L'utilisation du principe des appareils à sténopé pour la compréhension et la conception des optiques freeform pour l'illumination

Journée Calcul Optique

Palaiseau, France

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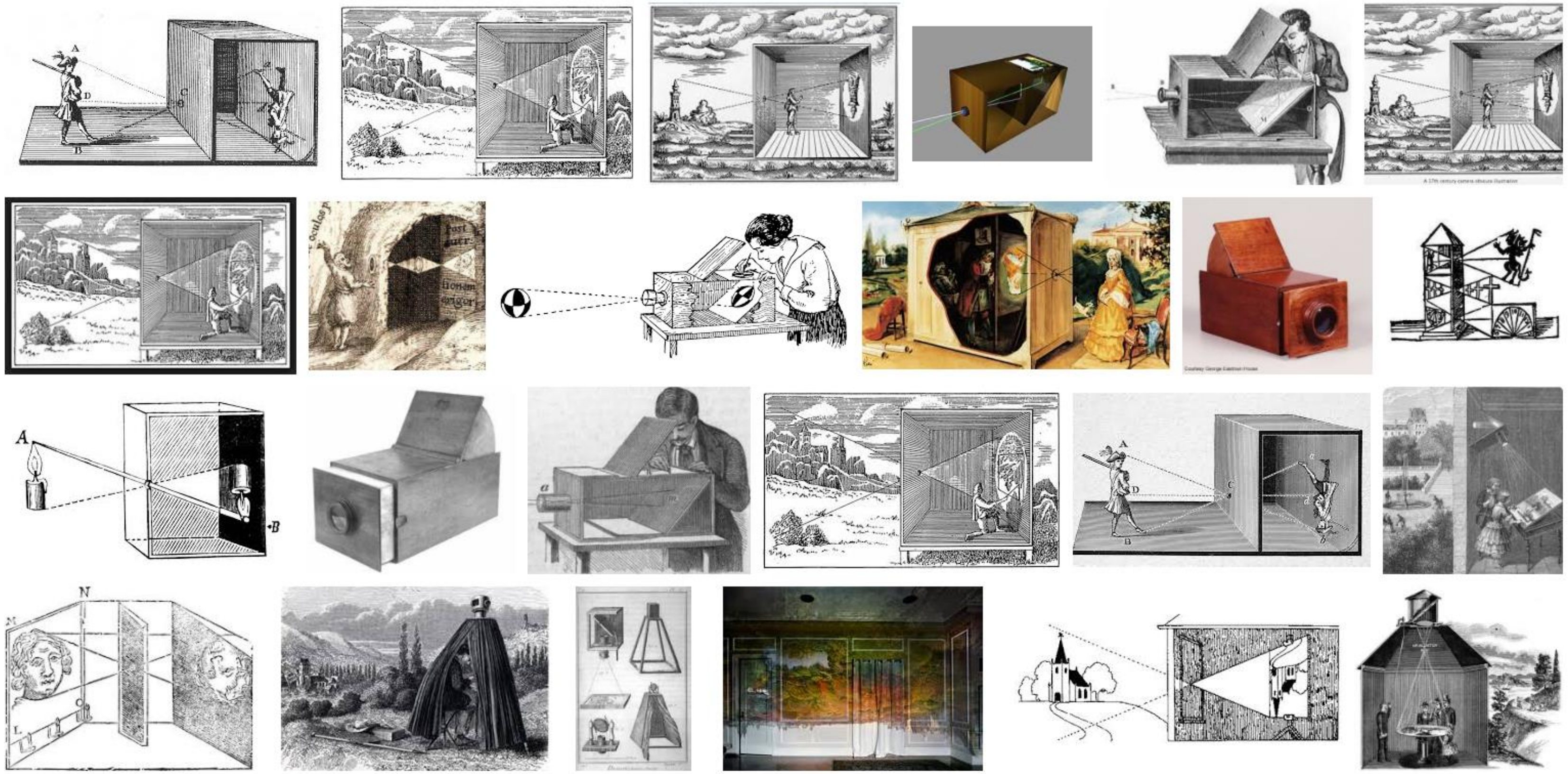
Introduction

- The design of illumination optics that use extended sources and freeform surfaces is relatively common. We show how these nonimaging optics can be better understood by using pinhole images. Numerous examples are used to illustrate.



Outline

- Pinhole Images
  - Background and Terminology
- Examples
  - First Order Examples
    - Source size, Optic size, Distance to Target
  - Interesting Observation Examples
- Conclusions

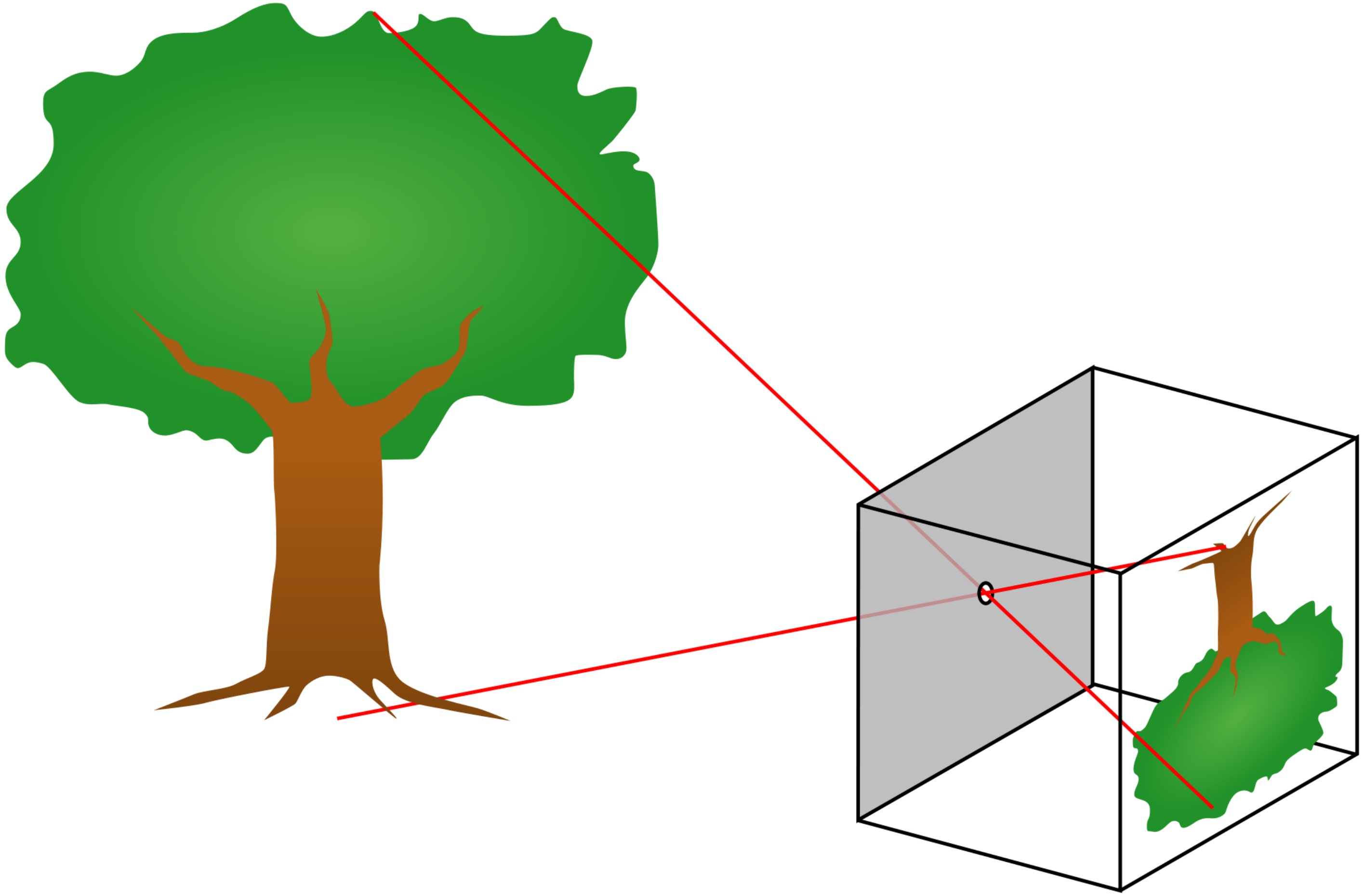
Background

Classic Pinhole Camera

A unique feature of pinhole cameras is that **depth of field is of no concern** sample photos.; everything in front of the camera is equally in focus. This was the reason that **Ansel Adams** used this type of camera for many of his nature shots. You can get countless different effects by bending the film, putting it in diagonally, or by wadding up the negative.

Our unique camera designs make it possible to use cut film holders or Polaroid backs such as those used with lensed cameras, thus eliminating the need to load the camera in the darkroom. Of course if you prefer, you can still load the film in the darkroom the traditional way by using the back that comes with the camera.

http://www.pinholecamera.com/

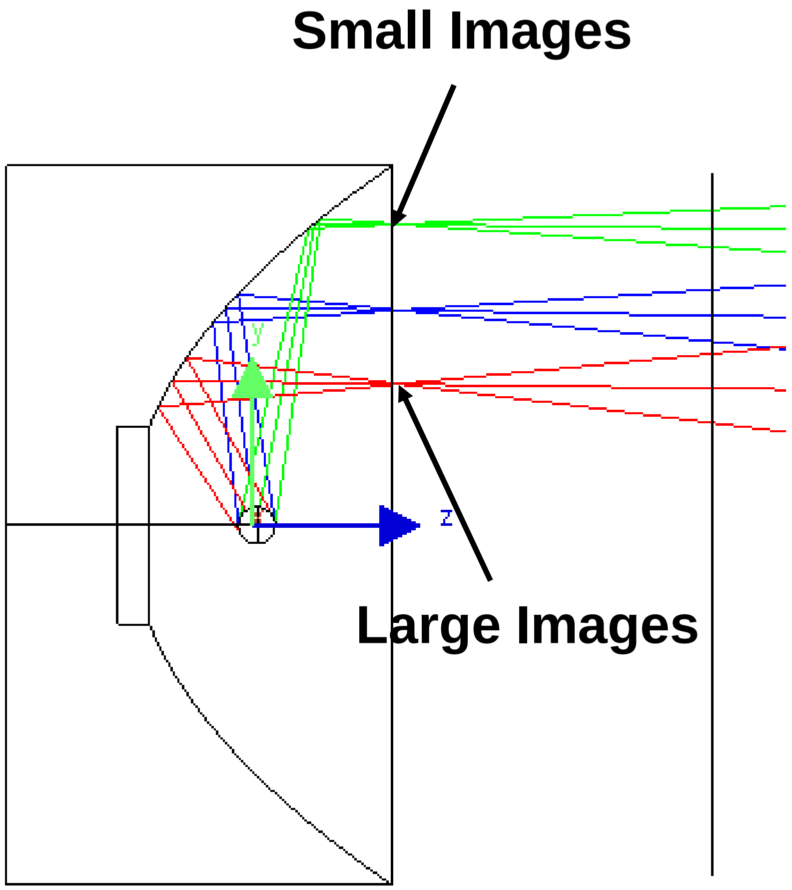


https://commons.wikimedia.org/wiki/File:Pinhole-camera.svg

Background

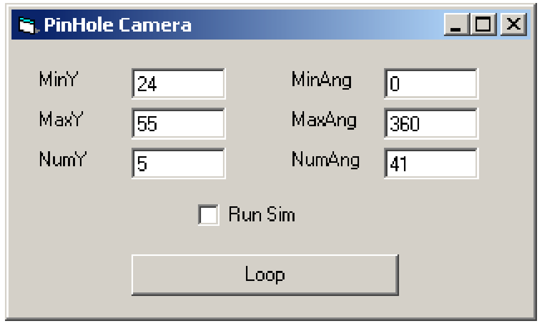
- Typical illumination system
  - a source, some optics, and a target surface.
- Pinhole Analysis
  - We can place a small aperture (pinhole) at any point in the illumination system and examine the distribution that the source produces on the target surface.
    - We call this distribution a **pinhole image**.
  - The term pinhole image is loosely based on ‘pinhole camera’ which uses a tiny aperture instead of a lens to create an image.
    - With real hardware, we can place a physical aperture in our system to visualize pinhole images.
    - Using optical ray trace software, we can compute these images
      - First tracing rays from the pinhole to the source.
      - For rays that hit the source, we then reverse the ray and trace from the source to the target surface.
  - We’re mainly interested in the size of the source image, so we show the pinhole images using the outline of the edge of the imaged source.

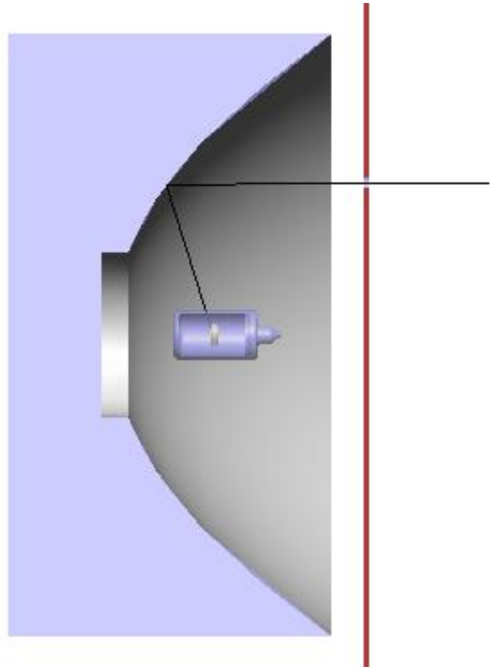
Pinhole Images

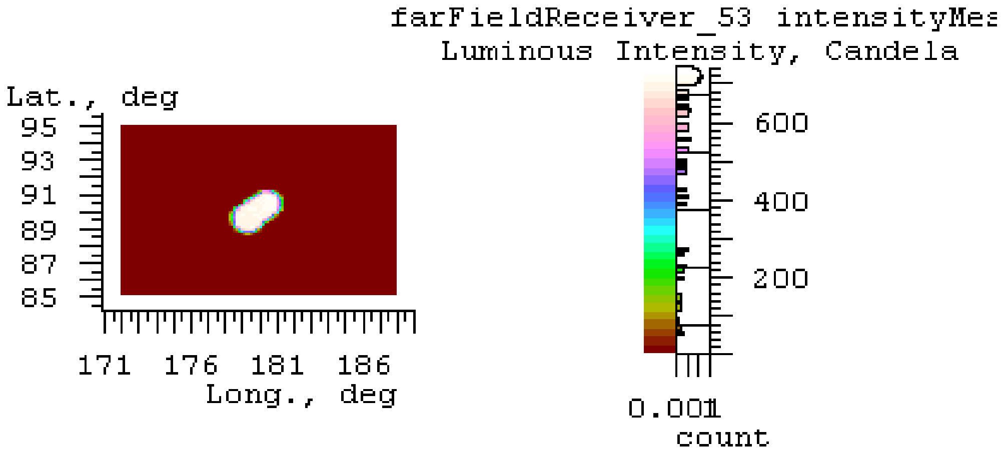


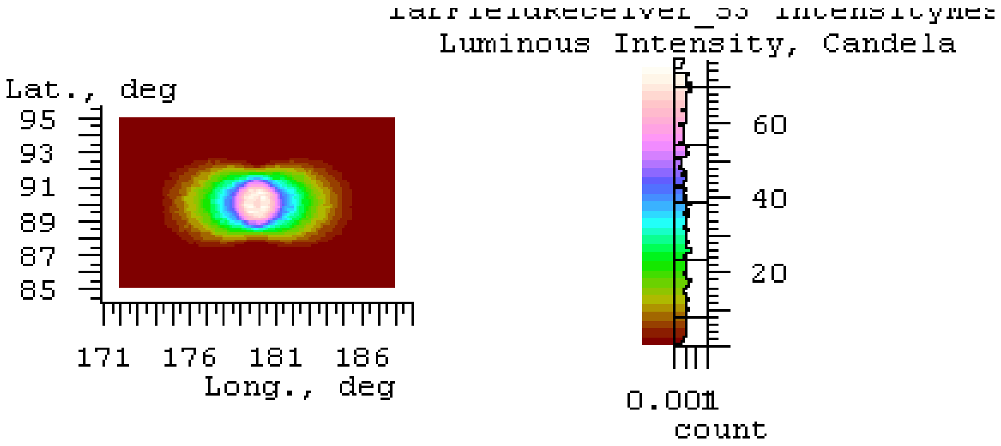
- Small pinhole shows images of the source
- Source to reflector distance varies
  - pinhole images also vary
- Beam pattern is the superposition of those pinhole camera images

Beam Forming

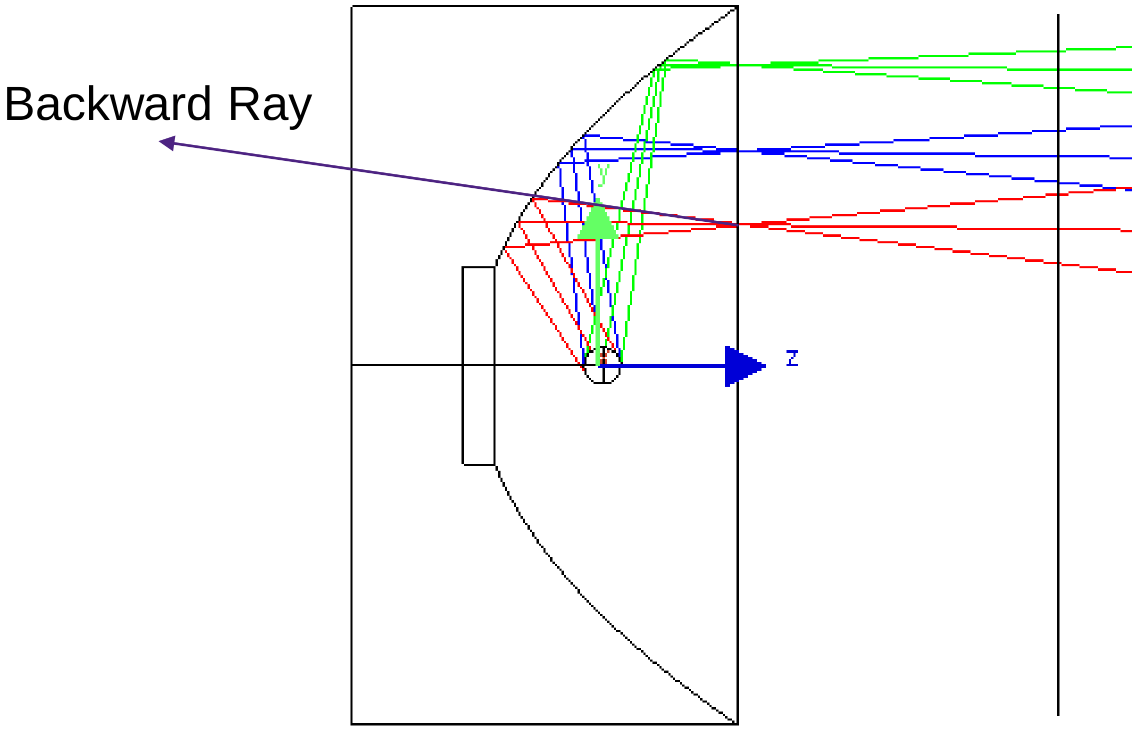








How to compute Pinhole Image Outlines



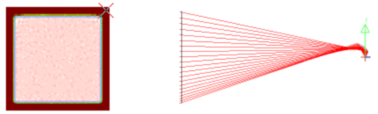
- Nominal Approach
  - Choose pinhole location
  - Trace from pinhole back to source and find directions associated with edges of source
  - Reverse those rays to determine the pinhole image outline on the target surface.

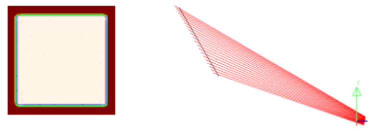
- Alternative Approach
  - Choose pinhole location
  - Choose points along edge of source and ‘find’ the direction associated with the pinhole
  - Trace those rays to the target

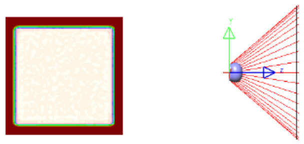
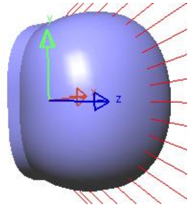
First Order Examples

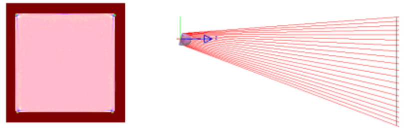
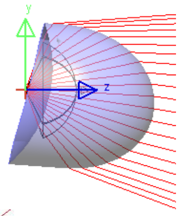
Freeform Designer (FFD)

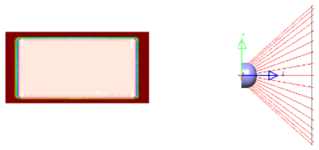
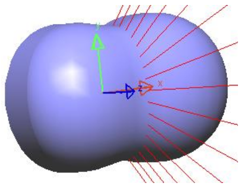
- Point source design algorithm.
- Specify source aim region + desired target distribution
- Freeform surface that provides the desired target is computed.
- Handles a wide range of cases

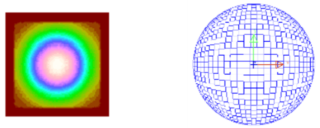

Crossed

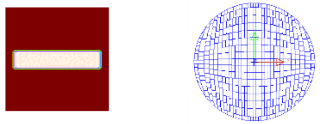

Tilted/off-axis target

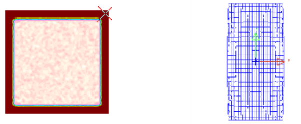

Refractive


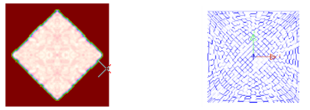

Conic or Cartesian oval input surface


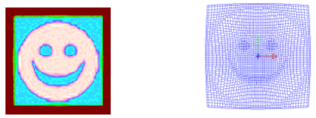

Refractive 'peanut'


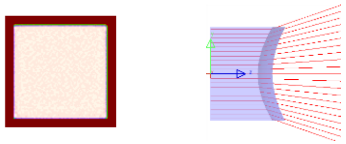

Non-uniform target

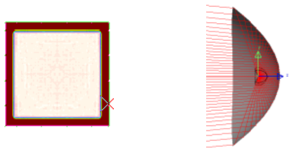

High aspect ratio target

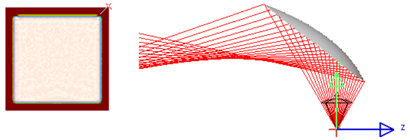

Rectangular source output

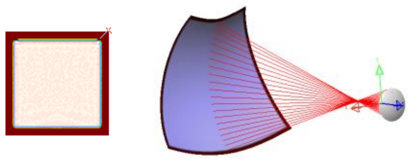

Square to diamond


Binary targets


Collimated

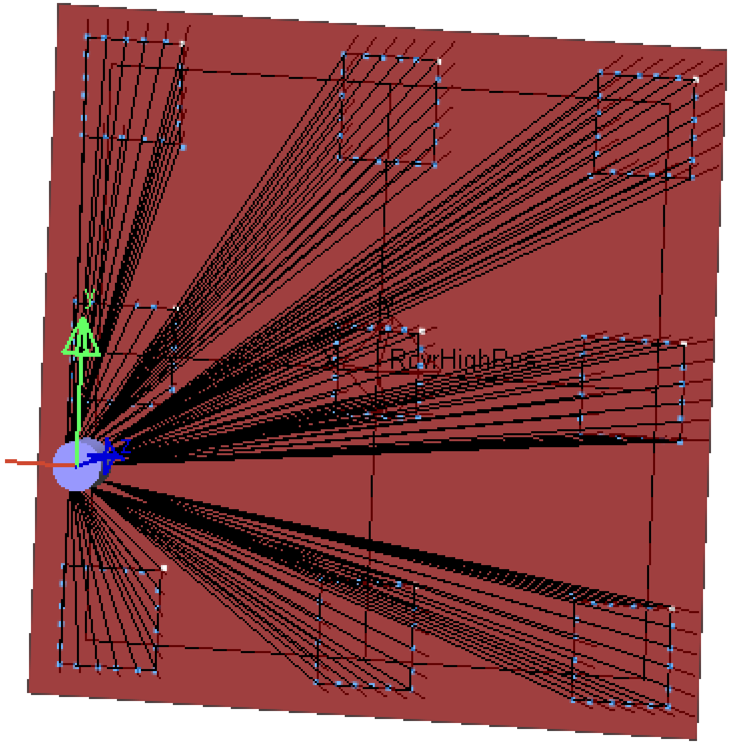

Large collection angles
(> Hemisphere)


Off-axis source aim

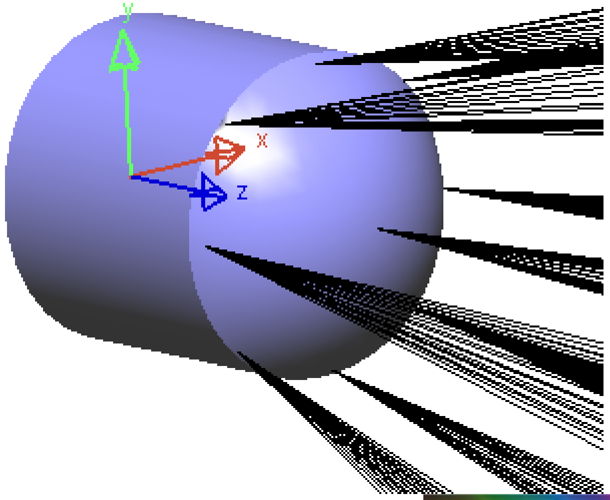

Curved target surface with nonuniform boundary

Pinhole Locations

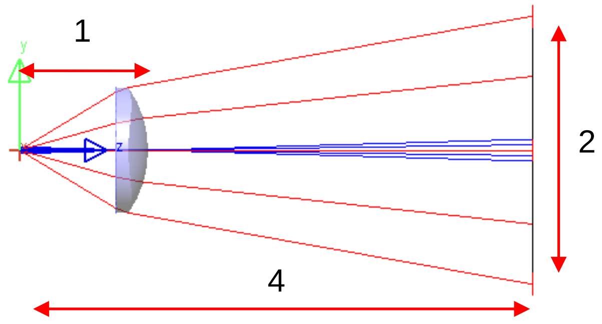
- By default, pinholes are located at the freeform surface and are associated with corners, middle-edges, and center of the target.
  - Each location on target corresponds to a different point on the freeform surface.
  - A list of pinhole locations can be specified using the string parameter ‘PinHoleLocations’



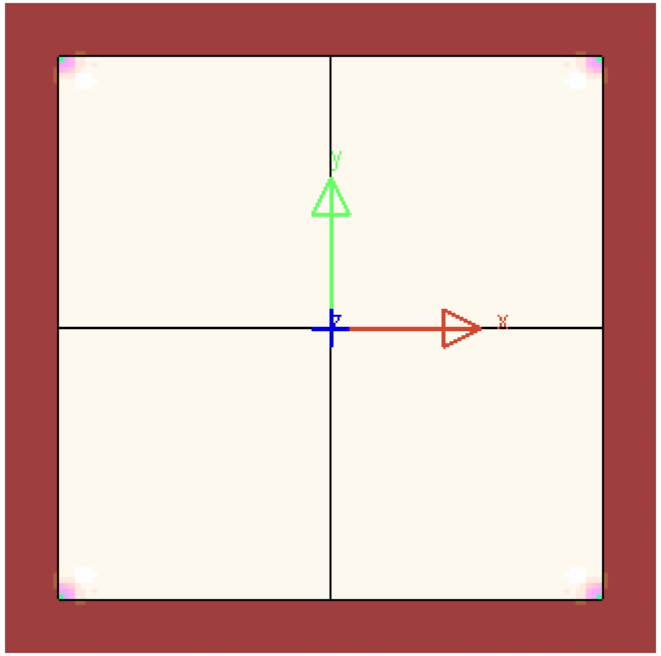
Name	PinHoleLocations
Value	0.25,0.25 0.25,0.75 0.75,0.25 0.75,0.75 0.0,0.0 0.0,0.5 0.0,1.0 0.5,0.0 0.5,0.5 0.5,1.0 1.0,0.0 1.0,0.5 1.0,1.0



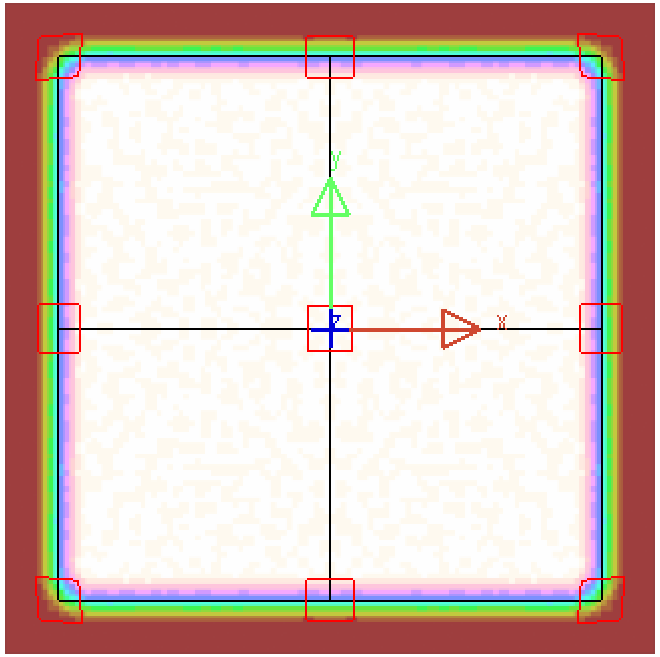
Point Source vs Extended Source



System layout



Illuminance using a
point source

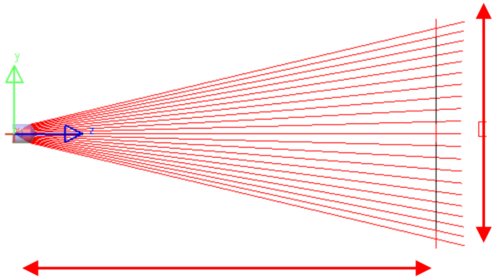


Illuminance using
0.05 x 0.05 source

- For many systems, the first order impact of switching between a point source and an extended source is a blurring of the edges of the beam pattern.
- We can use pinholes images to estimate the size of that blurring. First order estimate
  - Pinhole Image Size ~ Source Size * Pinhole-to-Target / Source-to-Pinhole

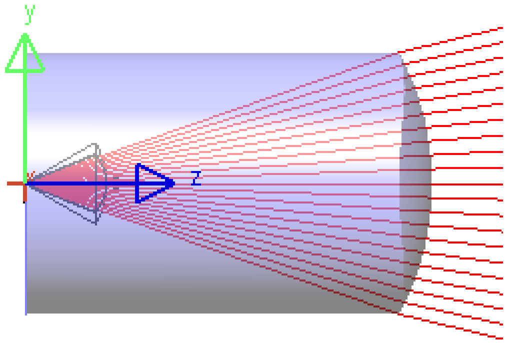
Lens Thickness

- Optical distance between tailored surface and source can be used to control pinhole image size
    - With target far from optic, scaling lens by t results in pinhole images that are scaled by 1/t
- Generally,
    - Larger lens → Smaller Pinhole Images

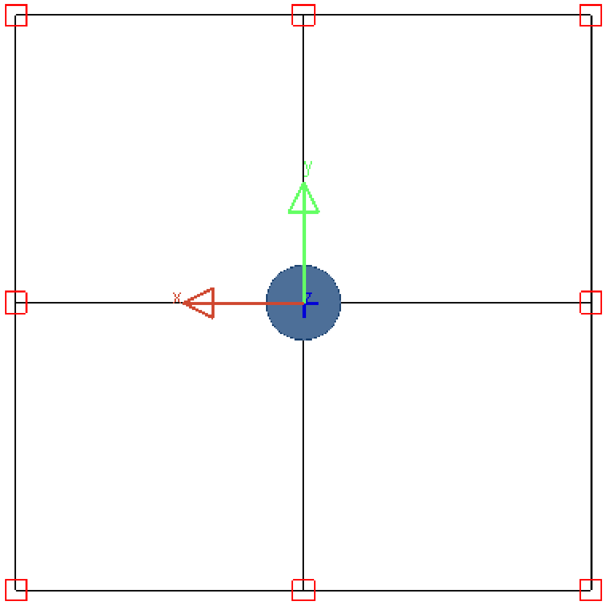


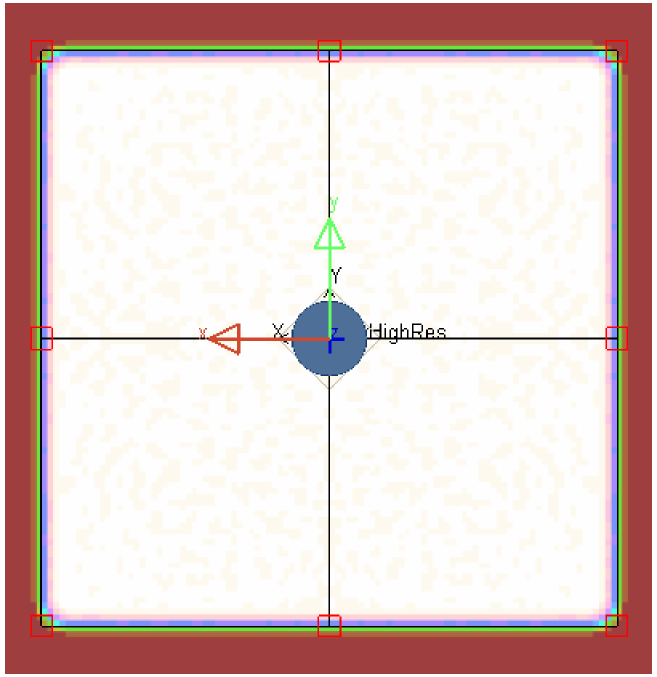
10

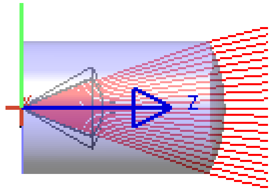
Source to Target = 20



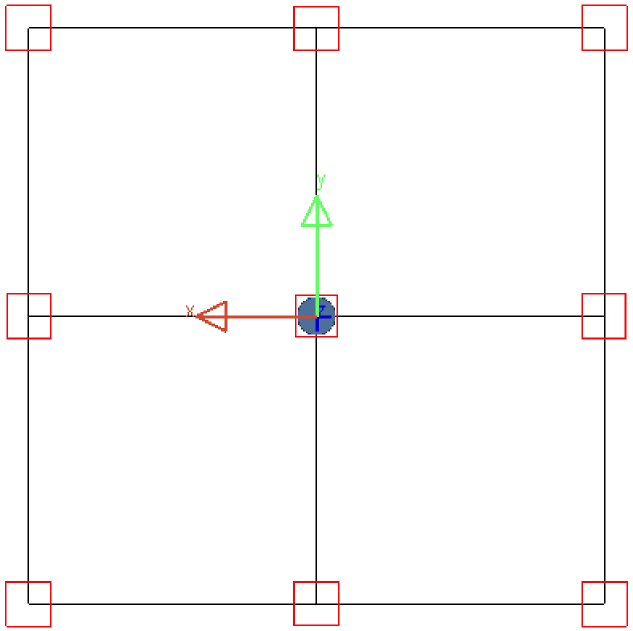
Thickness=2

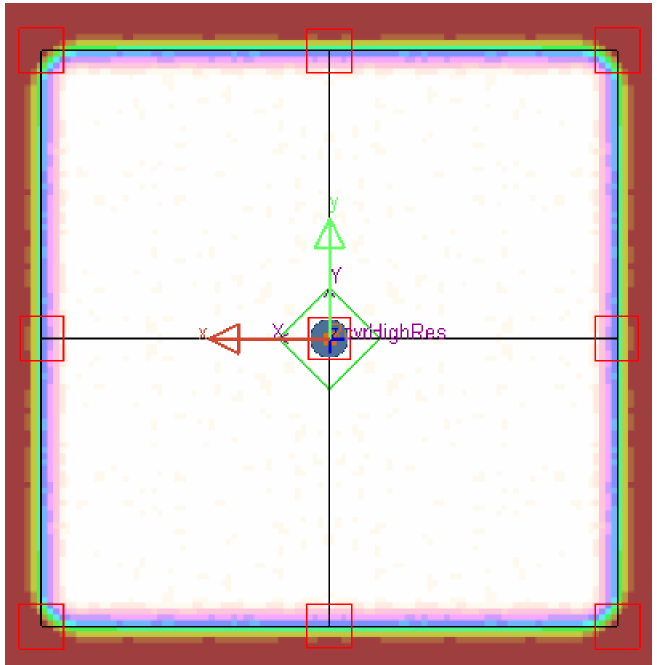






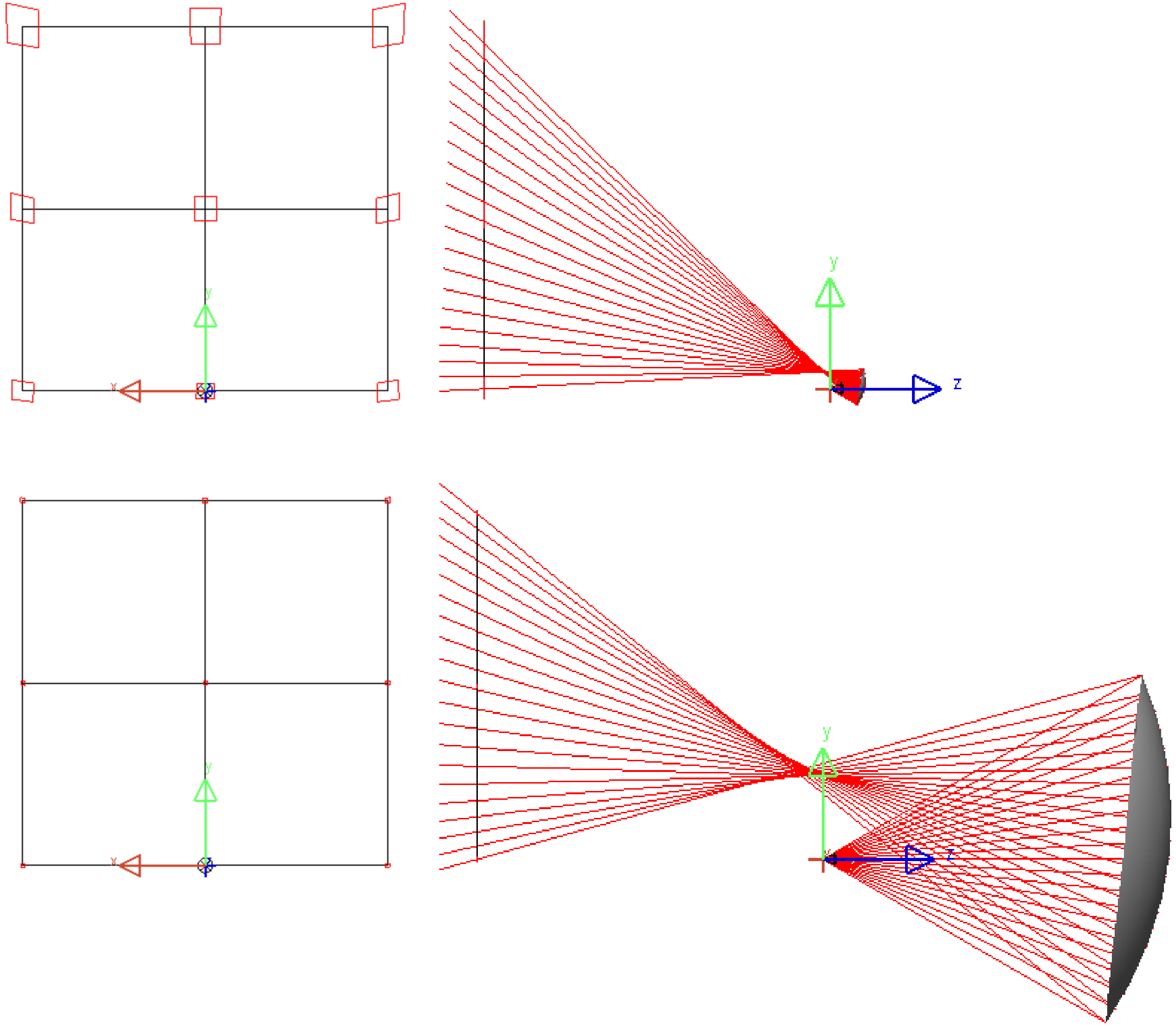
Thickness=1



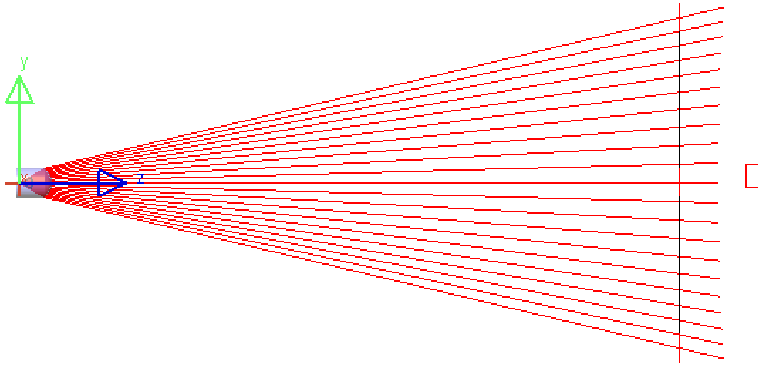


Distance to Freeform surface impacts Pinhole Image Size

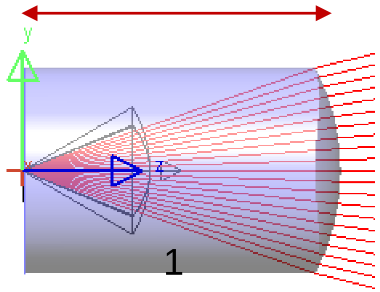
- Similar to lens case, but here we scale the size of the optic by 10X
  - pinhole images are almost negligible compared to the target size.
- Scaling the size of the optic is the most common approach to adjust the amount of edge blurring.



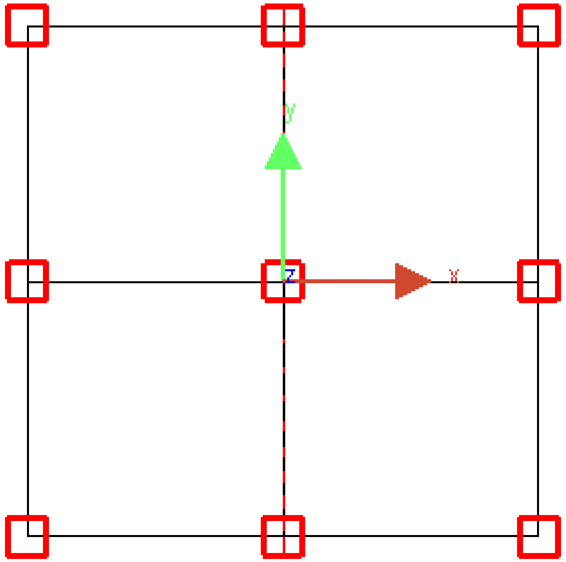
Thick lens nominally results in larger pinhole images.

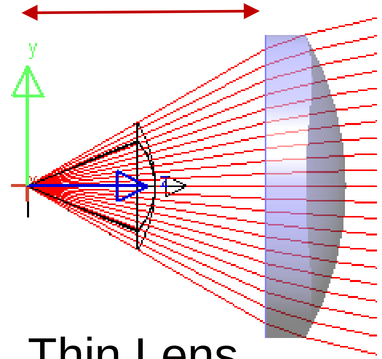


- Central pinhole image size scales by ~ 1/n for Thick vs Thin lens
    - Notice that size of lens also changes.

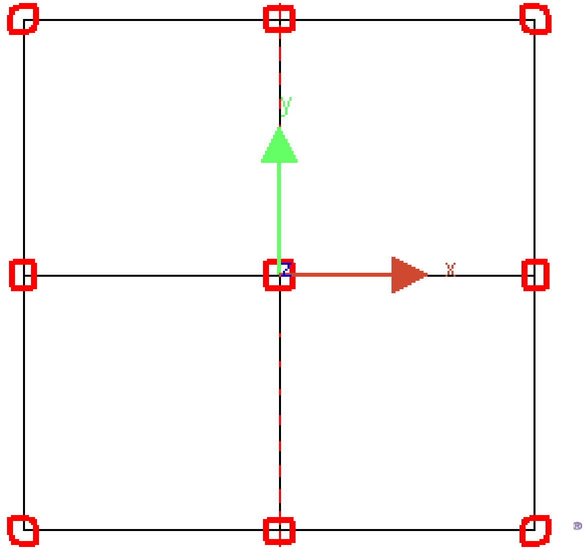


Small gap

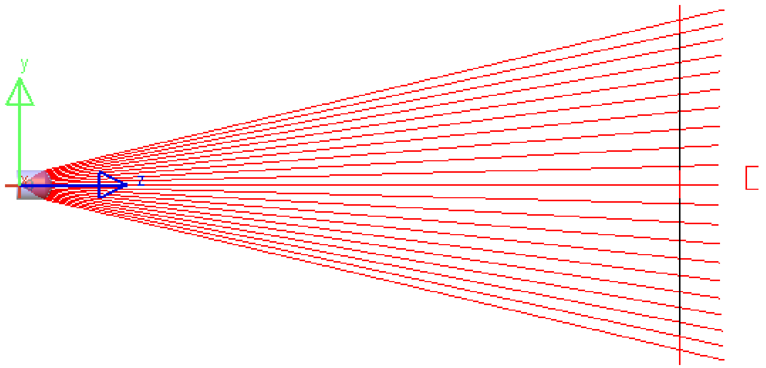


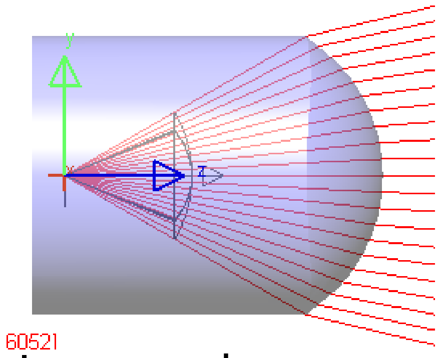


Thin Lens

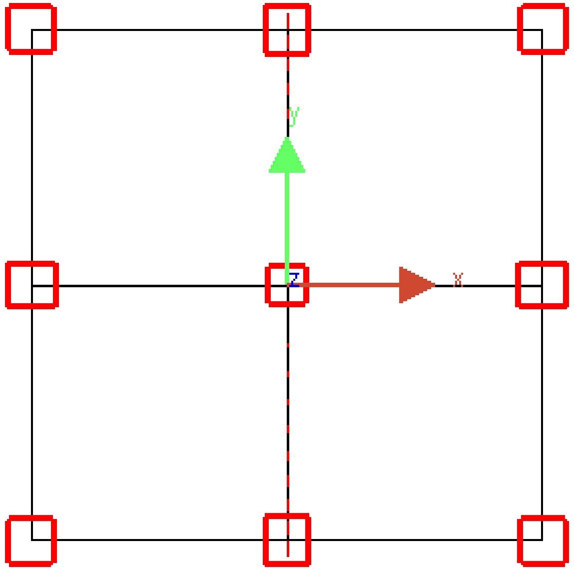


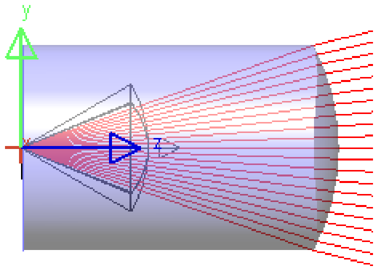
Immersed Source



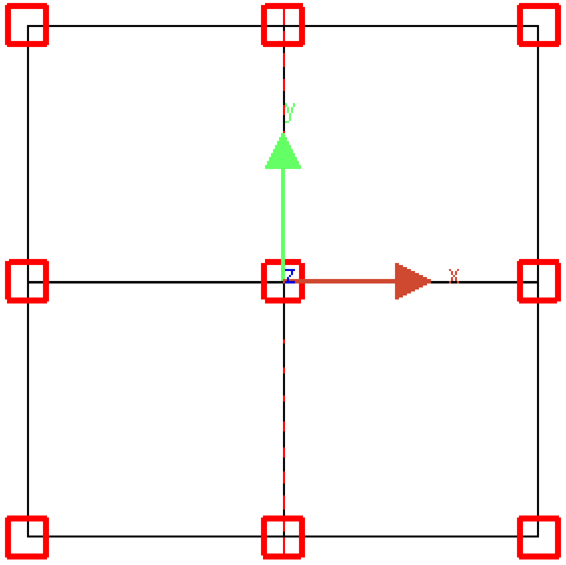


Immersed source





Small gap



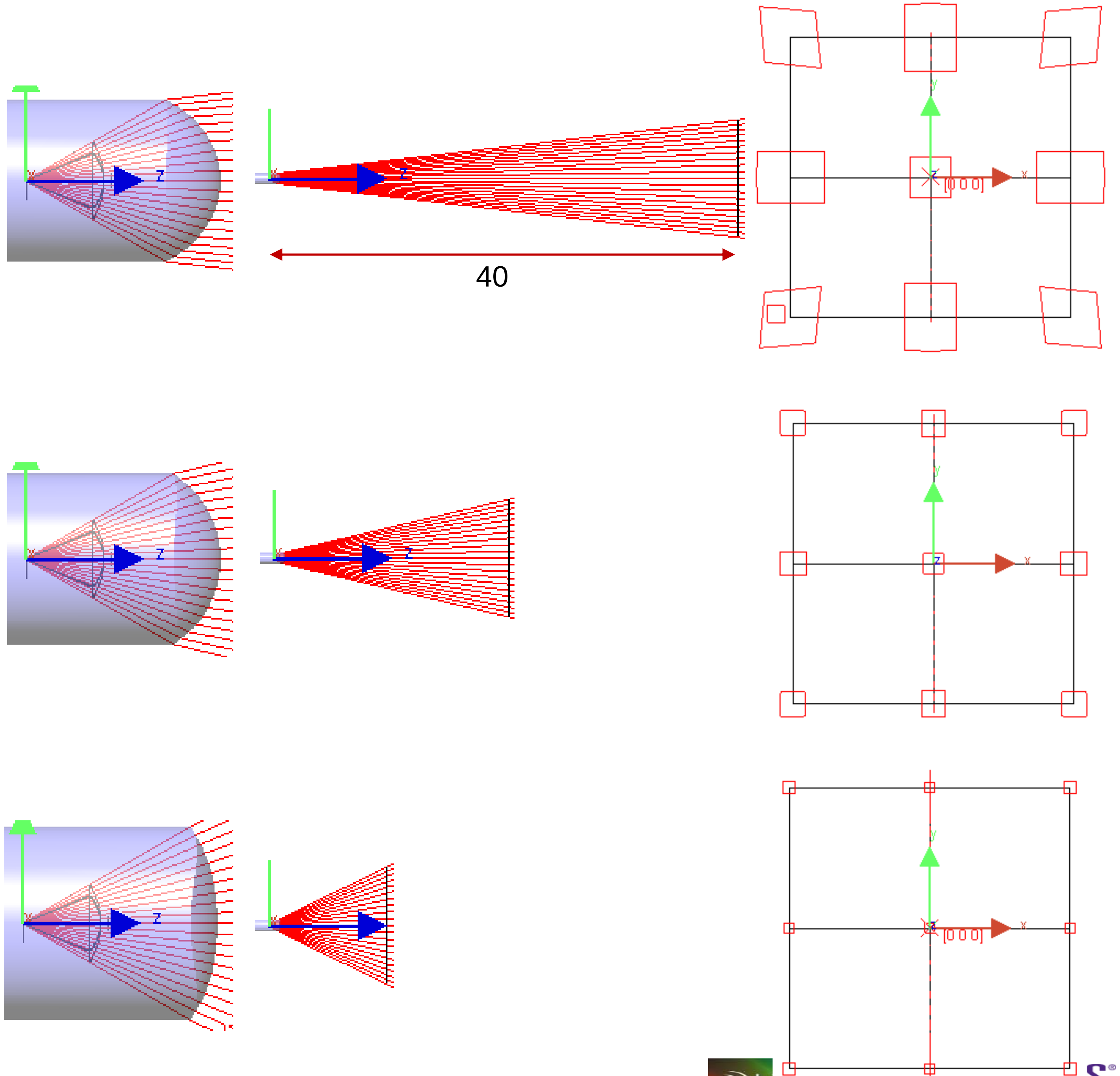
- When source is immersed, as compared to a small gap between source and first surface of lens, the on-axis image size is the same.

- Edge images change slightly, as does the size of the optic.

Distance to Target

- Pinhole Image Size generally gets larger as the same size target is moved farther away from the optic.
- This example uses a 0.025 x 0.025 source immersed in a 1mm thick optic.
  - Target is 10x10
  - Lens is recomputed for each target distance.

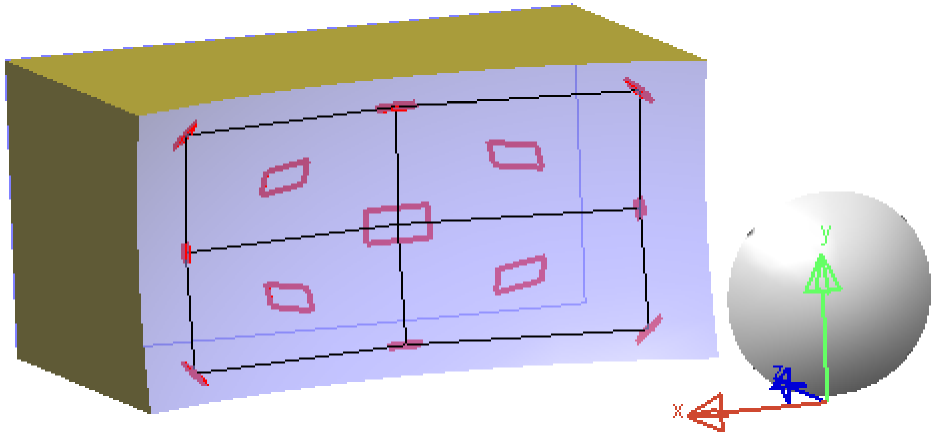
- If we scaled target size and target distance together, then pinhole image size would scale with the target…

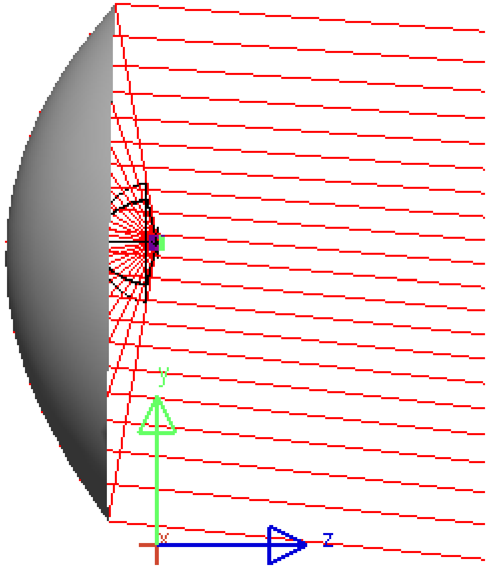


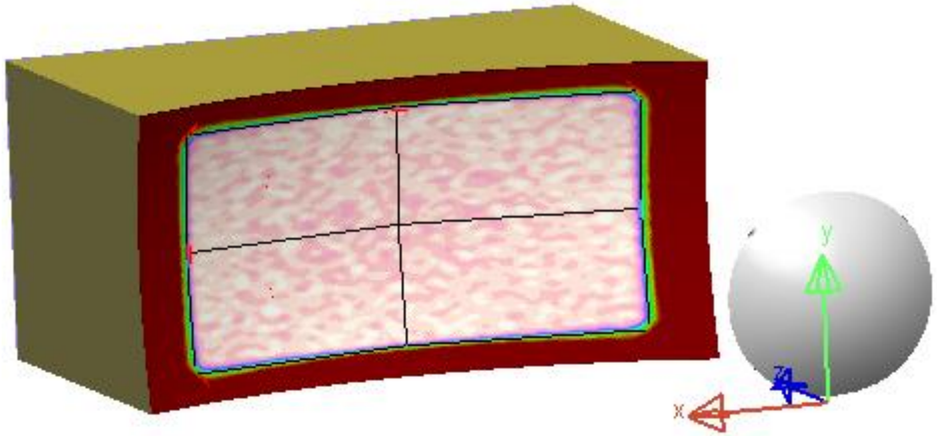
Interesting Observation Examples

Image size of Planar Lambertian source can vary significantly.

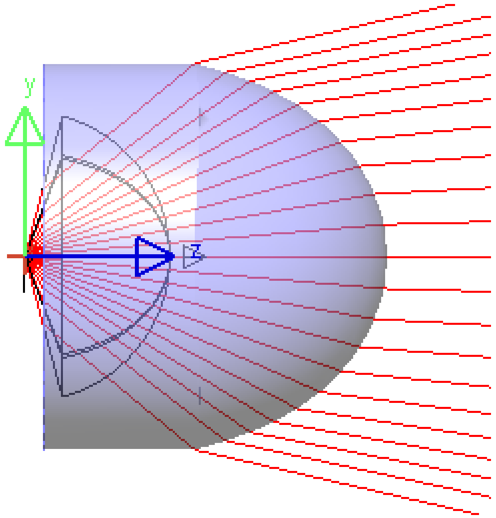
- With large collection angles, pinhole image near edge can be small.
  - Source looks like skinny rectangle instead of square.
- This can provide ‘sharp’ edges in the target distribution.



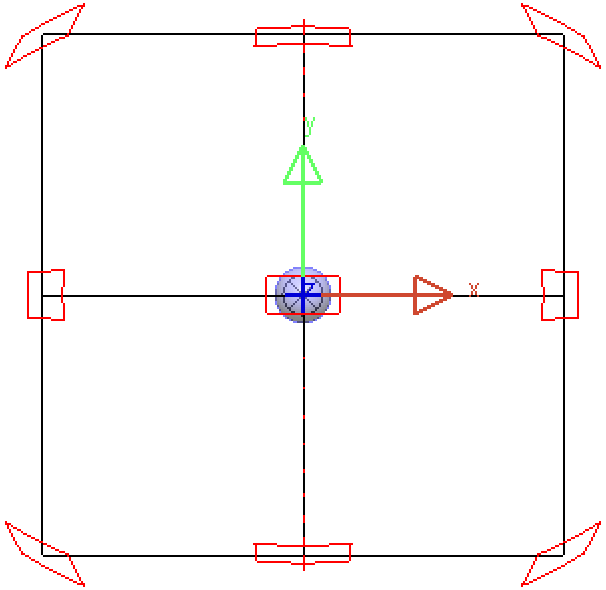




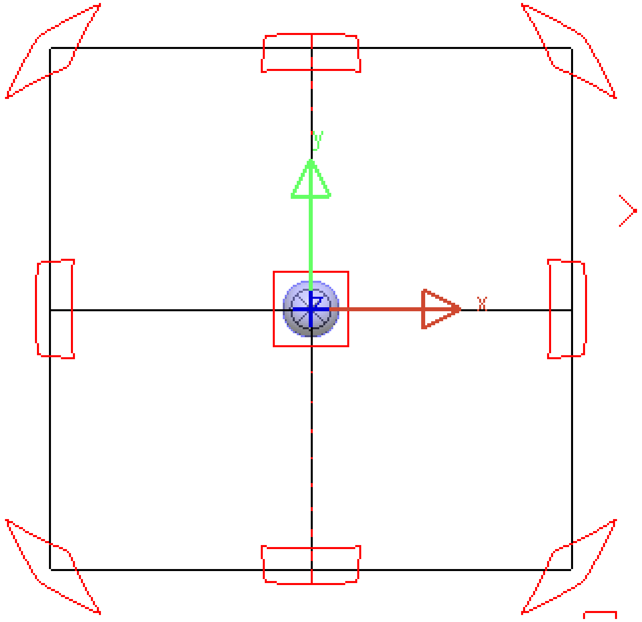
Asymmetric Source



Rectangular Source
0.05 x 0.025 Source



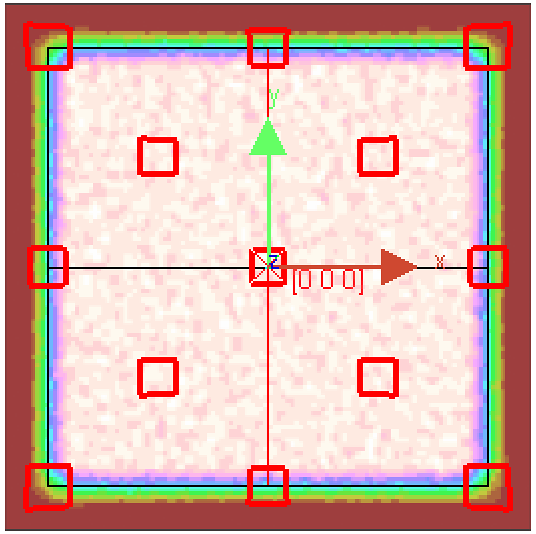
Square Source
0.05 x 0.05 Source

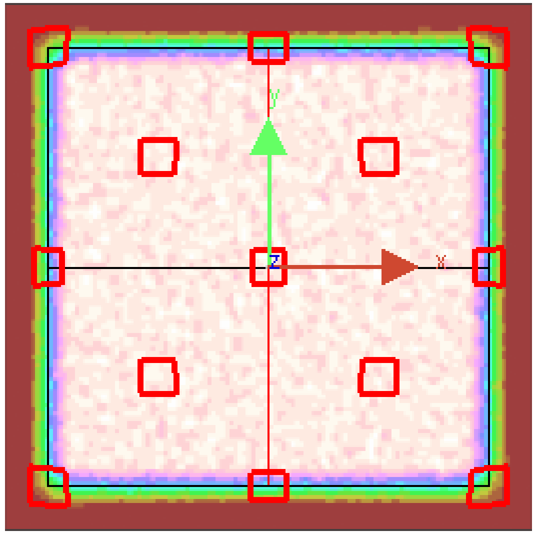


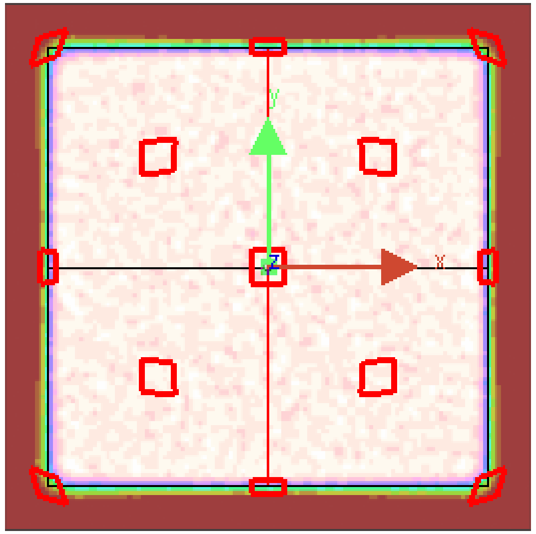
- Notice the on-axis pinhole outline matches the source aspect ratio
- Higher angles can have an asymmetric magnification relative to on-axis source size
  - Square source can result in rectangular images
  - Rectangular source can result in square images.

Increasing Collection Efficiency -- Reflector

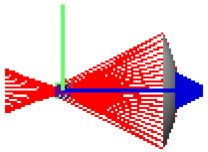
- Source Half Angles of 30, 45, 60



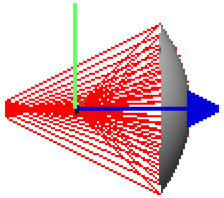




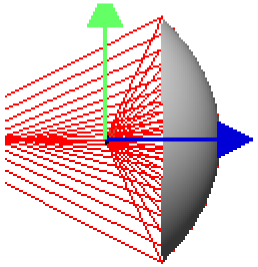
+/- 30



+/- 45



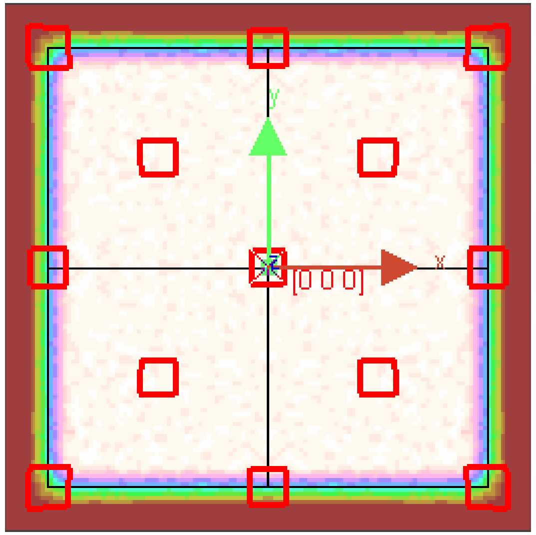
+/- 60

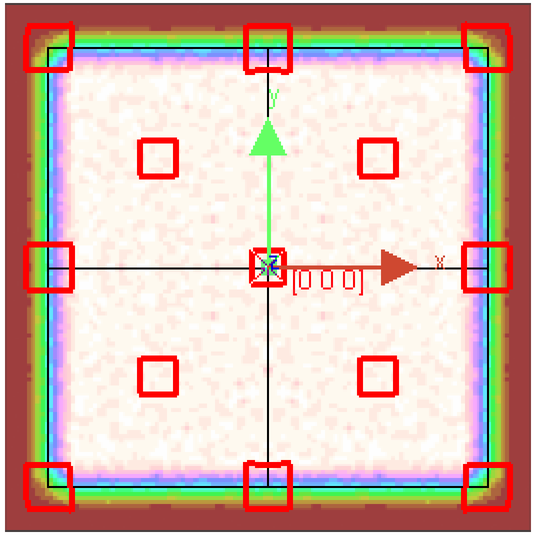


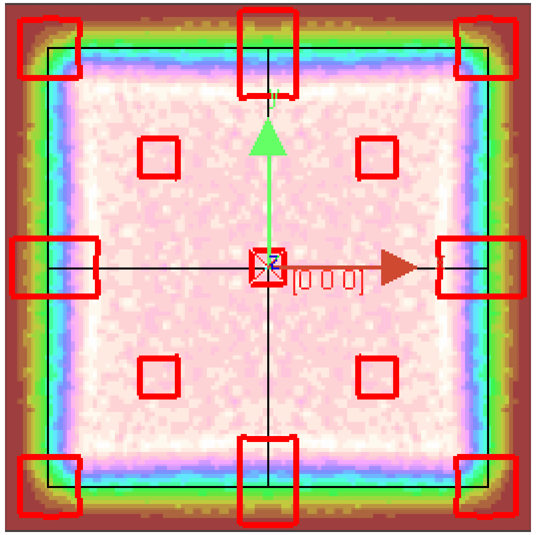
When reflector views square source from high angles, the source can look like a rectangle

Increasing Collection Efficiency -- Lens

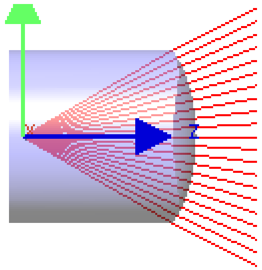
- Same Source Half Angles as Reflector case (30, 45, 60)



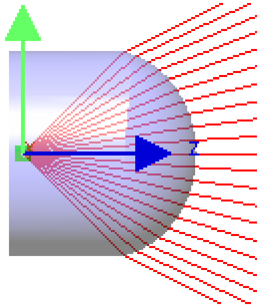




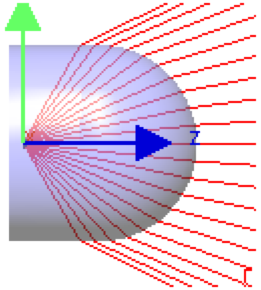
+/- 30



+/- 45

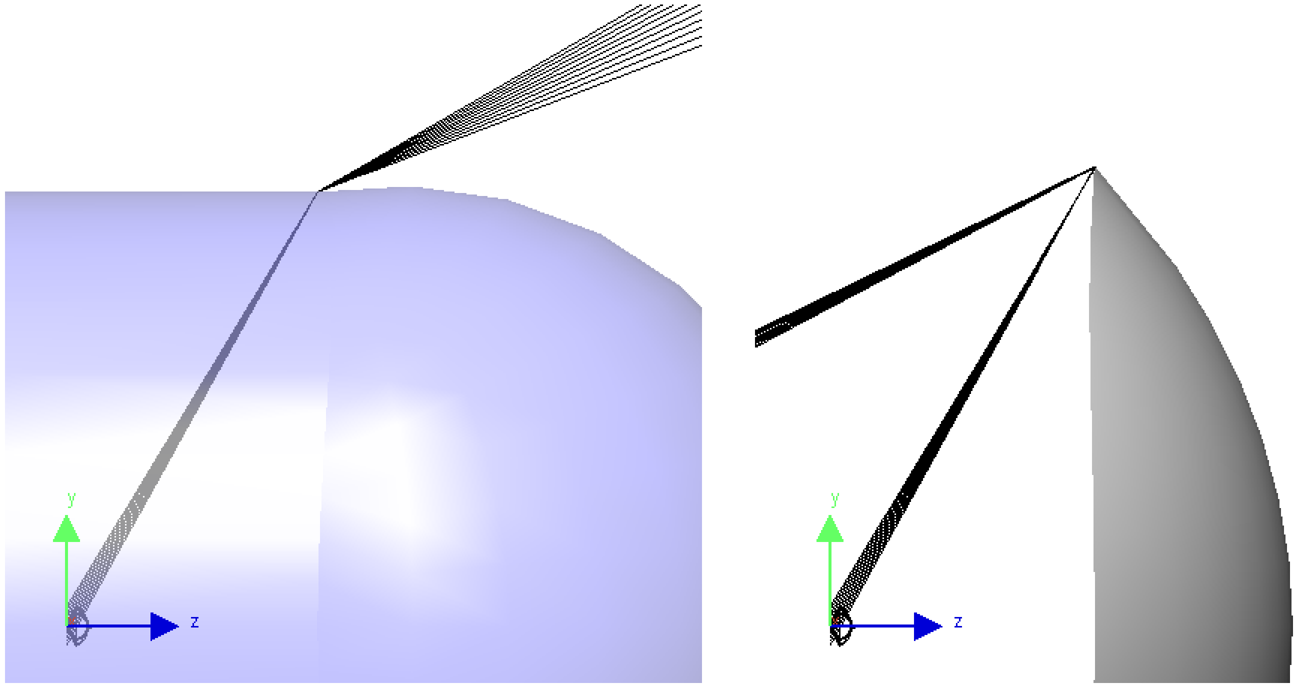


+/- 60

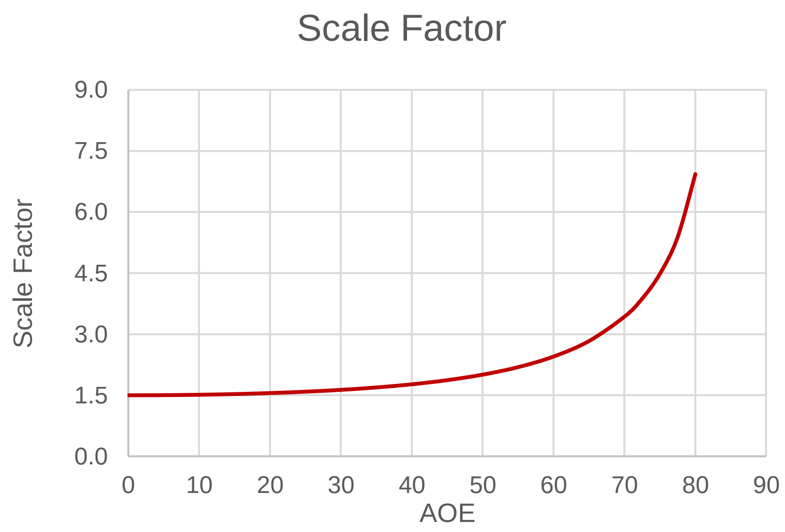


Unlike reflector case, edge pinhole images increase as collection angle increases

Refractive vs Reflective

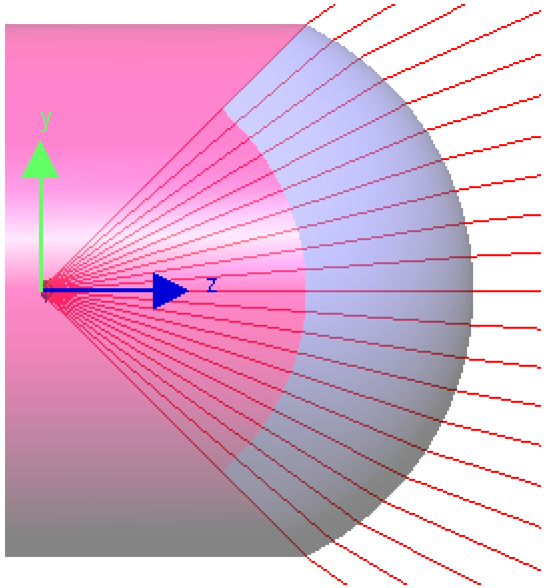


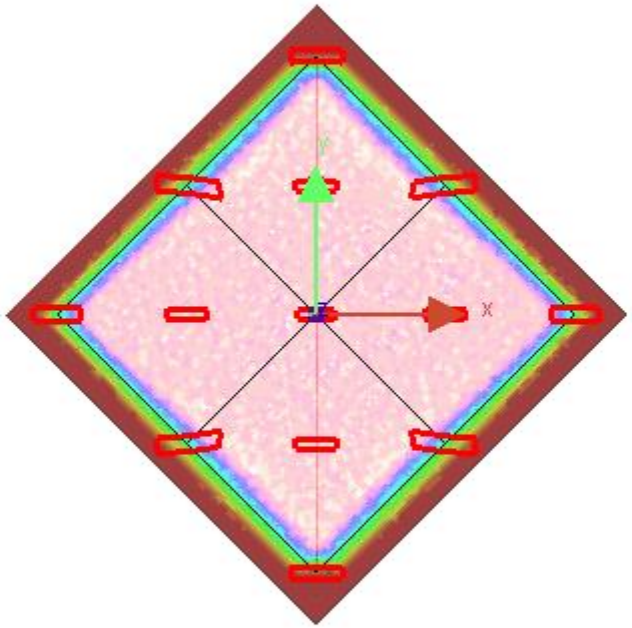
- Two factors dominate
  - Projected source size
    - Planar source
  - Angle scale factor
- At large collection angles, cosine factor makes planar source look smaller.
- In reflective case, angle scale factor is 1
- In refractive case, the non linearity of Snell's law comes into play and cone angle scale factor varies with AOE.
  - If AOE=0, then cone angle scale factor is n
  - The cone angle scale factor increases at larger AOE
    - Sin(AOE)=n*Sin(AOI)

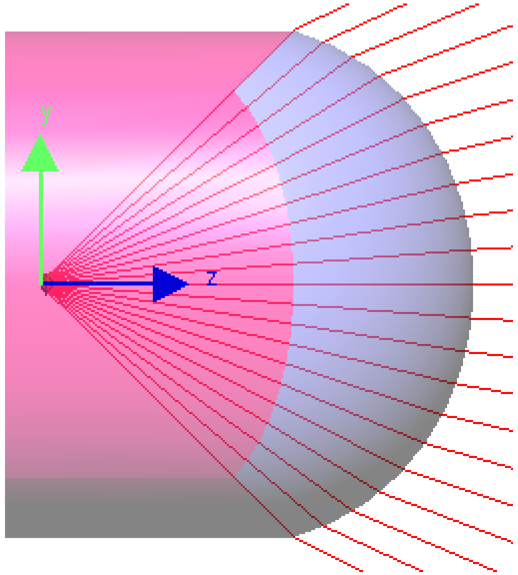


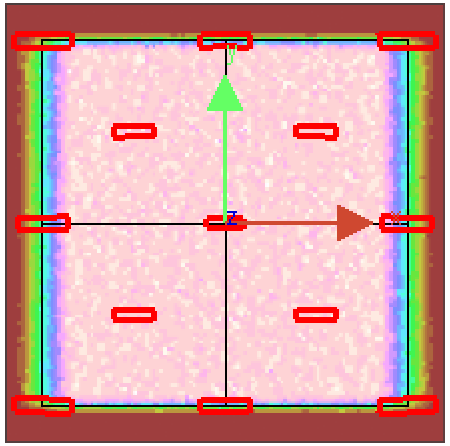
Source Orientation

- Square-to-Diamond vs Square-to-Square car be used to adjust whether edge smearing occurs along all edges or preferentially along different edges.



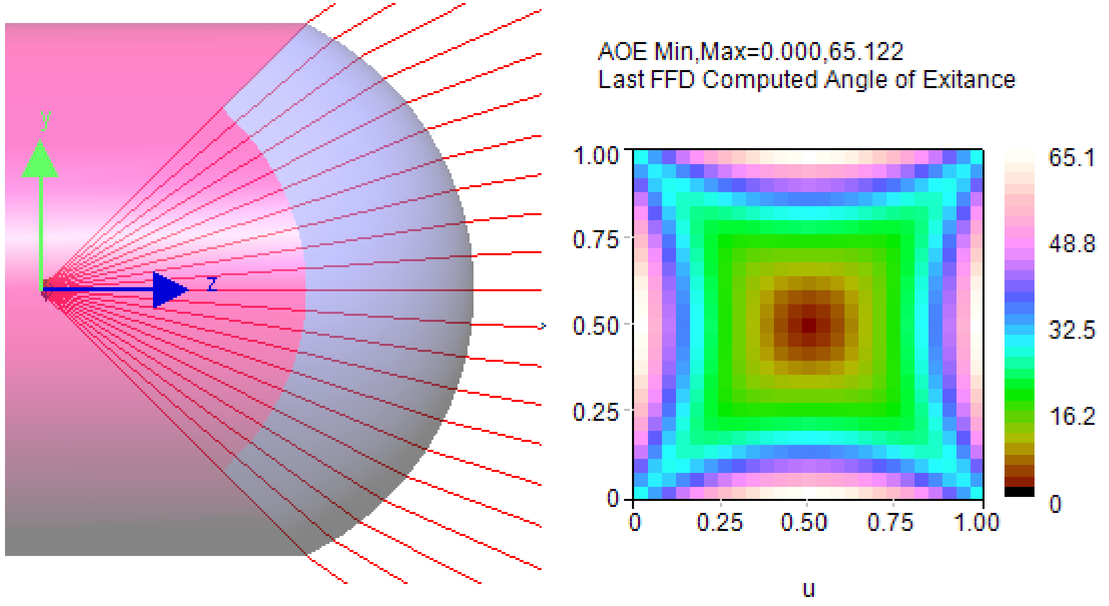


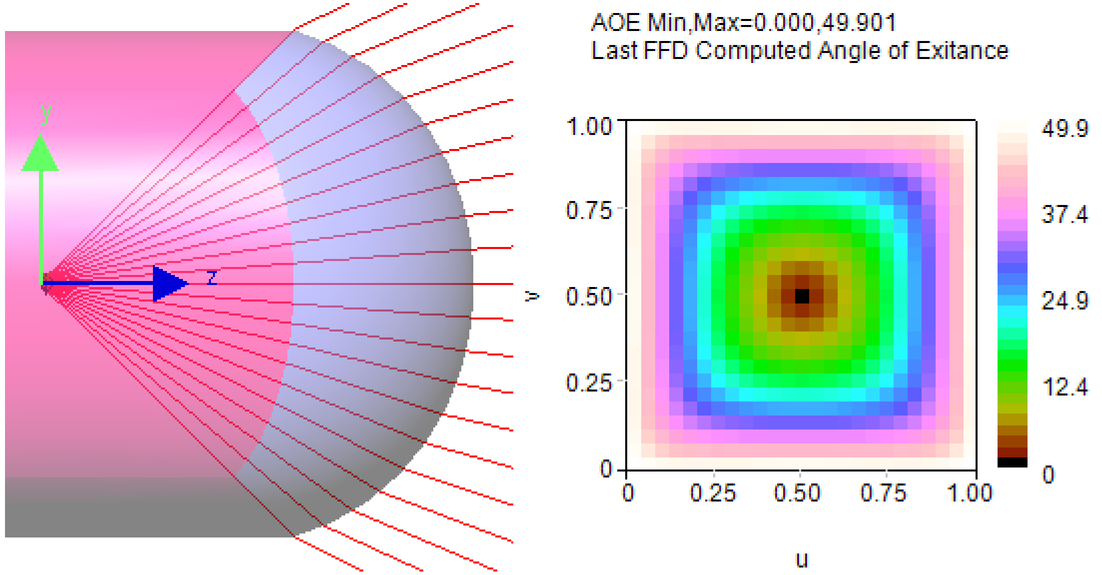




Rotated Target - AOE

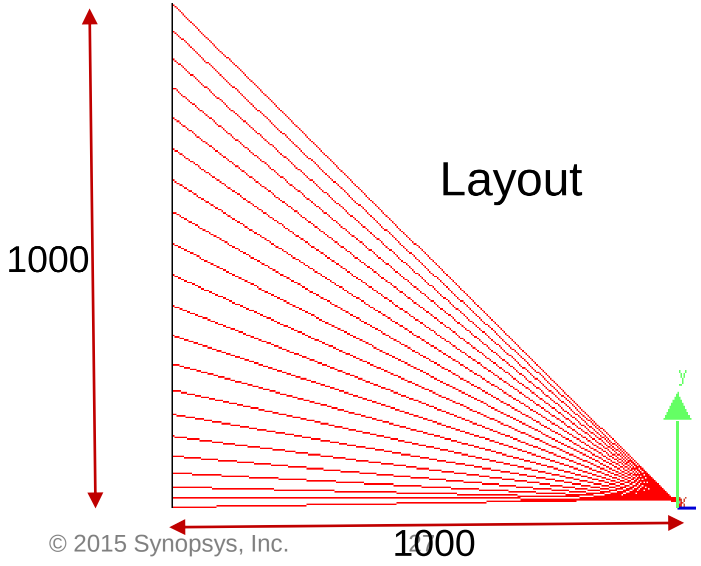
- Angle of Exitance (AOE) is a measure of how much bending power is required to direct ligh from the source to the target.
  - AOE=90 means ray is skimming the surface and is very near TIR
  - Large AOE corresponds to high Fresnel Loss
- Peak AOE is higher for square to diamond compared to square to square.

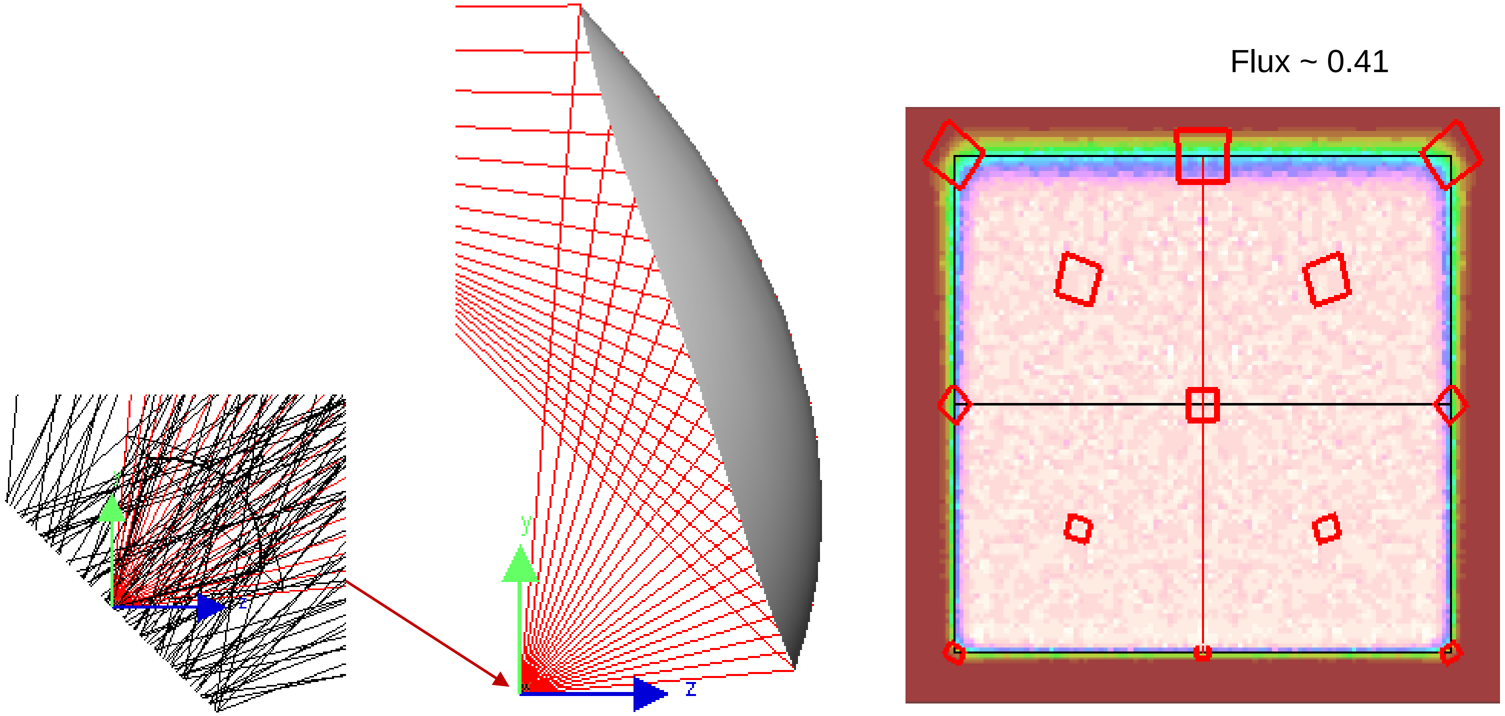


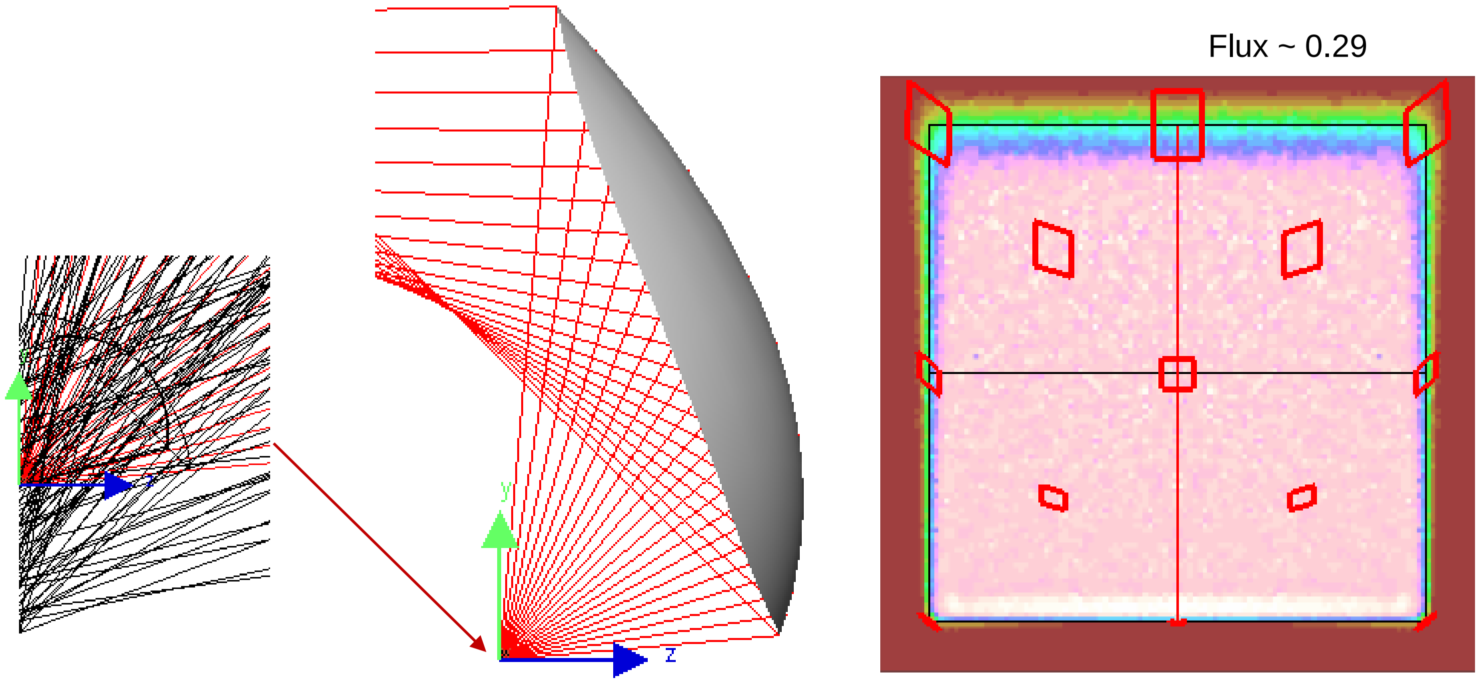


Tilting Source

- Tilting the source can sometimes help control edge smearing
  - 0.5 X 0.5 Lambertian source
  - Collect +/-40 degree cone oriented 45 degrees from Z.
    - Can orient source oriented at 45 degree or parallel to Z
- Mounting tilted LEDs is sometimes more difficult than untilted, but it can have benefits...

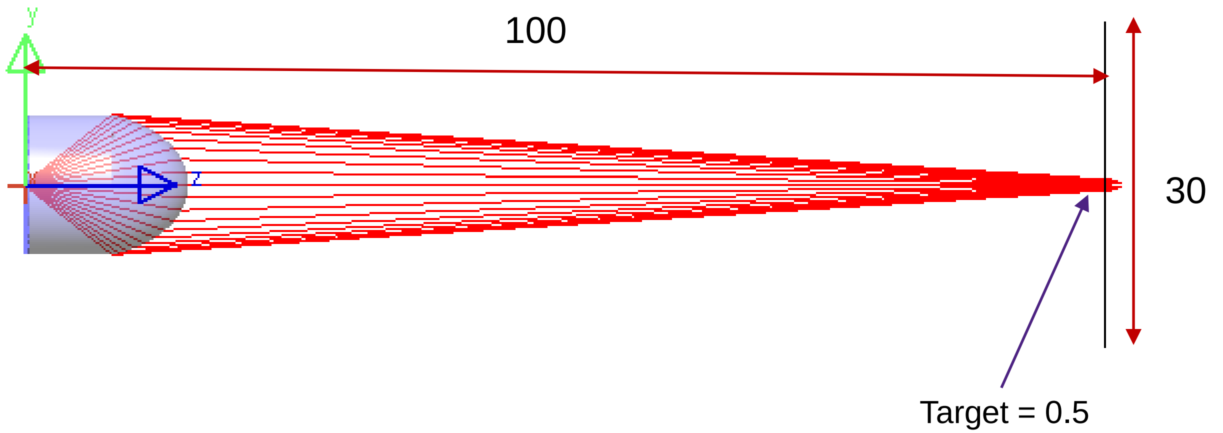


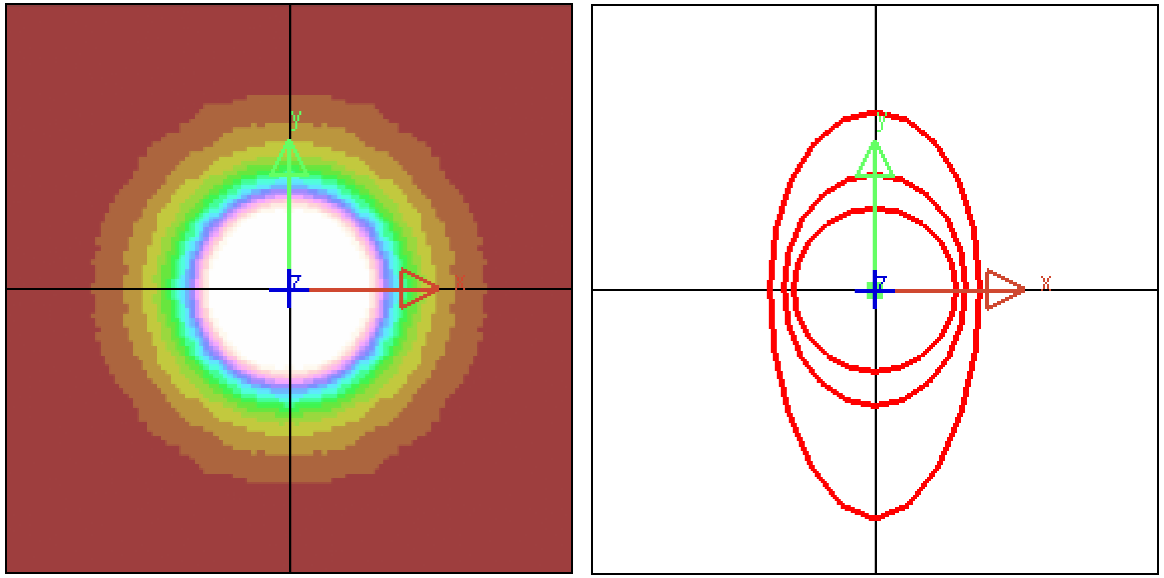




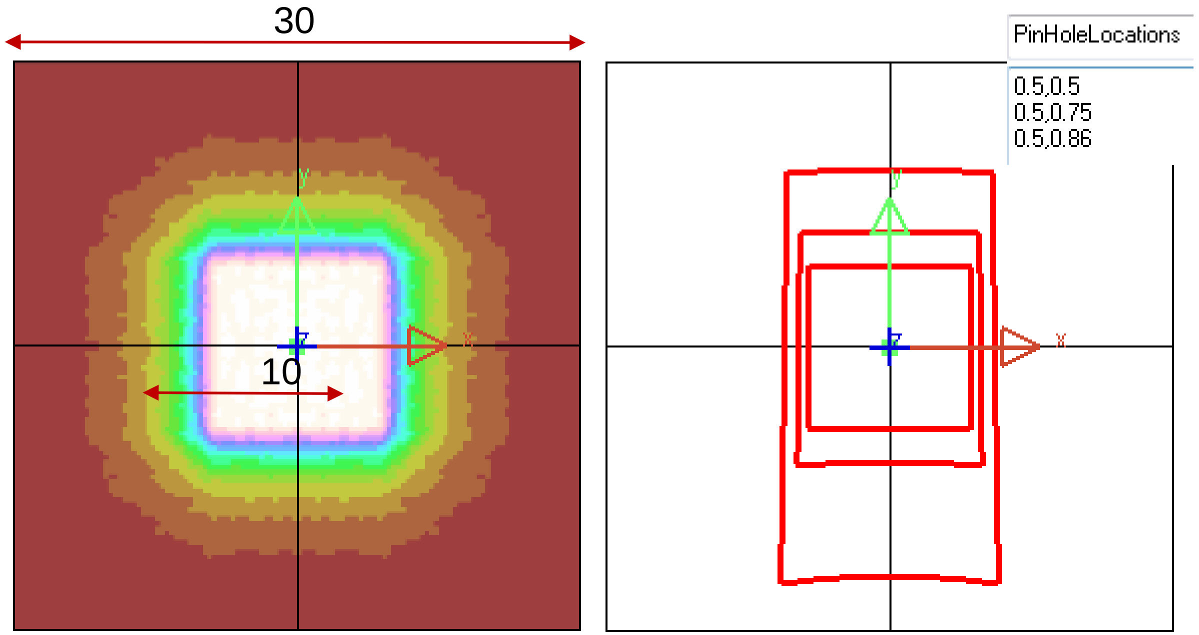
Large Source

- When target size is small compared to pinhole images, typical result is a blurred ‘image’ of the source
- Consider case where we *try to* collect +/-70 degree cone with 1X1 source into a 1X1 target that is 100 units away from a 12mm lens
  - Source Etendue = $1*1*\sin^2(70) \sim 0.88$ mm^2-st
  - Targe Etendue = $.5*.5*\sin^2(4) \sim 0.0012$ mm^2-st
  - Physics does not like to break its rules…





1mm Diameter Circular Source



1mm x 1mm Square Source

Summary

Summary

- Pinhole image outlines provide a quick diagnostic
  - Numerous examples used to illustrate the edge smearing that occurs with single surface tailored surfaces
- Pinhole images quickly identify systems where distribution from a point source solution is dominated by the source size.
- For planar sources
  - Reflectors generally show a decrease in the edge pinhole image size because of cosine factor
  - With lenses, nonlinearity of Snell’s law can offset the cosine factor and result in an increase in edge pinhole image size
- Pinhole images can be used in many systems, including those with multiple surfaces

Thank you for your attention!
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