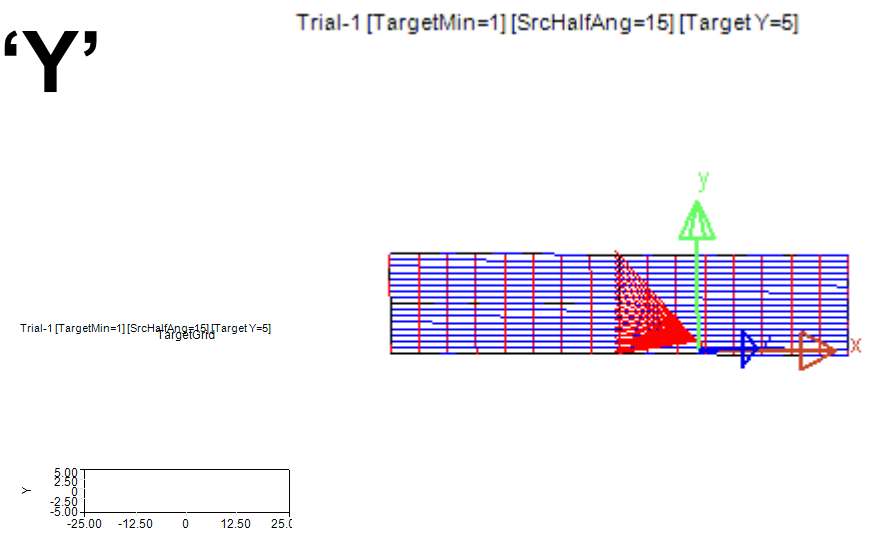


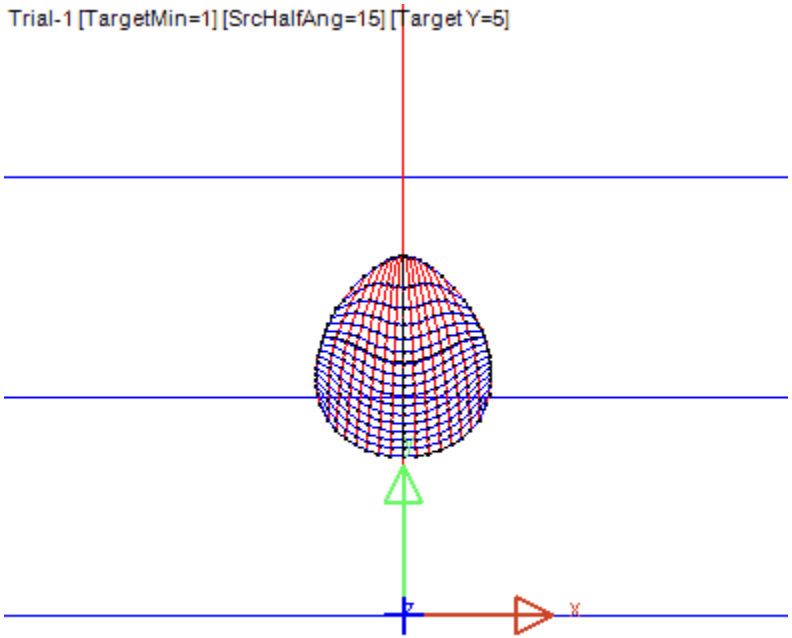


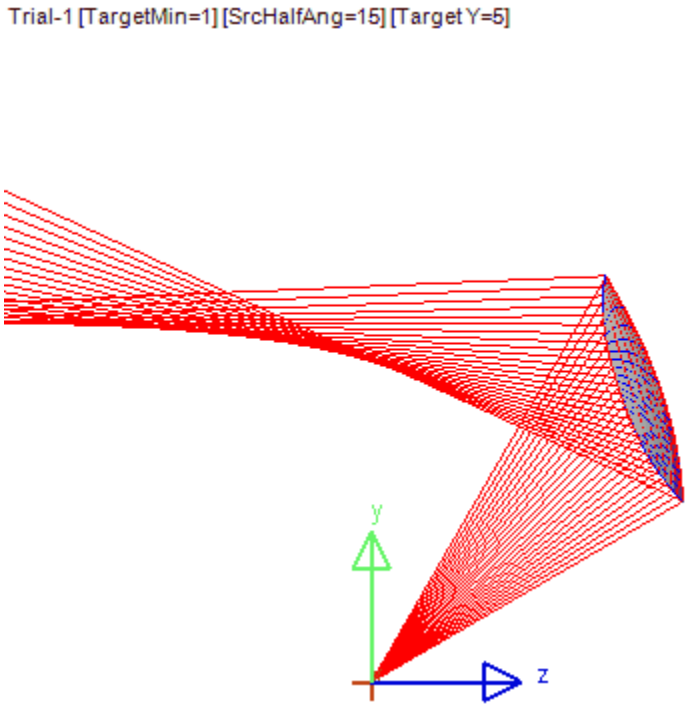


Reflector: Vary Target ‘Y’

- Shifting target decenter can result in ‘football’ shape

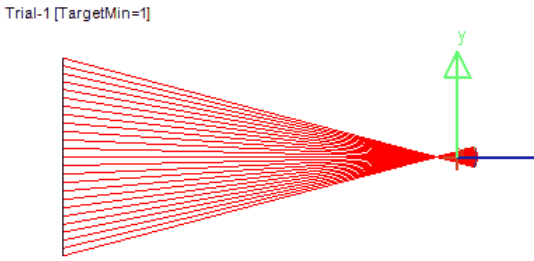


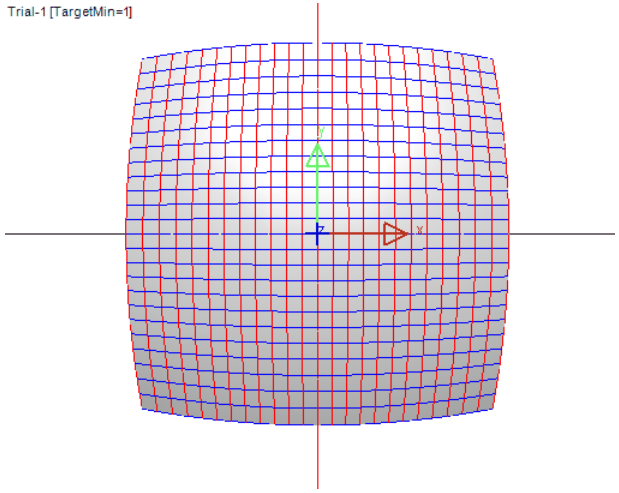


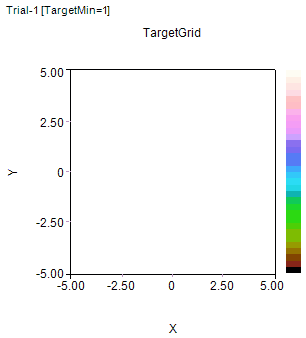


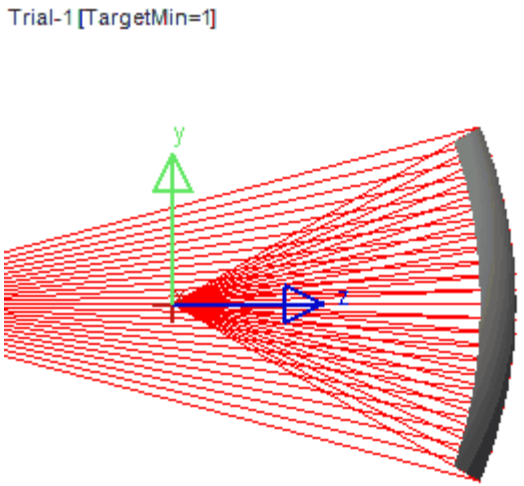
Reflector: Vary Contrast Ratio

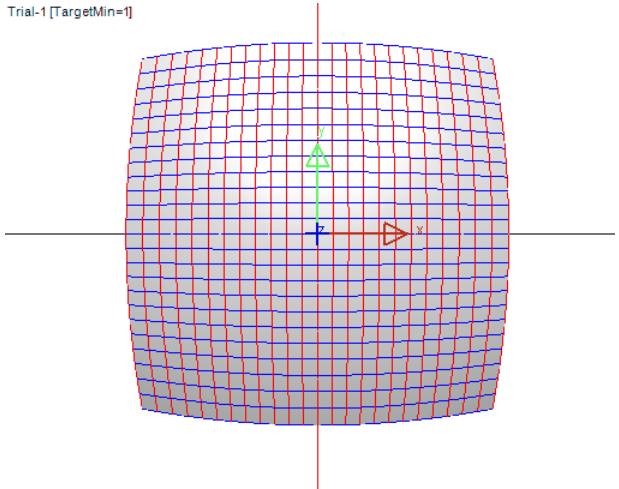
- Overall shape of reflector does not vary much for targets where FWHM of remains similar.

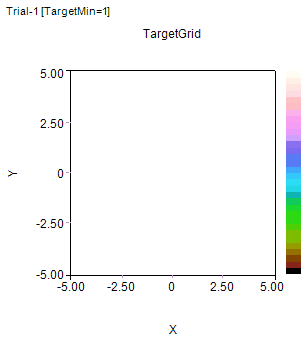


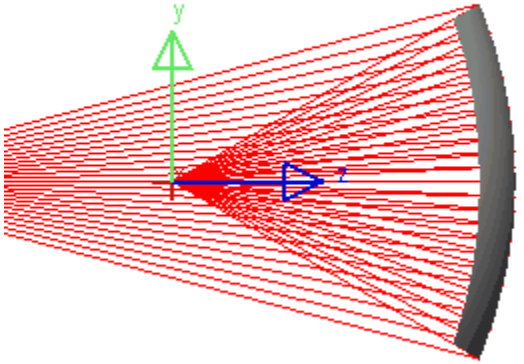




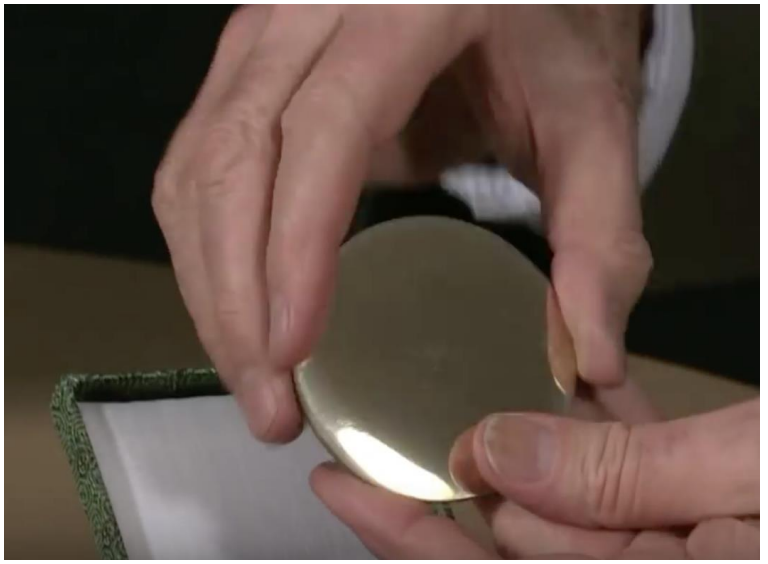






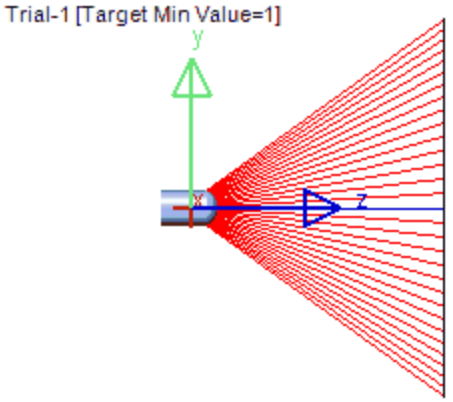


Magic mirrors

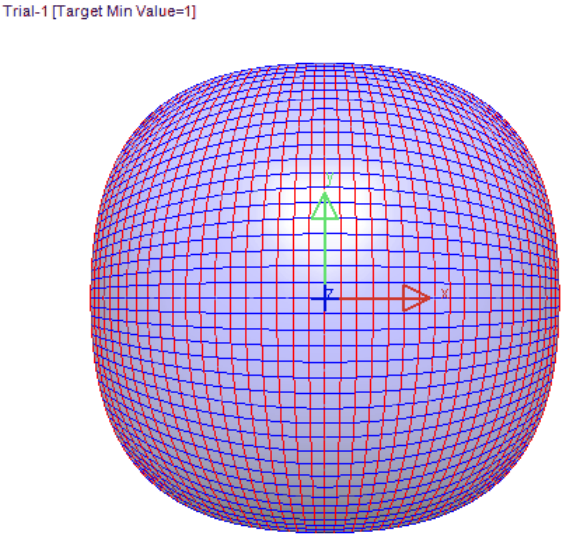


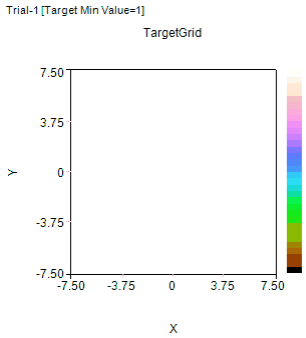
Lens: Vary Contrast Ratio

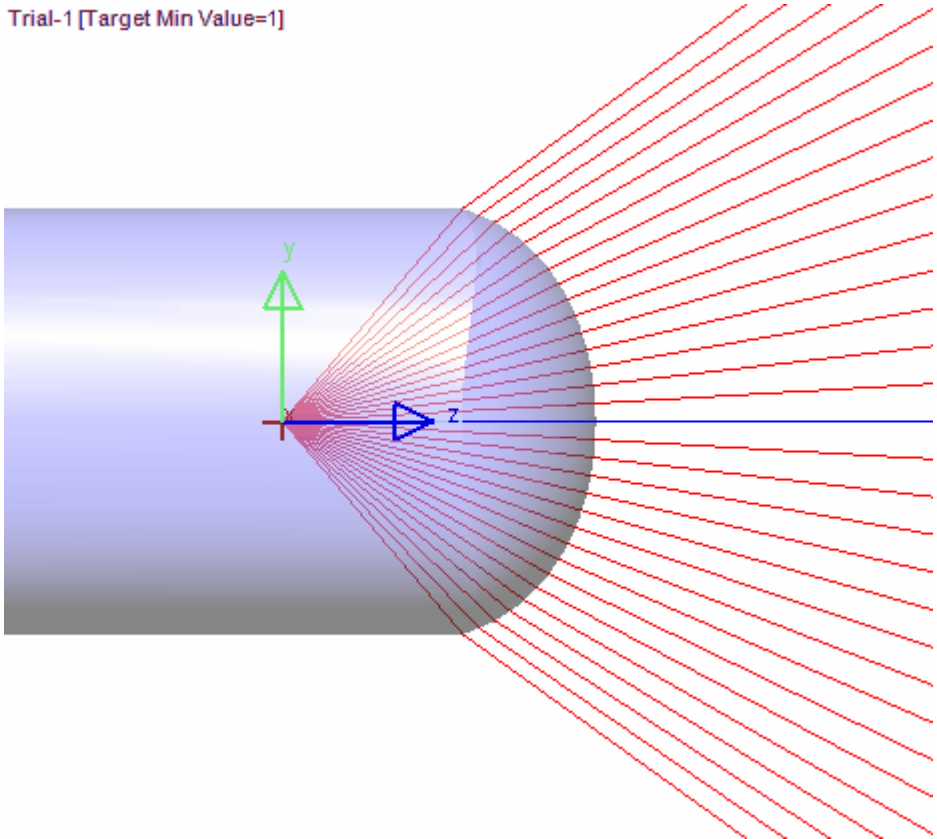
- FWHM changes by small amount
  - Lens shape changes accordingly
  - Significant changes to grid mapping



15X15 Target

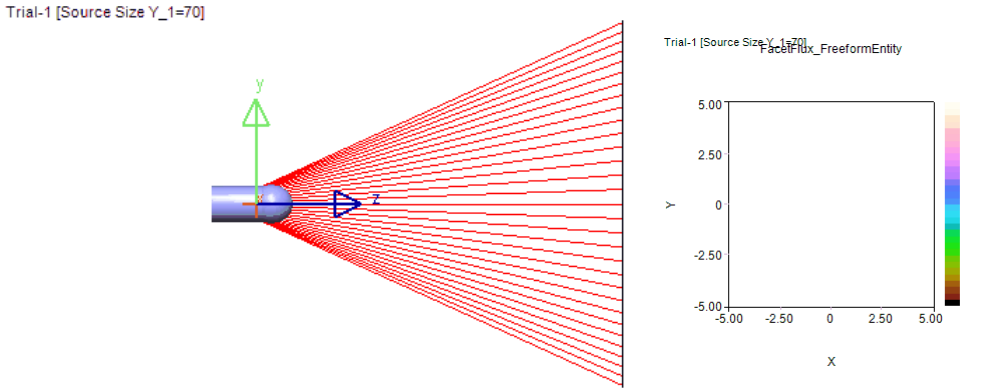


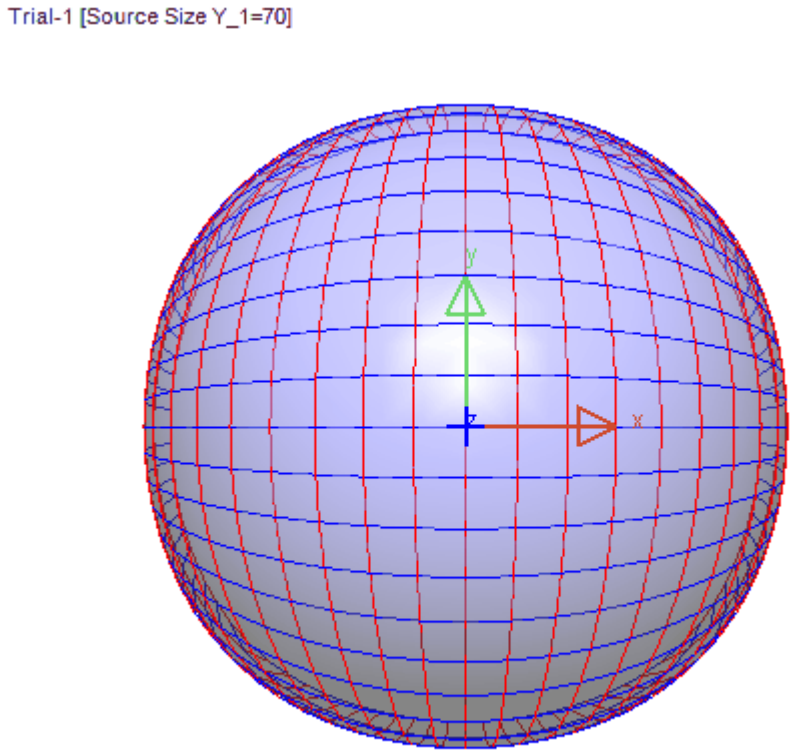




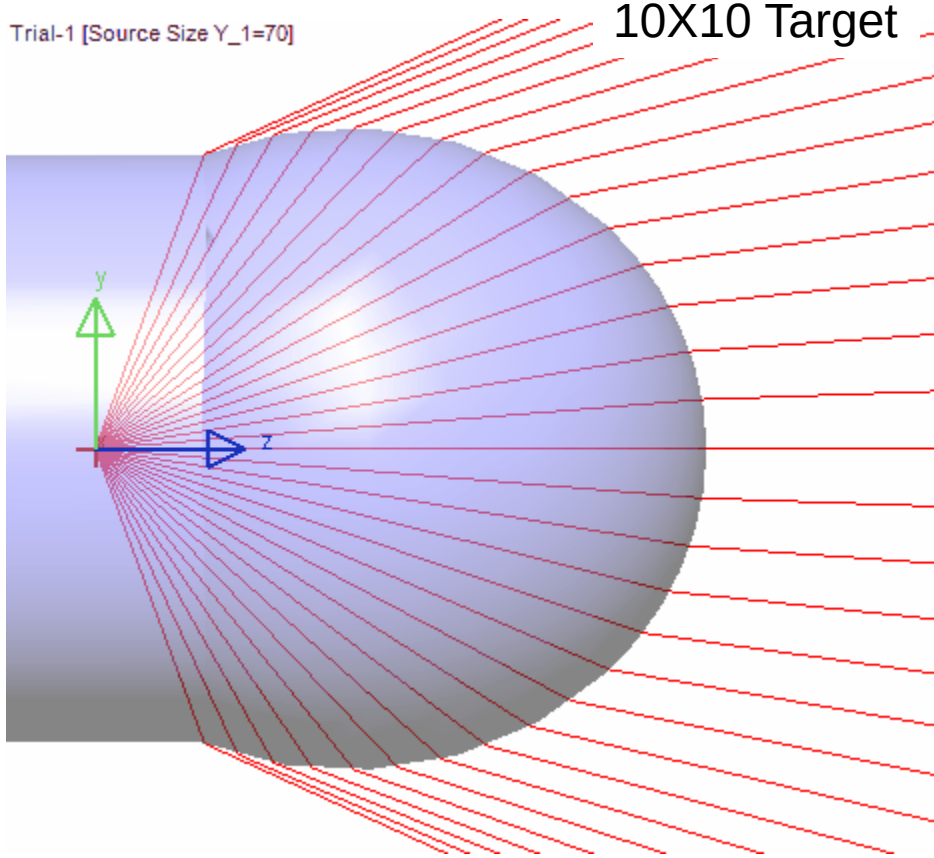
Lens: Vary Collection Angle, 1:1 Target

- Lens changes from concave to convex as collection efficiency increases



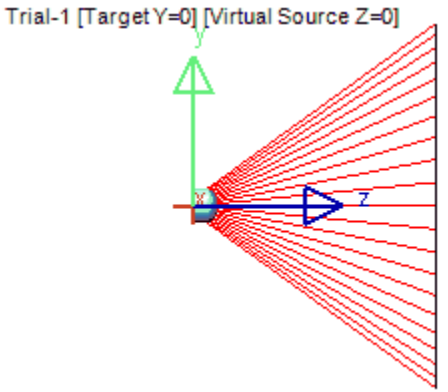


10X10 Target

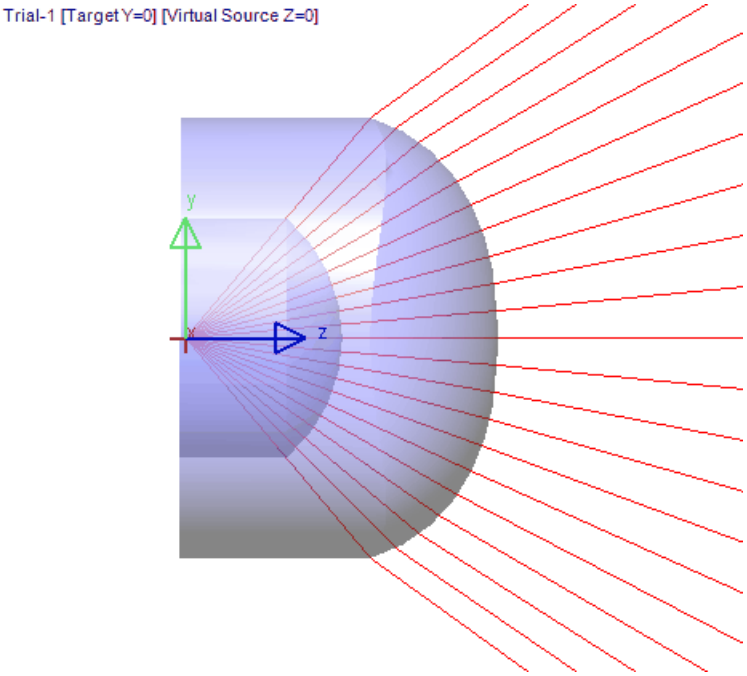


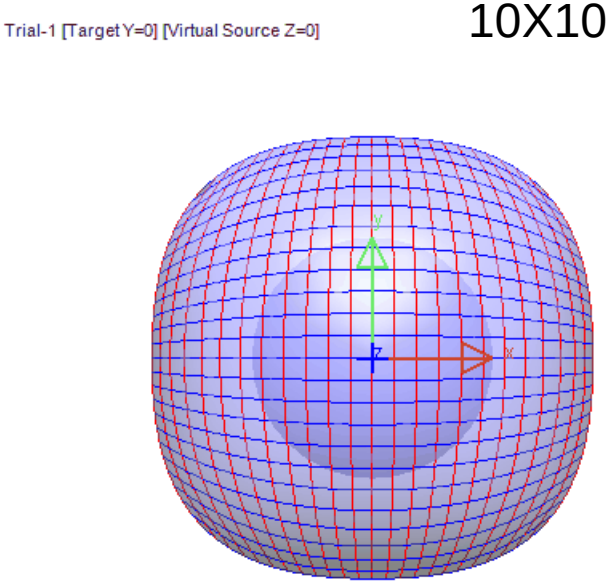
Lens: Two Surfaces to Increase Collection

- Adding a second lens surface allows increase in collection efficiency, but also impacts shape of the other surface.



10X10 Target

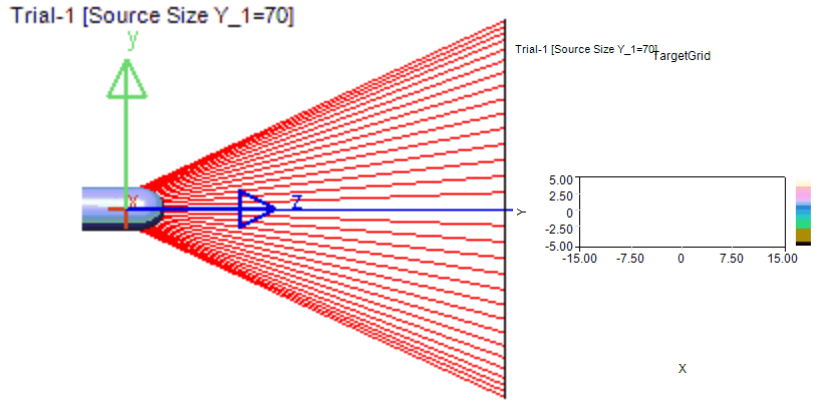




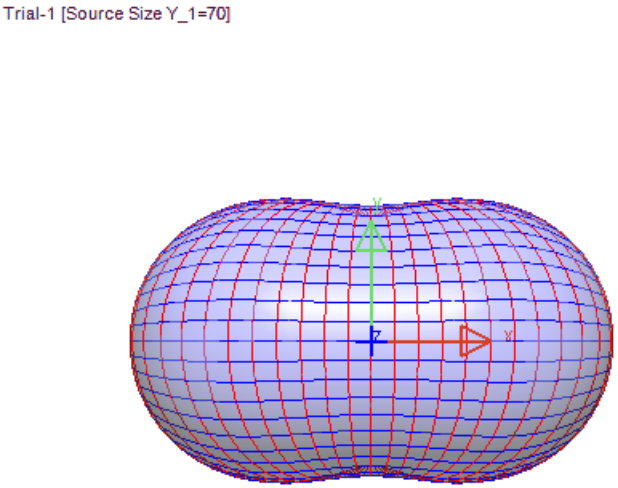
SYNOPSYS®

Lens: Vary Collection Angle, 3:1 Target

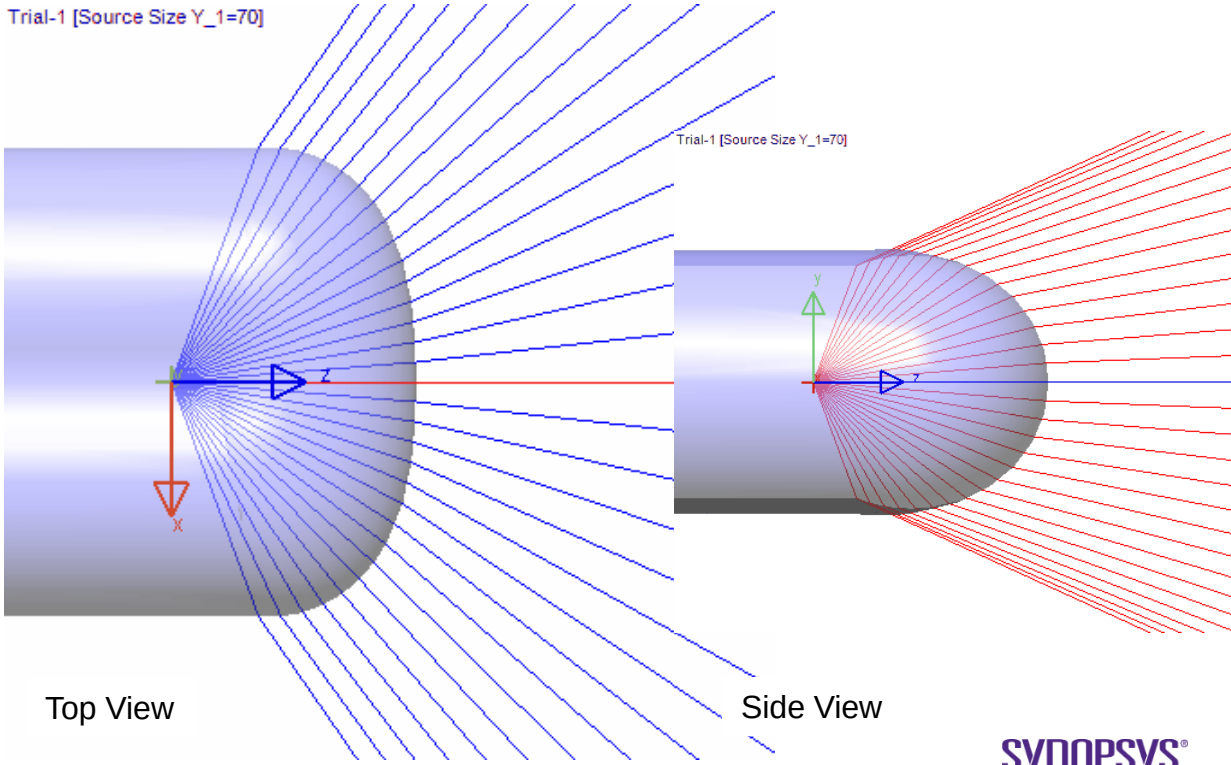
- Lens shape often trends toward ‘peanut’ shape for asymmetric targets, especially at higher collection efficiency.



30X10 Target



Front View



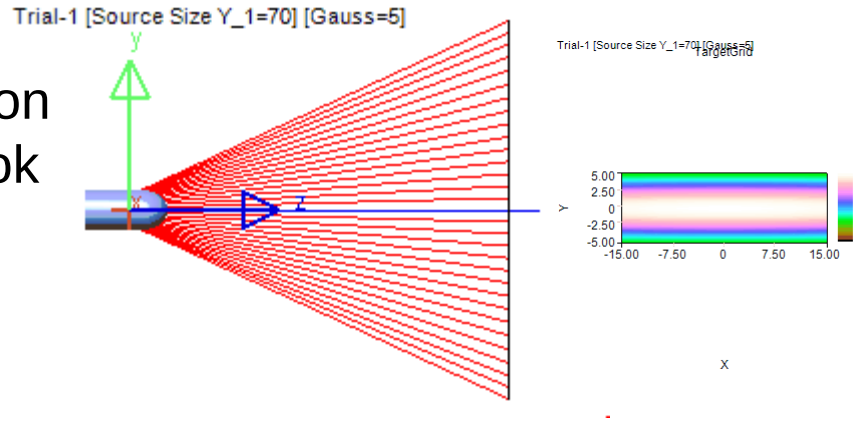
Top View

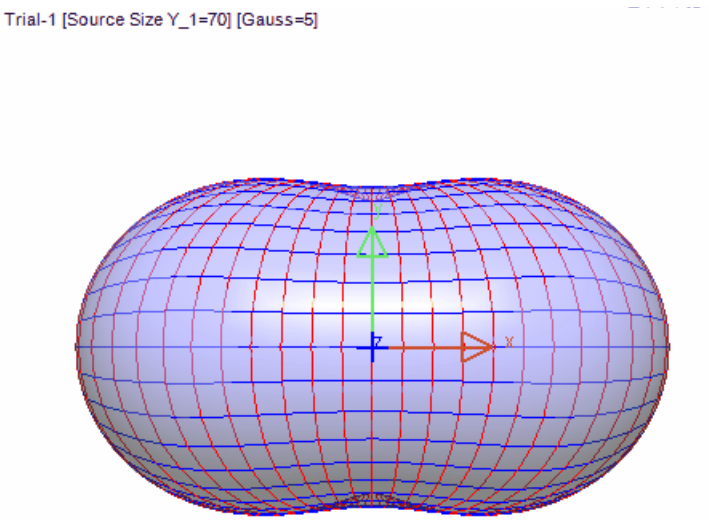
Side View

SYNOPSYS®

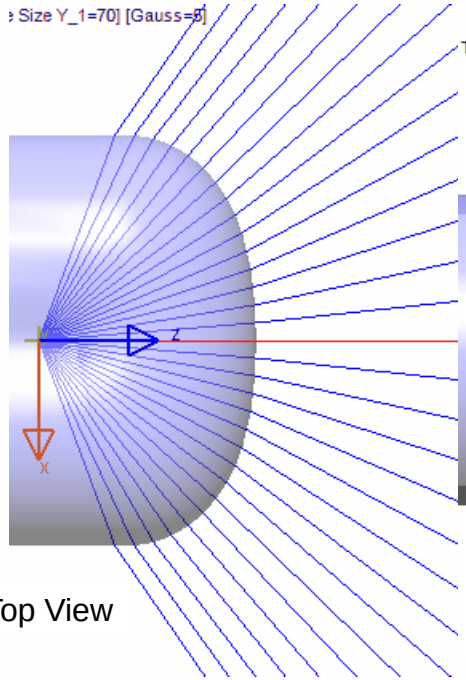
Lens: Vary Target Width with 3:1 Target

- Varying FWHM of the target distribution can push 3:1 aspect ratio target to look more like a 2:1 aspect ratio target.

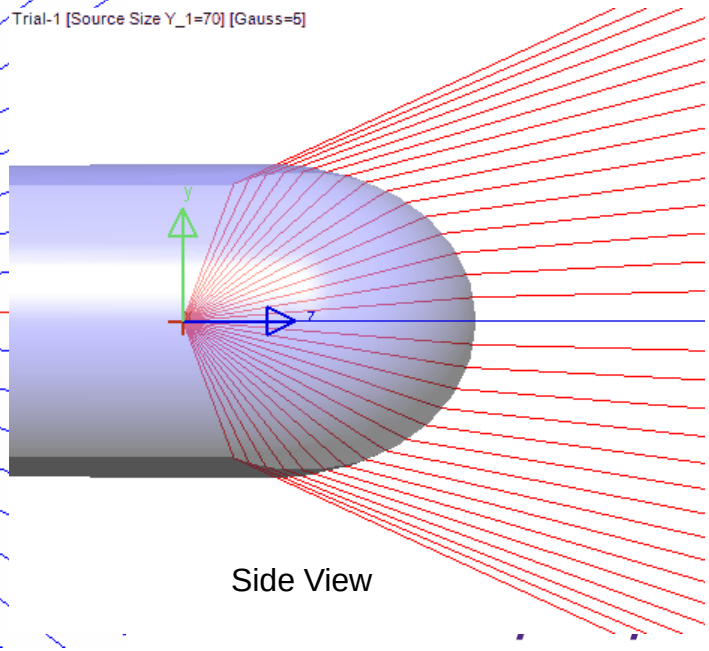




Front View



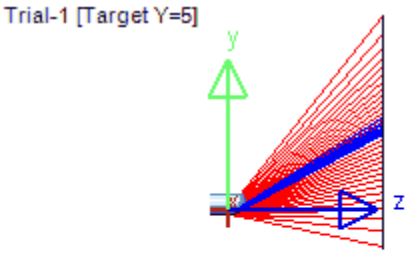
Top View

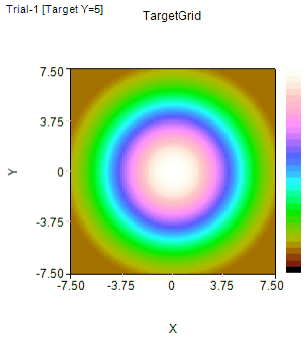


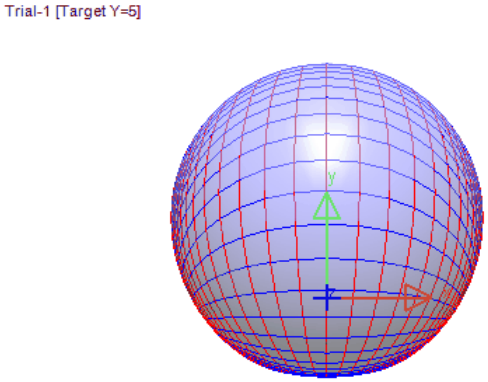
Side View

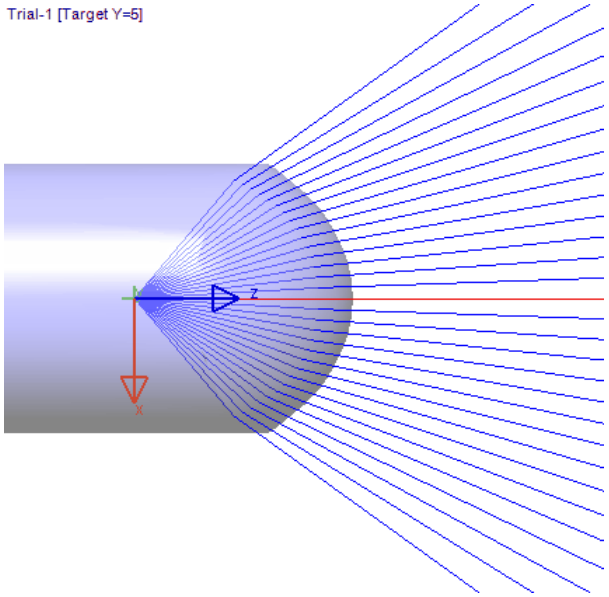
Lens: Vary Target ‘Y’ Decenter

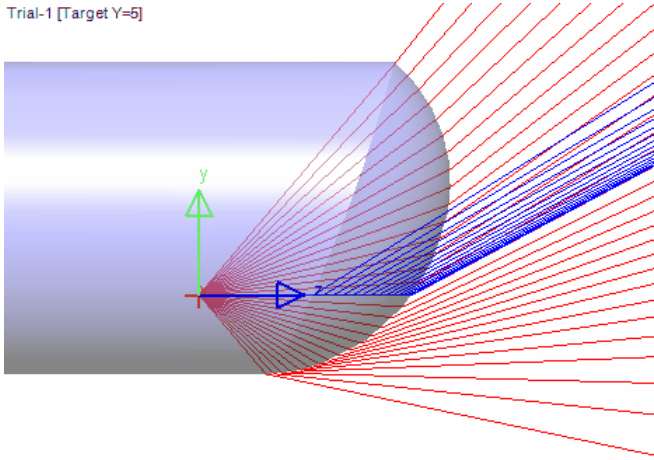
- Decentering the target results in more asymmetric design
- One side of the lens has high Fresnel losses.
  - Approaching TIR condition





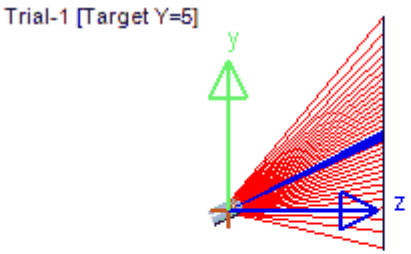


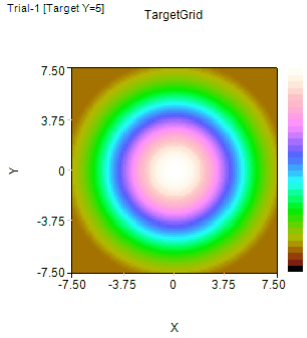


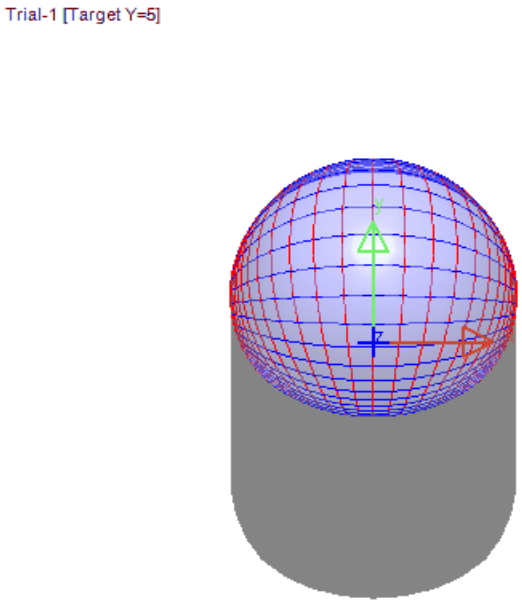


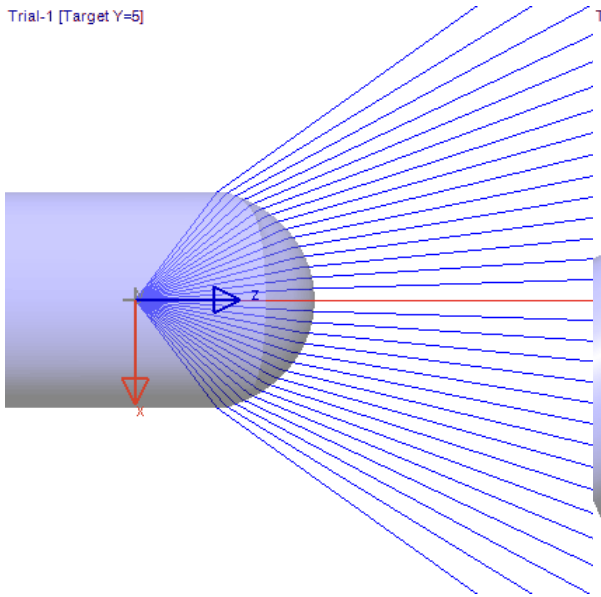
Lens: Vary Target ‘Y’ Decenter + Source Tilt

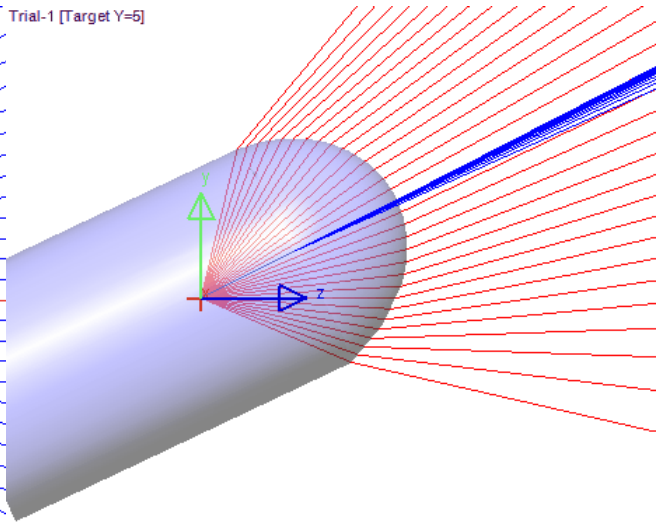
- Rotating the source so it is aimed toward center of target can avoid ‘using up’ the lens bending power.
  - Reduce Fresnel Loss issues











Summary

- Macroscopic Freeform Shape/Size changes significantly when
  - Range of source collection angles change
  - Target location/size changes
- The target distribution often has 2nd order impact on the Freeform Shape/Size
  - Difference often small unless target FWHM changes significantly.
- Reflective Freeform designs are limited by
  - Avoiding light passing back through the source
  - Design specifications result in a ‘Football/Rugby’ shape.
  - Rays hitting reflector twice
- Refractive Freeform designs are limited by
  - Bending power of a refractive surface
    - Often forces use of 2 surfaces and/or aiming source toward target center
  - Design specifications often result in a ‘Peanut’ shape.

