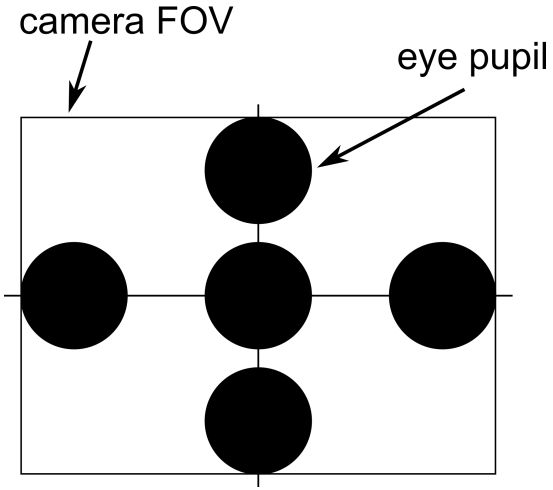
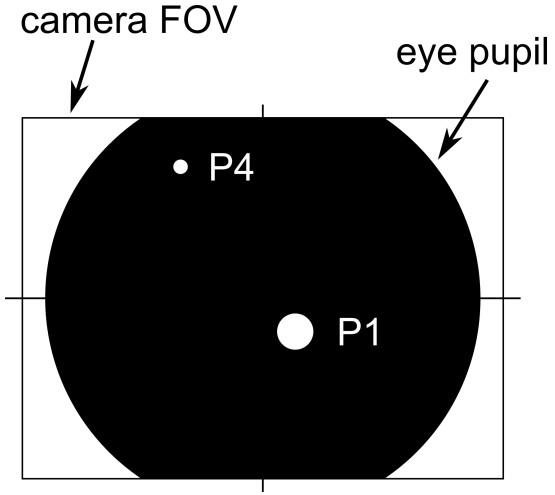
Using Purkinje reflection locations to determine camera FOV



Previous approach, where eye pupil needed to remain within the camera FOV across the trackable range of eye rotations.

- Previous approach was too restrictive: it prioritized camera FOV at the expense of resolution
- New approach is more aligned with existing system, where pupil overfills the camera FOV
- New approach prioritizes resolution over trackable range



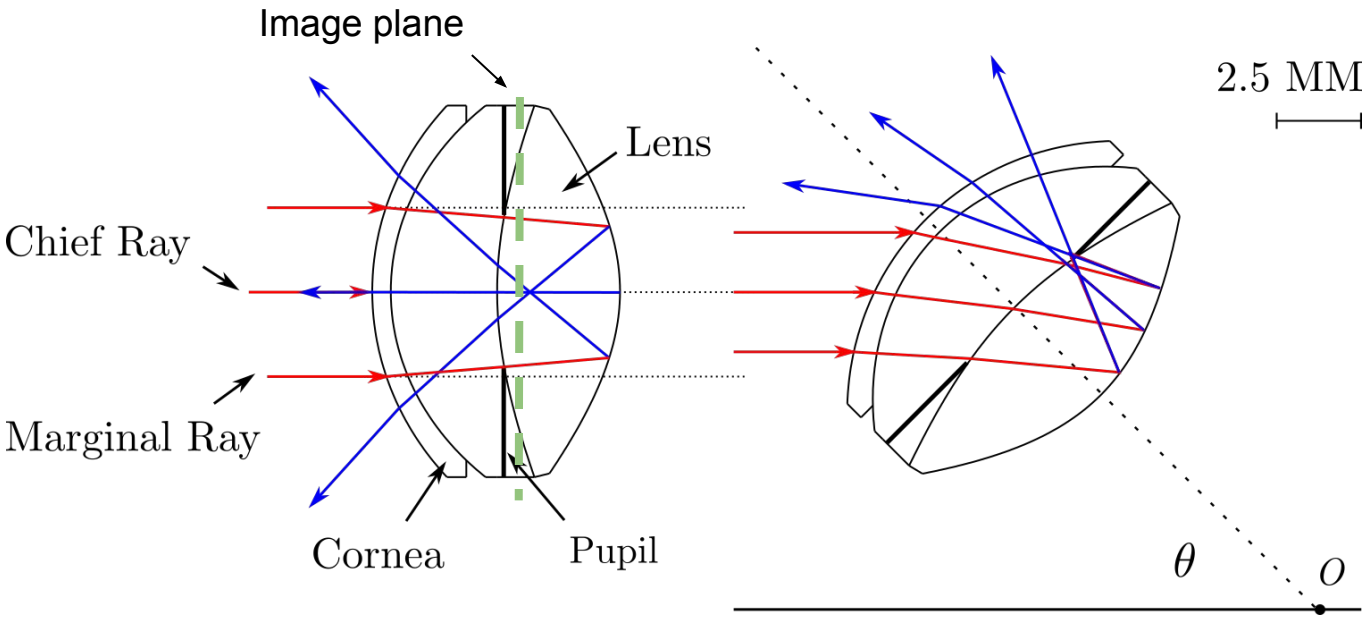
New approach, where Purkinje reflections must remain within the camera FOV across the trackable range of eye rotations.

dDDPI - Simulation

1. Movement of Purkinje Images with Rotation
    - How do P1 and P4 locations change with eye rotation?
    - What is the visible range of the fourth Purkinje image (due to SNR)?
    - How much do the Purkinje images move for 1 arcmin of eye rotation?
2. dDPI Sensitivity and Magnification
    - What is the size (diameter) of Purkinje images?
    - What is the optimized magnification of the imaging system for a given image sensor pixel size?

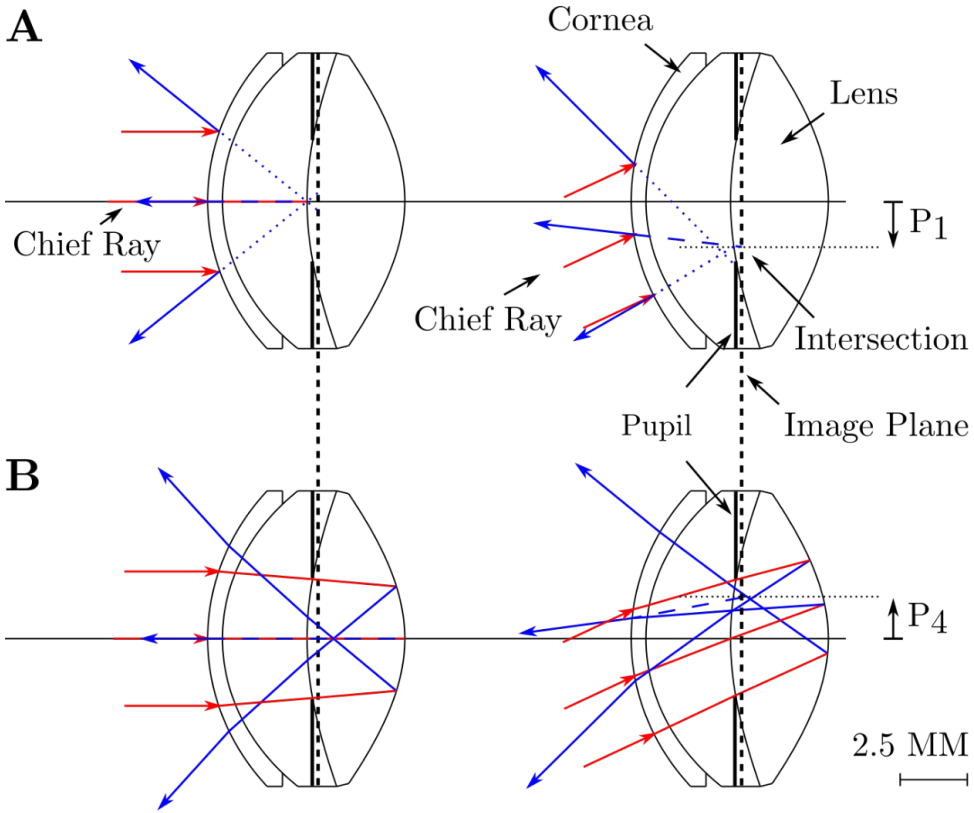
Ray Tracing Assumption

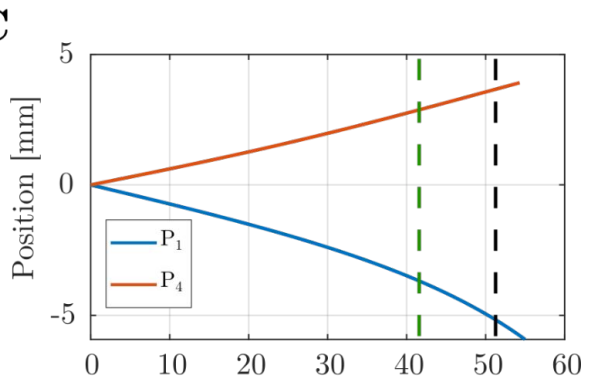
1. Atchison Eye Model
2. Uniform and collimated illumination with large beam diameter to cover the trackable range
3. Stop (5 mm in Diameter) at the pupil of the eye
4. The image plane is at the paraxial focus for P4

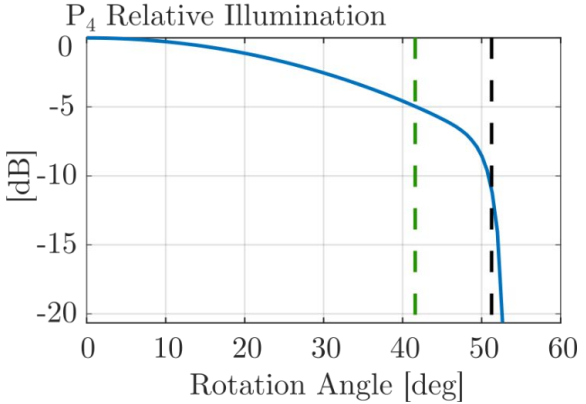


Ray Tracing Results at Eye Coordinate System

- What is the visible range of the fourth Purkinje image (due to SNR)?

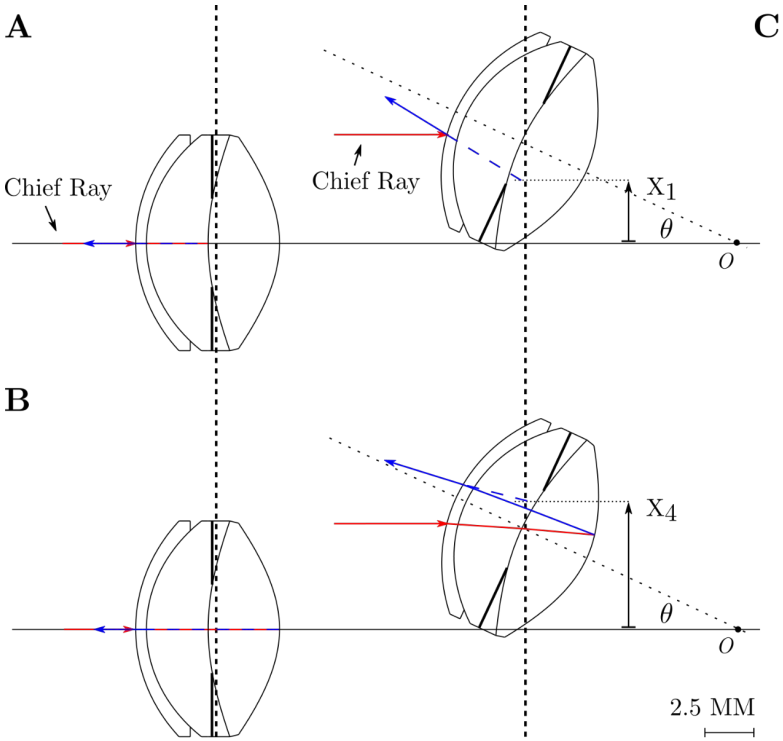


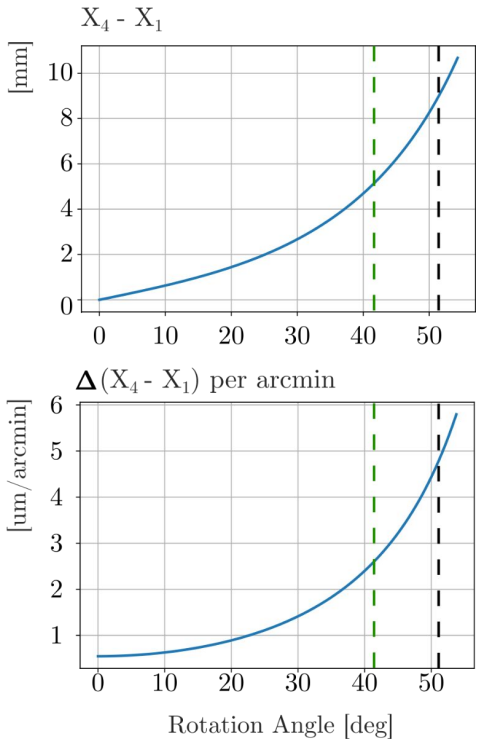




Ray Tracing Results at Global Coordinate System

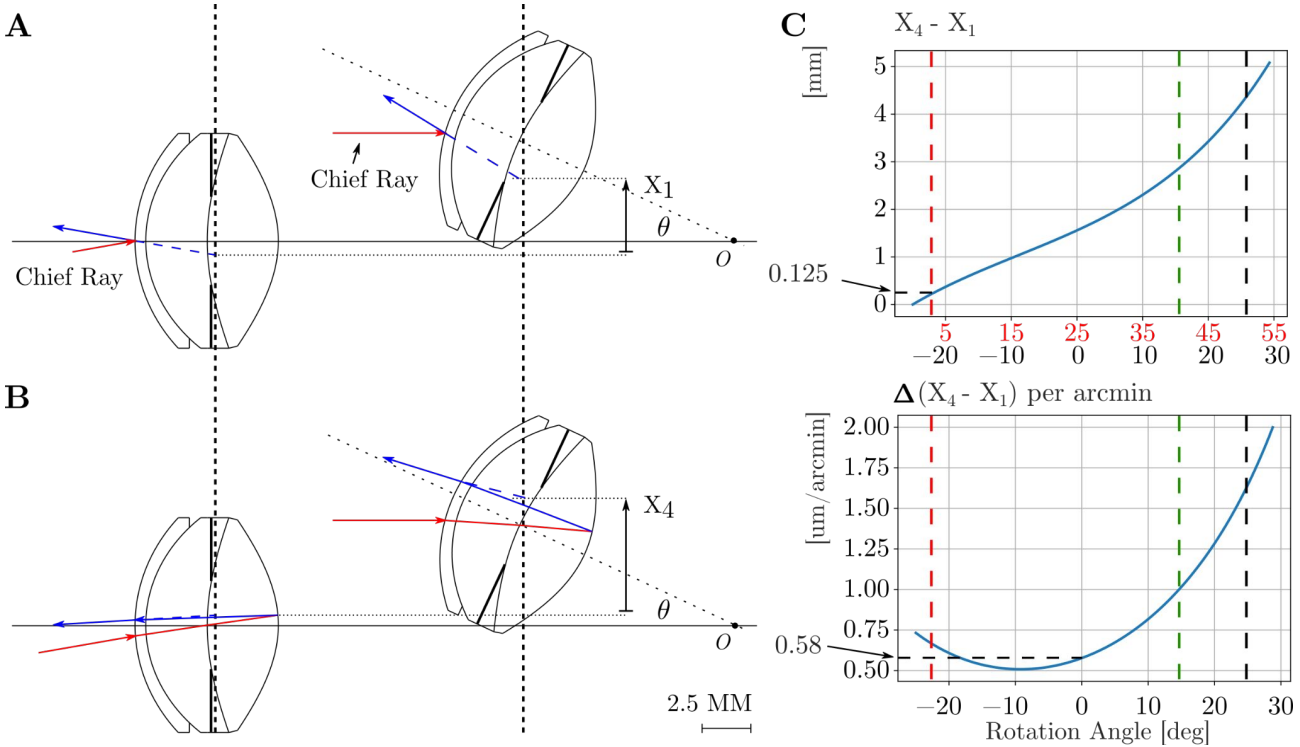
- How much do the Purkinje images move for 1 arcmin eye rotation?
- What is the optimum angle between the illuminator and camera?





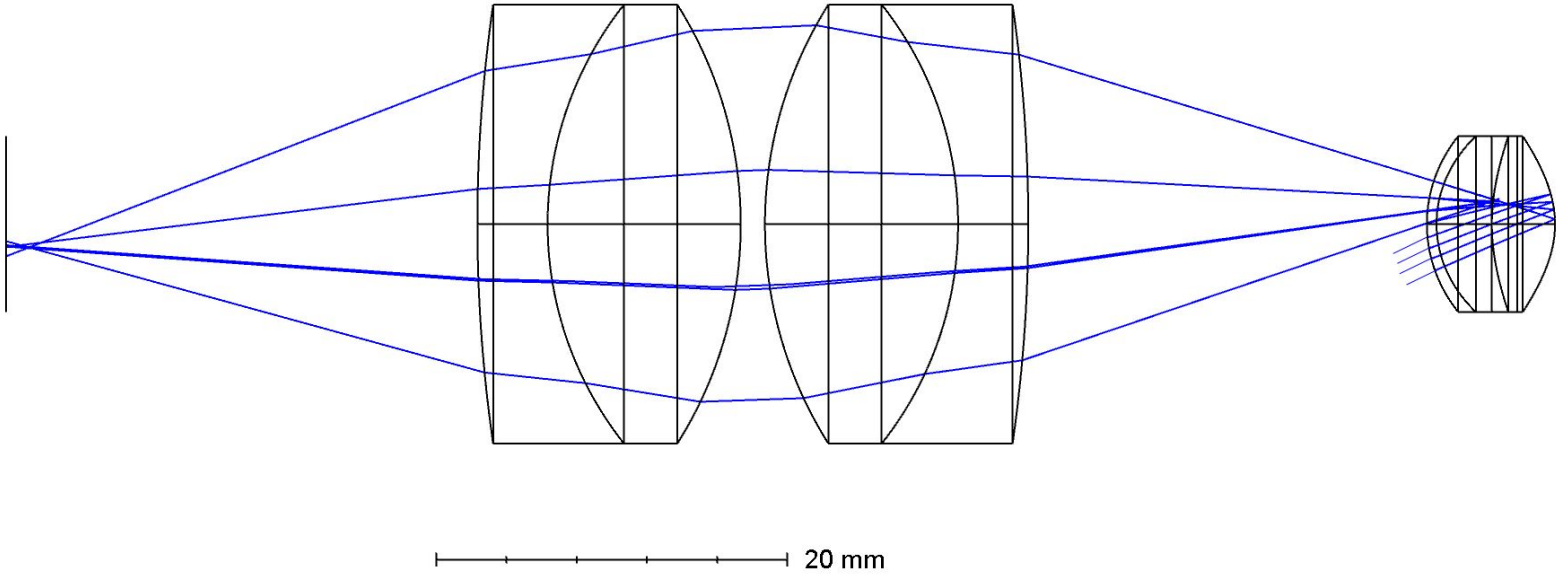
Ray Tracing Results at Global Coordinate System - Tilted Illumination

- The illumination is tilted by 25 degrees initially
- How much do the Purkinje images move for 1 arcmin eye rotation?
- What is the optimum angle between the illuminator and camera?



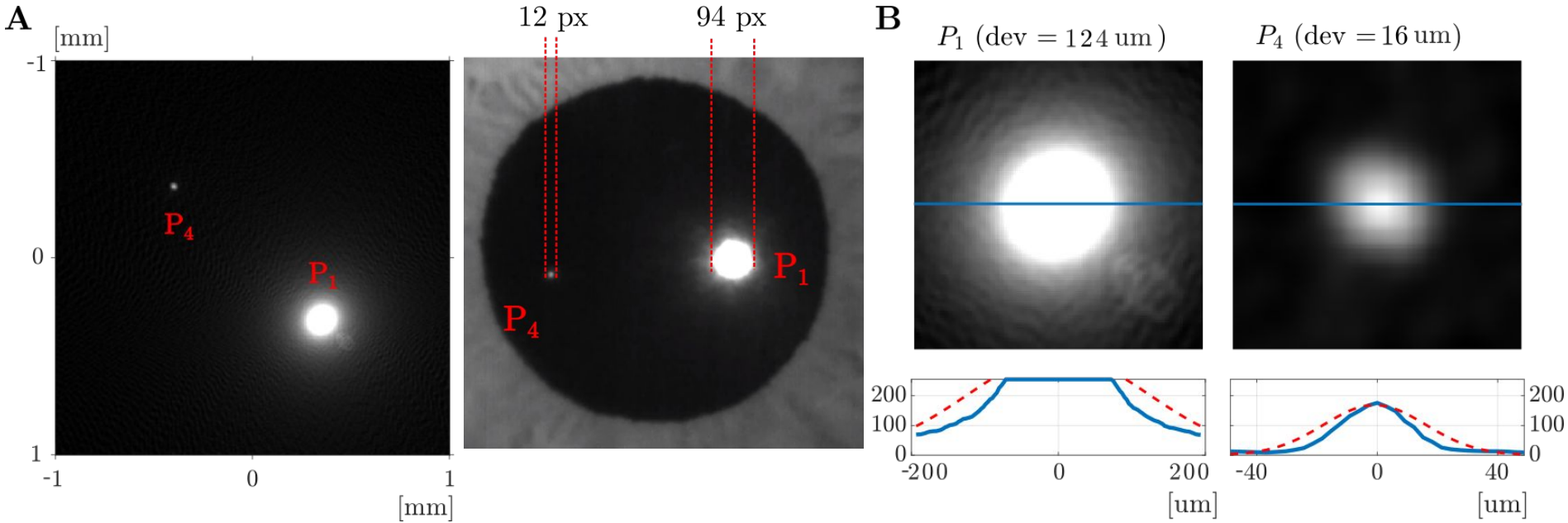
Simulation of dual Purkinje Images at 25 deg - Setup

- Relay lens: 1:1 with 35mm and 35mm EFL Achromats, NIR Achromatic Pair (Edmund 47-293), working f/# 0.645 > 0.634 (woking f/# of the eye for P4)
- Uniform Illumination (4mm in diameter) tilted by 25 degree in both x and y



Simulation of dual Purkinje Images at 25 deg

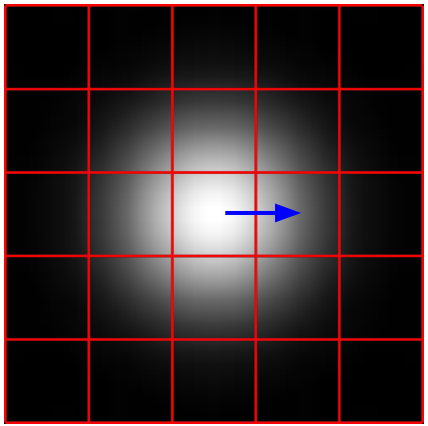
- What is the Purkinje image's size in [mm]



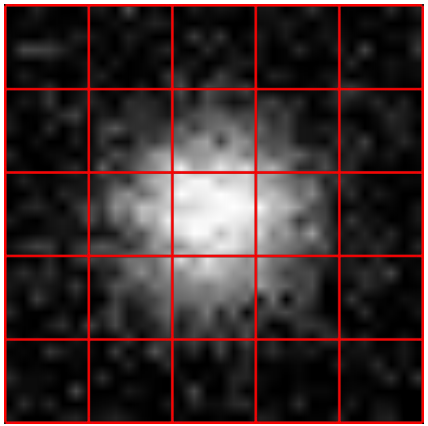
Evaluation of Image Localization

- Create a 2D Gaussian and shift by some small amount (d)
- Average over a single pixel
- Add noise
- Applied Radial symmetric center to estimate the position of image center
- Error = Estimated position - shift

2D Gaussian

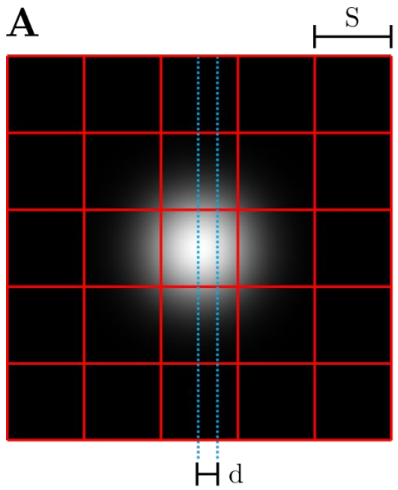


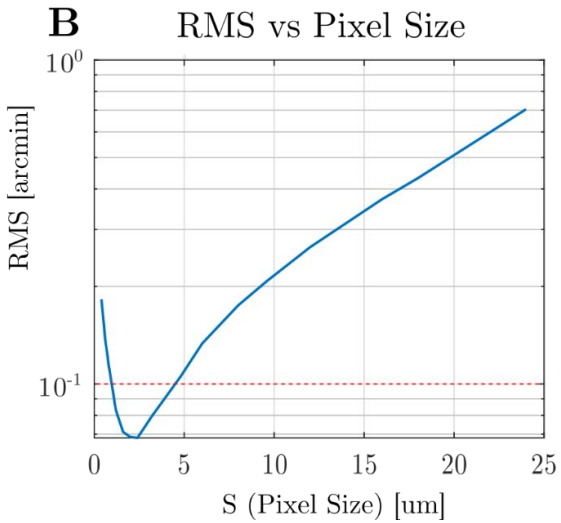
Add noise over each pixel

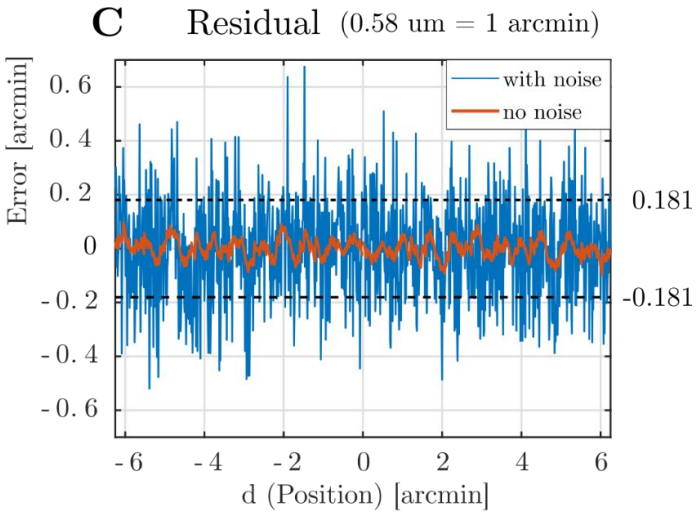


Evaluation of Image Localization

- Variable pixel size (S) (at the object plane of the image system)
- The shift, d, is varied from zero to the width of a single pixel size
- RMS = RMS of Error





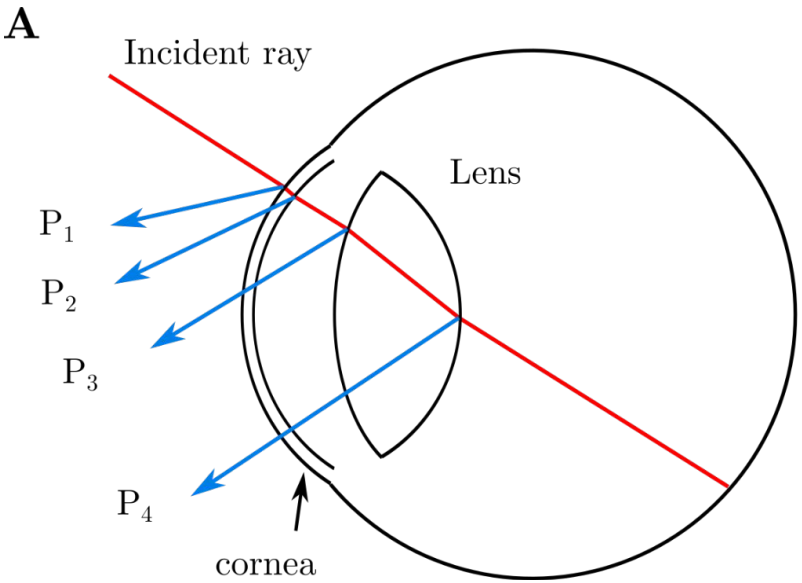


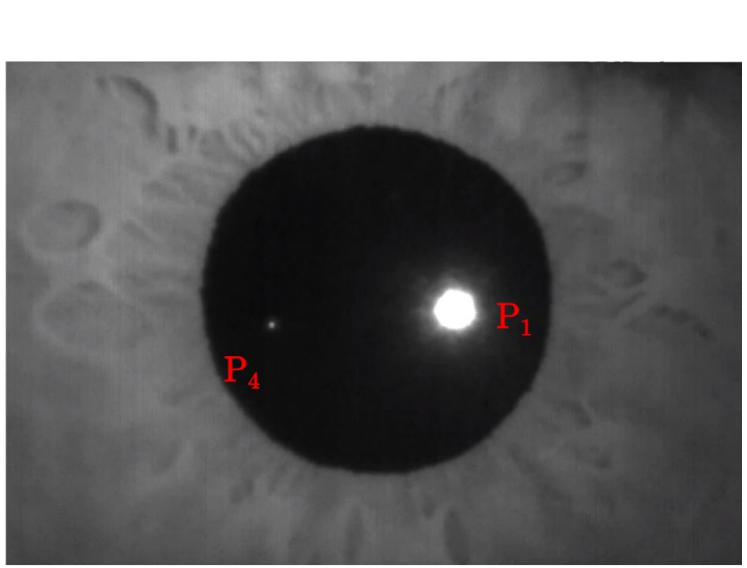
Gaussian with dev = 16 [um]

Conclusion

- Purkinje Images moves 0.58 um per arcmin
- Visible range (trackable range) is -15 to 15 degree
- To achieve ~0.2 arcmin, Pixel Size at Objective plane has to be 5um

Purkinje Images





$$\sin\theta \propto P_1 - P_4$$