DLP Lens Correction

PHY 432 Final Project

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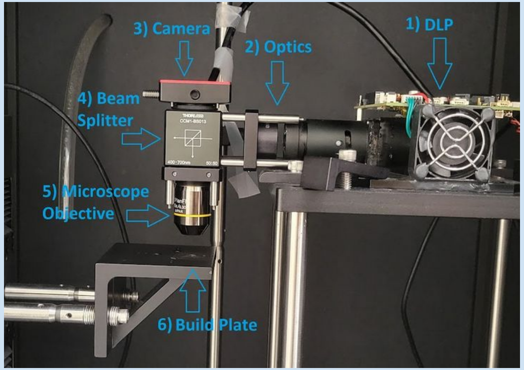
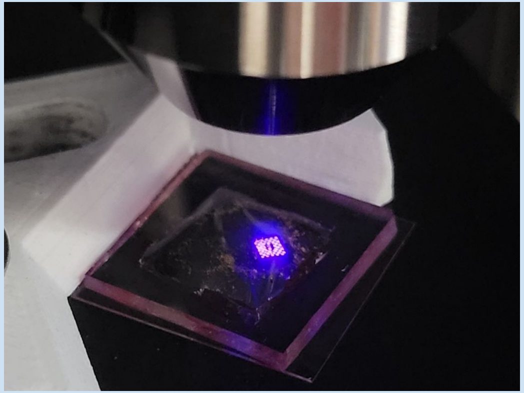
https://github.com/Py4Phy/final-2023-dlp_lens_correction

Background
Motivation

Photo-chemically Induced, Polymer-Assisted Deposition (PIPAD) is a form of additive manufacturing (3D printing) which is currently being used to print nanometer-thin micrometer-wide metallic structures.

This requires focusing optics from a Digital Light Projector (DLP) to display an image onto a substrate for printing.



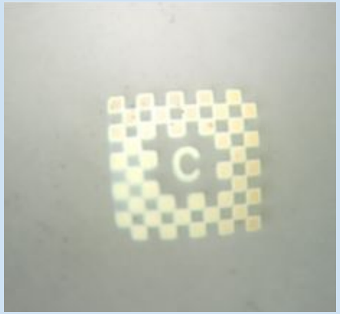


Background

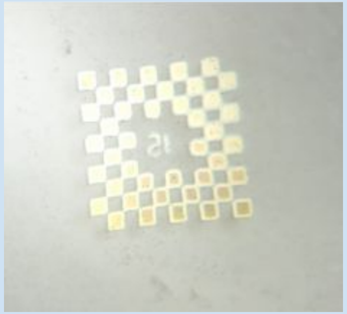
Motivation

The current problem that has arisen from this method is the radial distortion of the printed design caused by the lenses.

Python-script based image correction

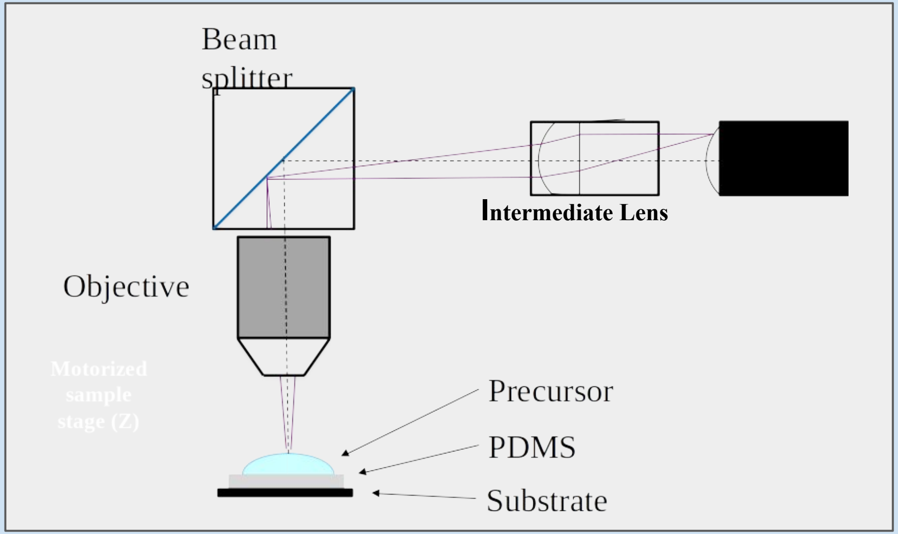


Distortion from passing through the optical elements.



Background
Motivation

Primary source of distortion comes from the AC254-030-AB-ML Lens Doublet from Thorlabs, shown as "Intermediate Lens"



Background

Objectives

1. Computationally model radial distortion of a rectangular image as it passes through a circular lens. Display the design before and after distortion.

2. Display the resulting images based on the different wavelengths of light, specifically 365 nm, 405 nm, and 436 nm.

3. Determine the theoretical magnification of the image due to the optical elements.

4. (Optional stretch goal) Construct a transformation matrix to correct lens distortion.

5. (Optional stretch goal) Construct a ray tracing diagram for the entire model.

Methods

Setup

To make the calculations we established some assumptions:

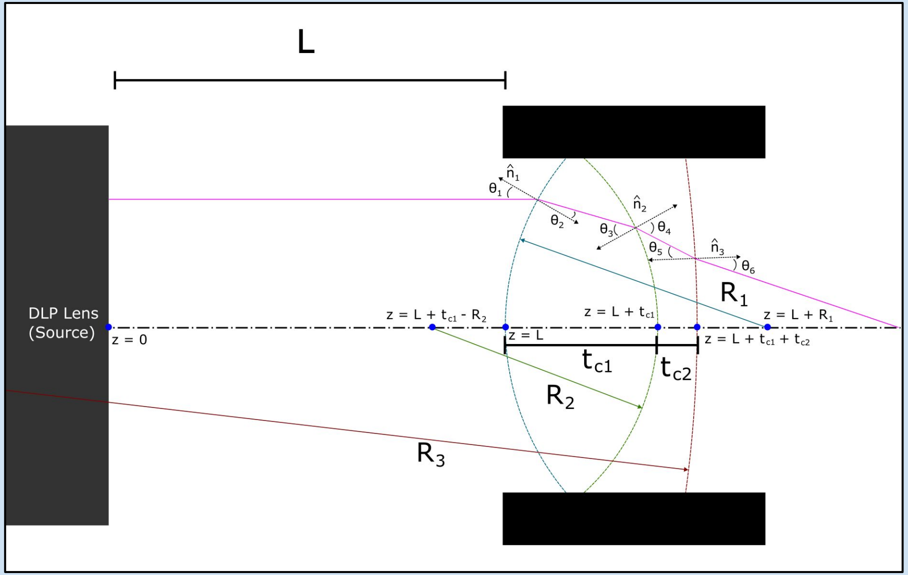
1. The lenses were thin lenses
2. The light source is collimated
3. The light source has infinite power
4. Each pixel was infinitesimally small and in the center of each DMD mirror

Methods

Setup

For our code we needed the following modules:

- OpenCV - to import the image and take pixel values as colors
- Numpy - to hold pixel location data in 2D arrays
- Matplotlib - for visual representation of data and error identification



Methods

Setup

- Import the image to create two arrays, one for the index of the pixel positions and another for the color at each pixel

```
DMD = np.zeros([columns, rows, 2], dtype=np.float64)
colors = np.zeros([columns, rows, 3], dtype=object)
x, y = 0, 0
for x in range(columns):

    xloc = x0 + x*px

    for y in range(rows):
        color = image[x, y, :]
        if y%2 != 0:
            # if y is odd
            xloc = 2*x0 + x*px
            yloc = y0 + y*y0
        else:
            # if y is even
            yloc = y0 + y*y0
            xloc = x0 + x*px

        DMD[x, y] = (xloc, yloc)
        colors[x,y,:] = color
```

- Using the known geometry of the digital micromirror device (DMD), the physical positions for each pixel were determined for the input array at (x,y,0)

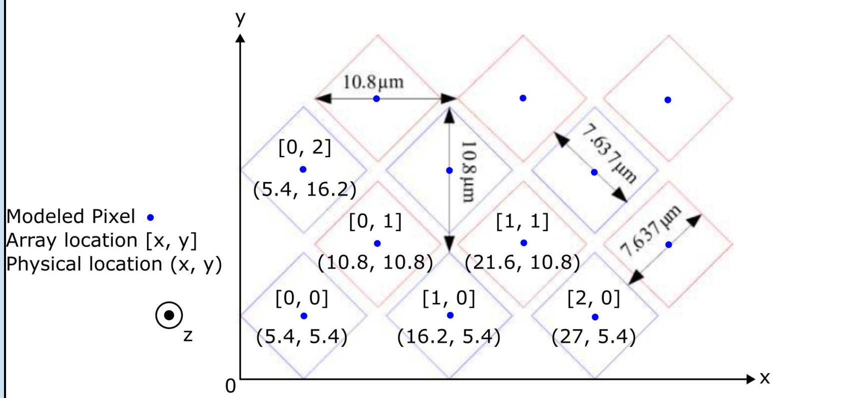


Figure 1-3. 0.45-Inch DMD Diamond Pixel Geometry

Methods

Equations

To solve these problems we primarily used the following equations:

$$\text{Snells Law:} \quad n_1 \sin(\theta_1) = n_2 \sin(\theta_2) \tag{1}$$

$$\text{magnification from a thin lens:} \quad m = -\frac{d_i}{d_o} = \frac{h_i}{h_o} \tag{2}$$

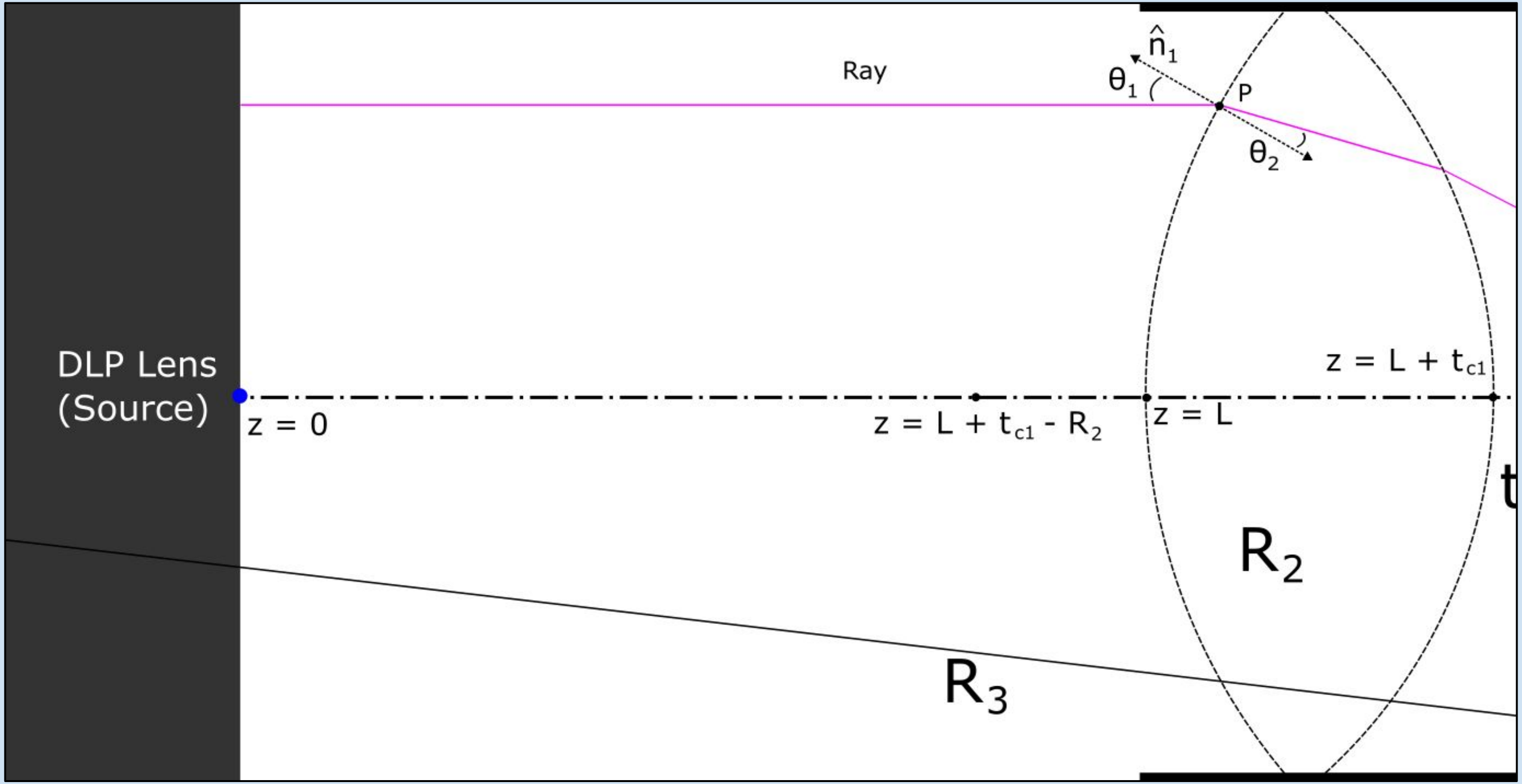
$$\text{barrel-pincushion distortion equation:} \quad r_u = r_d(1 + k{r_d}^2) \tag{3}$$

$$\text{Law of Sines:} \quad \frac{\sin(a)}{A} = \frac{\sin b}{B} = \frac{\sin(c)}{C} \tag{4}$$

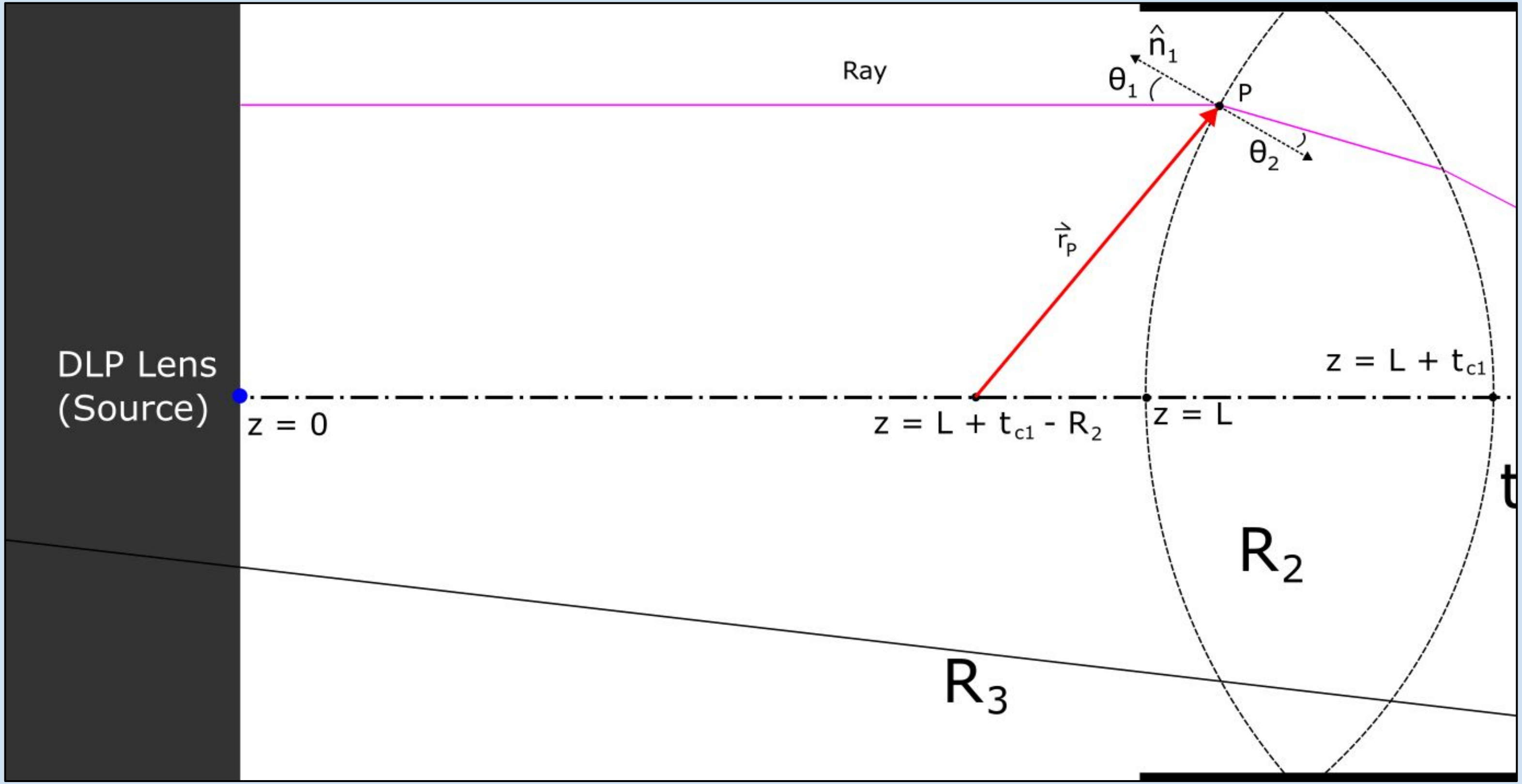
$$\text{normal vector:} \quad \hat{n} = \frac{\nabla F}{||\nabla F||} \tag{5}$$

$$\text{equation of a circle:} \quad R^2 = (x - x_o)^2 + (y - y_o)^2 + (z - z_o)^2 \tag{6}$$

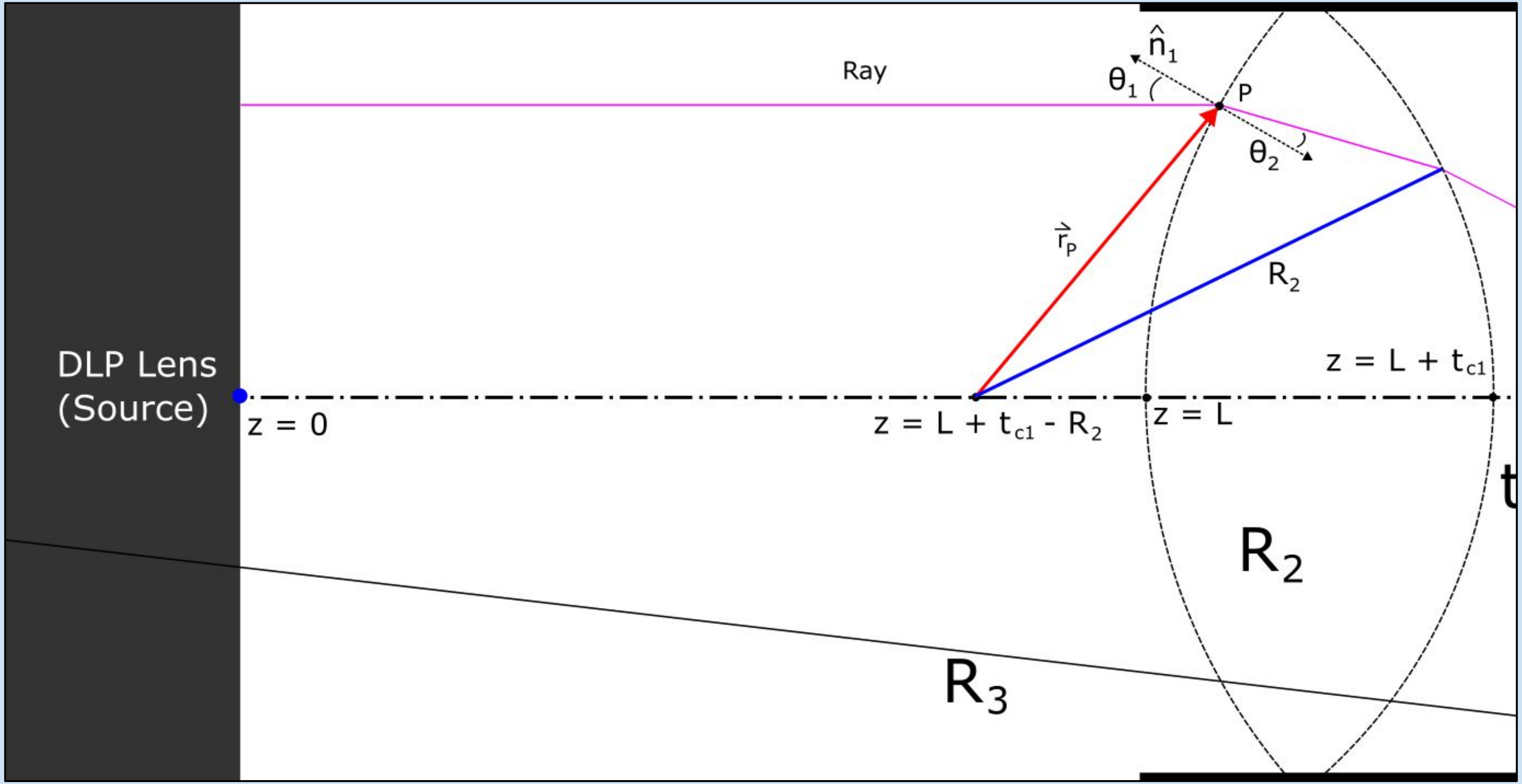
Simulating the Refraction - Step 1



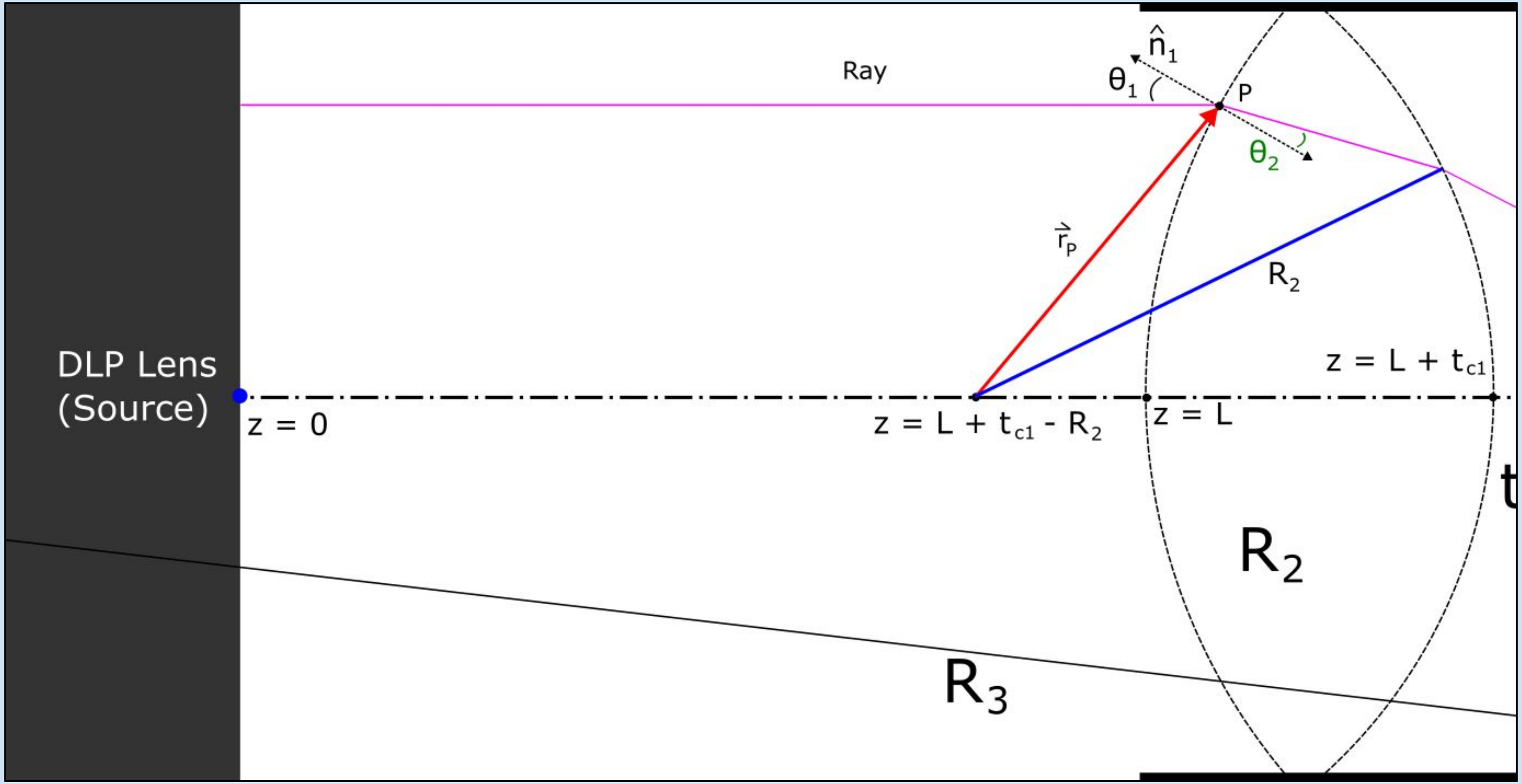
Simulating the Refraction - Step 2



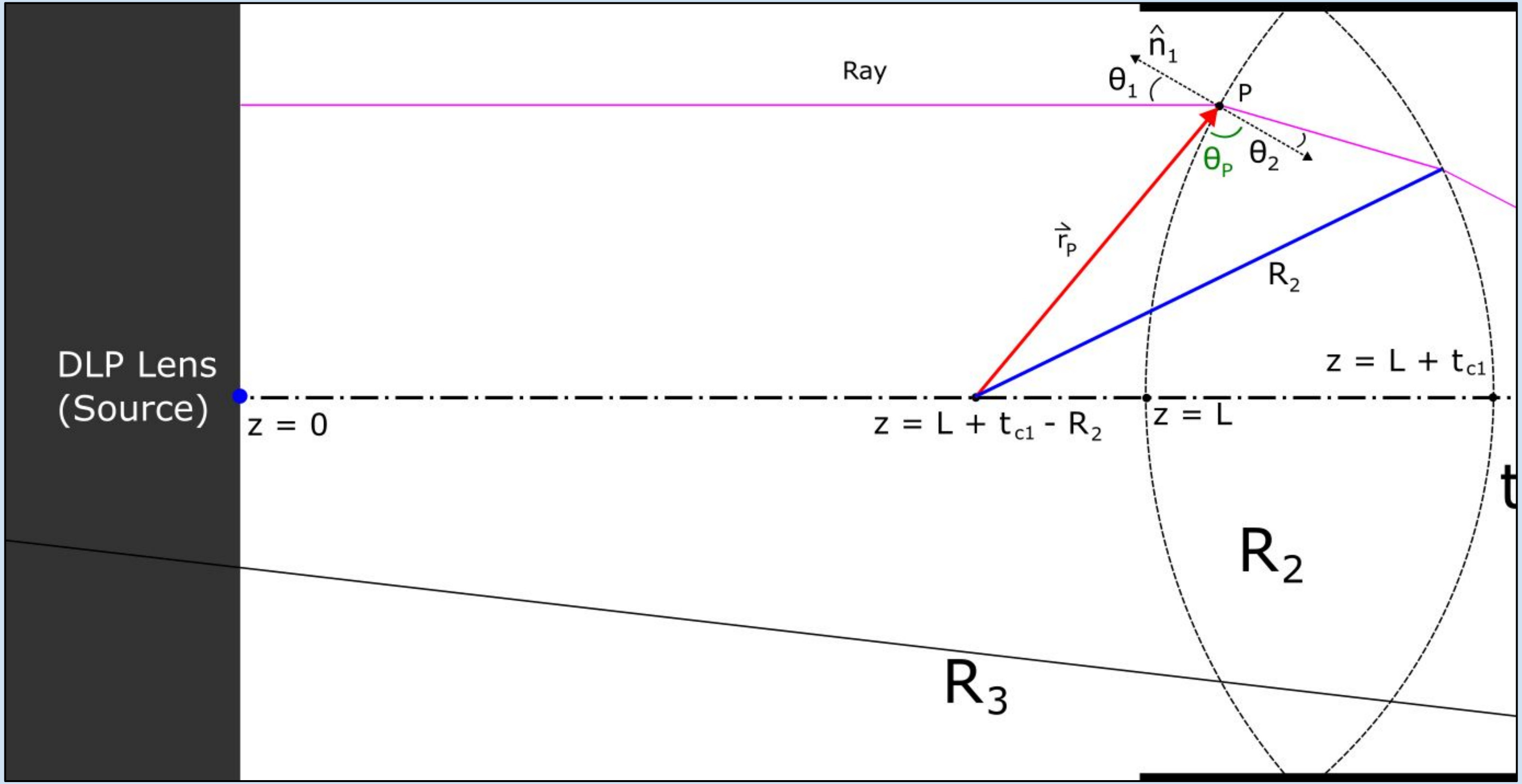
Simulating the Refraction - Step 3



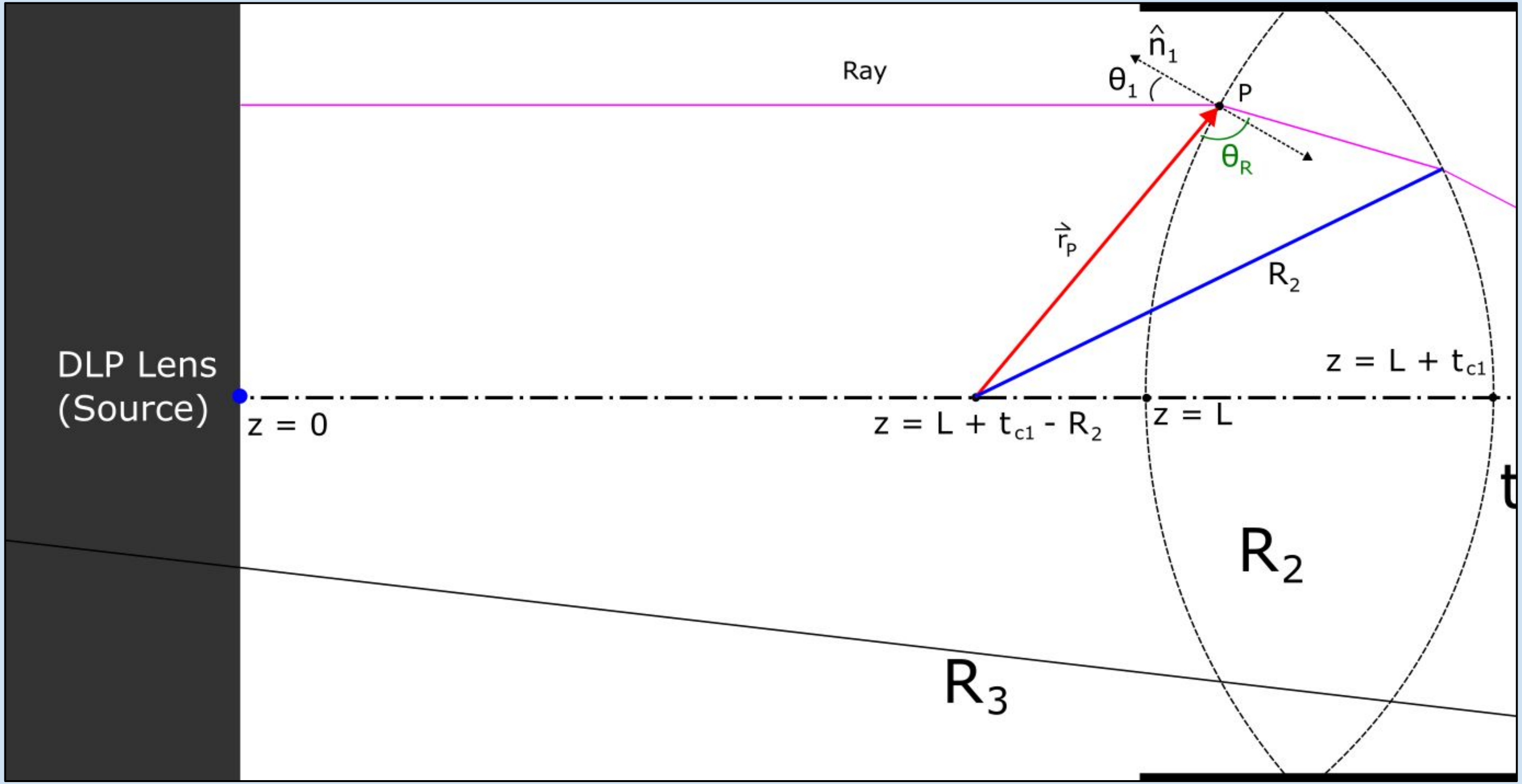
Simulating the Refraction - Step 4



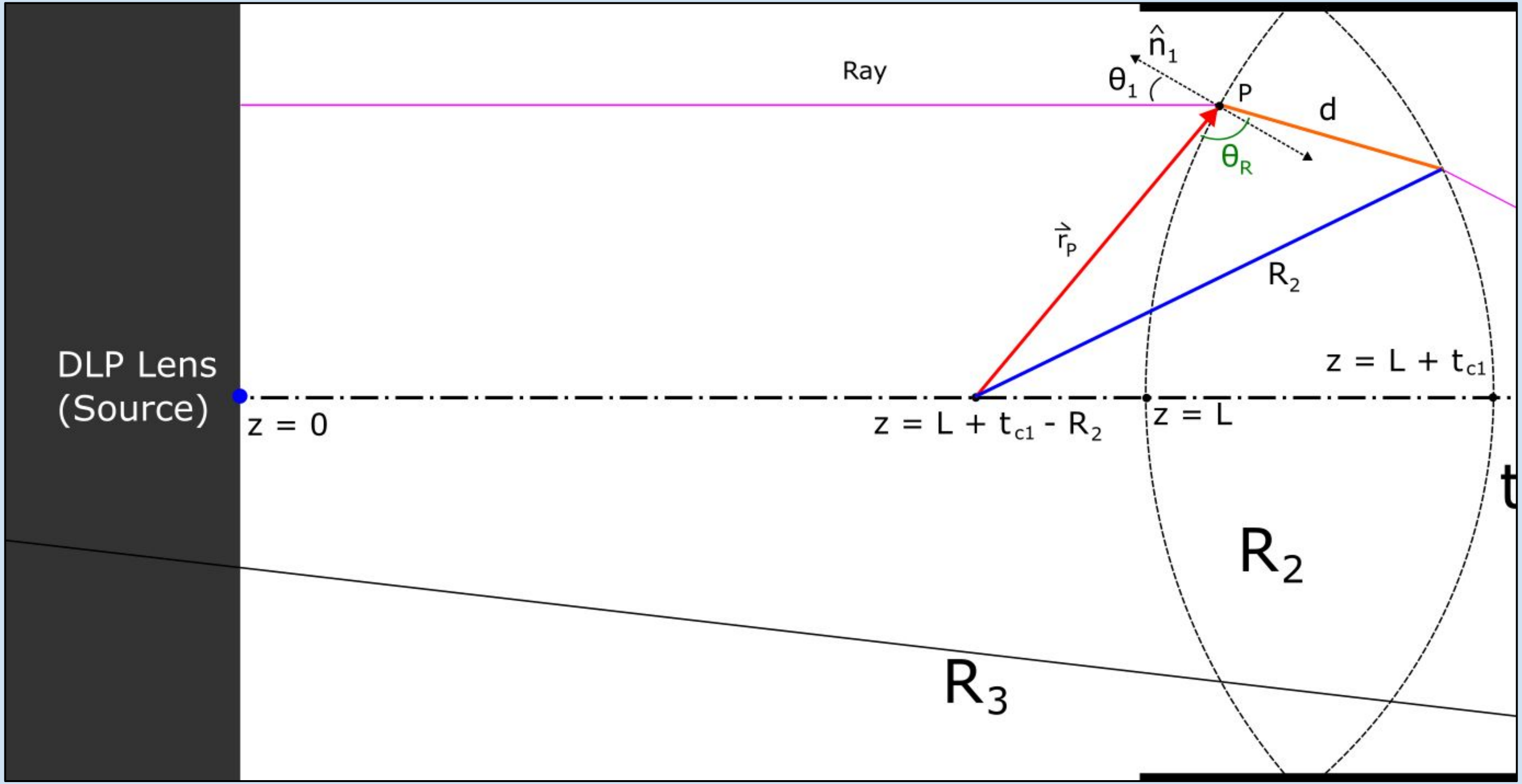
Simulating the Refraction - Step 5



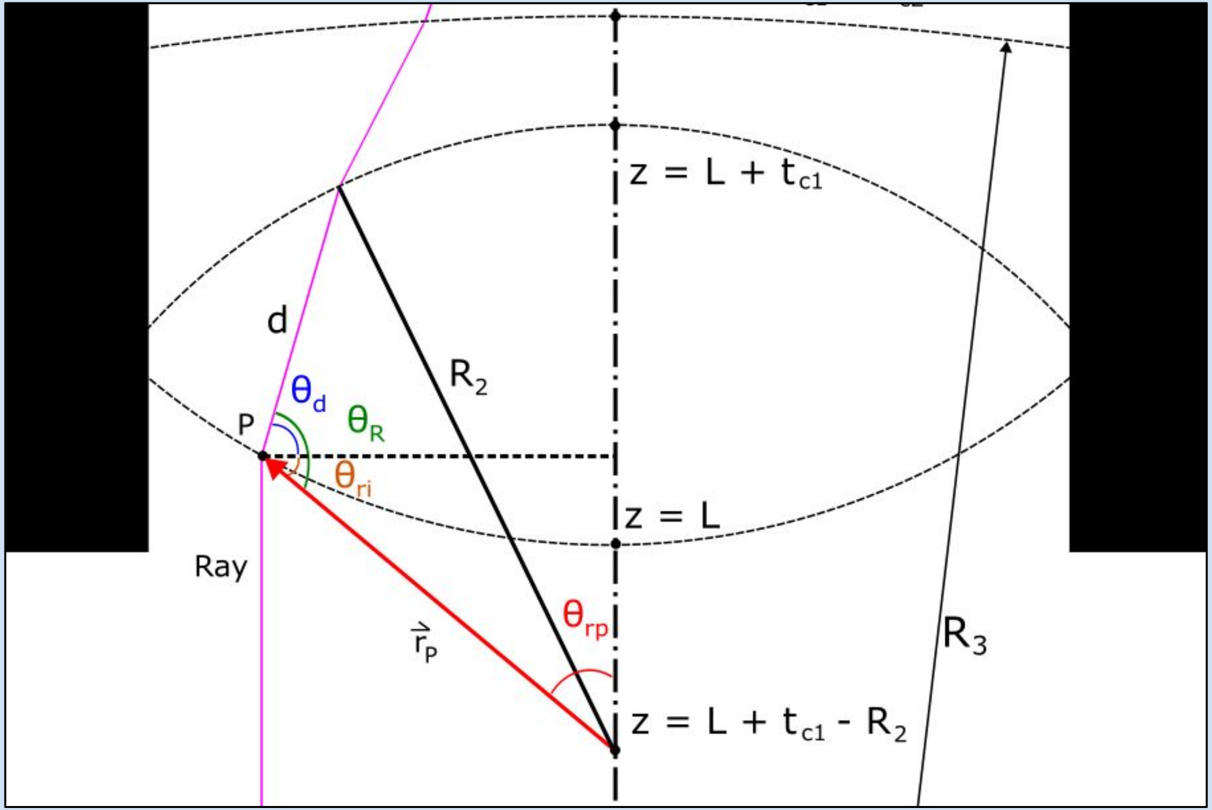
Simulating the Refraction - Step 6



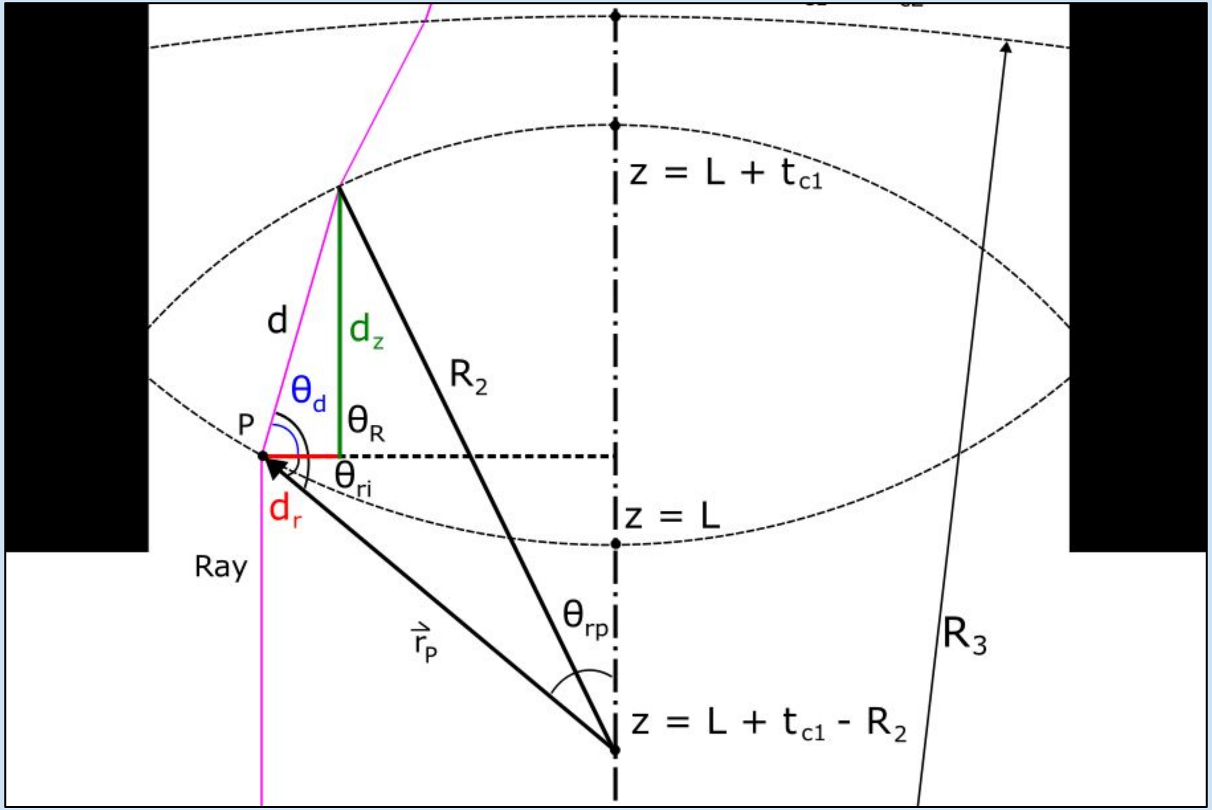
Simulating the Refraction - Step 7



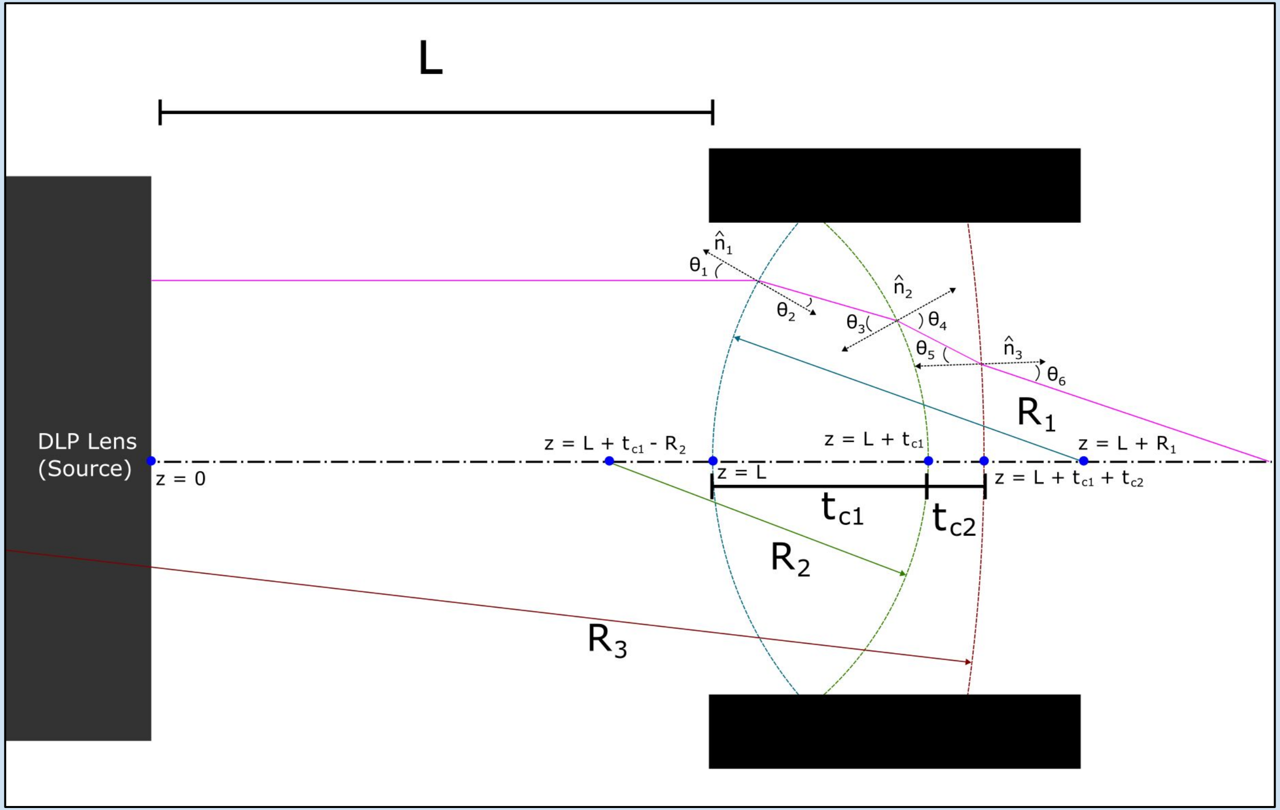
Simulating the Refraction - Step 8



Simulating the Refraction - Step 9



Simulating the Refraction - Step 10

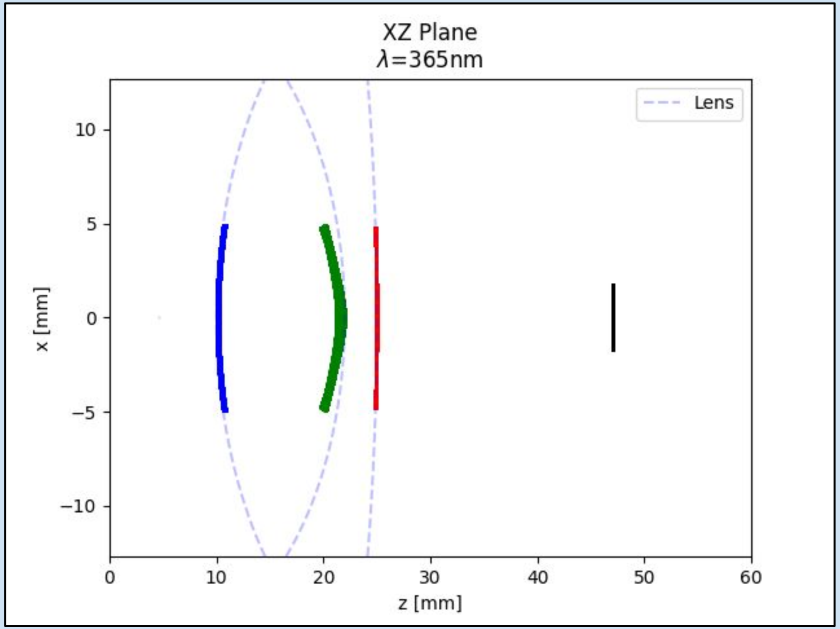


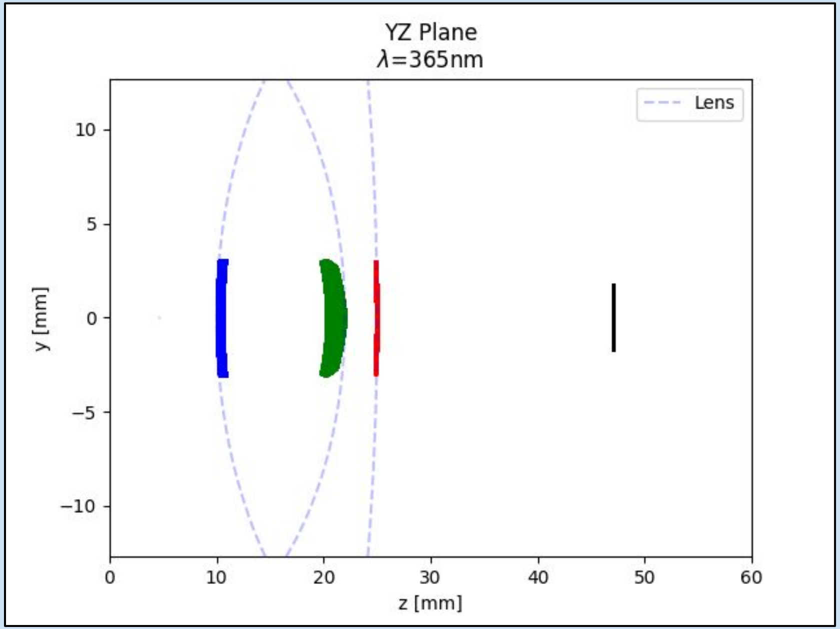
Results

Wavelength (nm)	**365**	**405**	**436**
Magnification using distance	-1.47	-1.47	-1.47
Magnification using height	-1.83	-1.94	-2.0
Magnification Error (%)	22.02	27.47	30.68
Chromatic Aberration (final/original)	x = -0.131 y = -0.549	x = -0.101 y = -0.52	x = -0.086 y = -0.504
Focal Point (mm)	19.365	19.904	20.189

Results

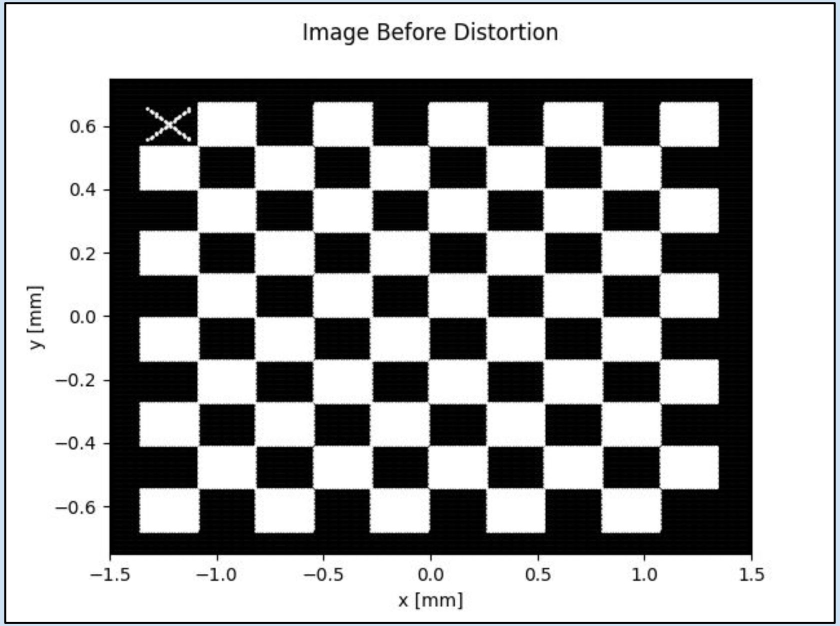
Comparing incident points with XZ and YZ planes:

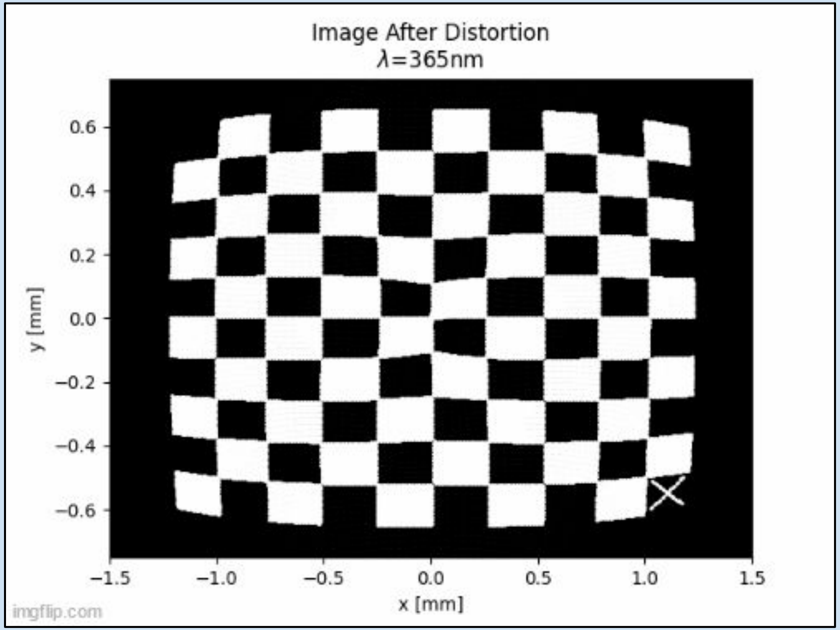




Results

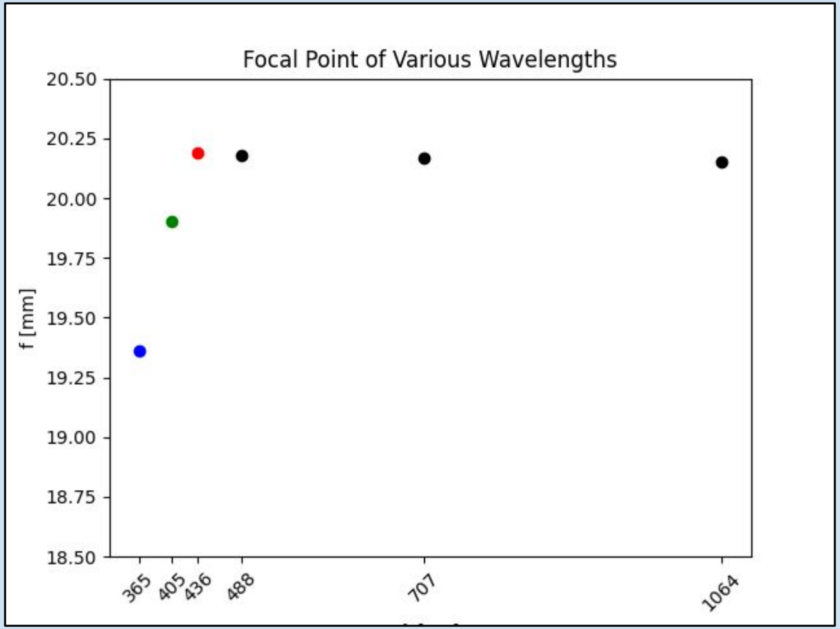
Final Image Distortion

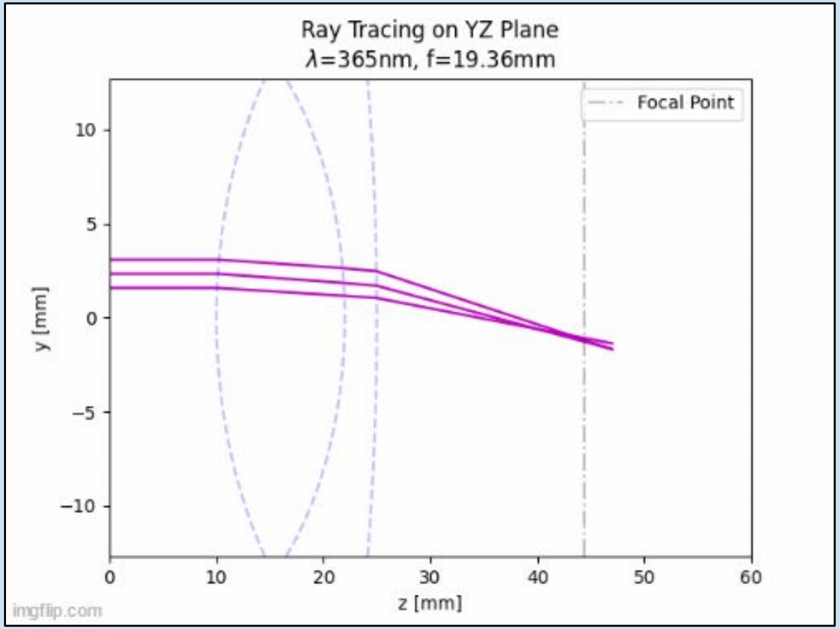




Results

Focal Points





Conclusions

What did we learn?

- Lens distortion varies with wavelength and distance.
- Chromatic aberration is stronger in lower wavelengths for this lens.
- Thin lens formula for magnification is not very accurate for this model because it does not account for wavelength.

Acknowledgements

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References

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