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# Two Image Based Methods for Measuring the Flatness of the MultiCCD Focal Plane

**Jiangang Hao, Juan Estrada**

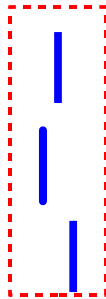
Center for Particle Astrophysics @ Fermilab



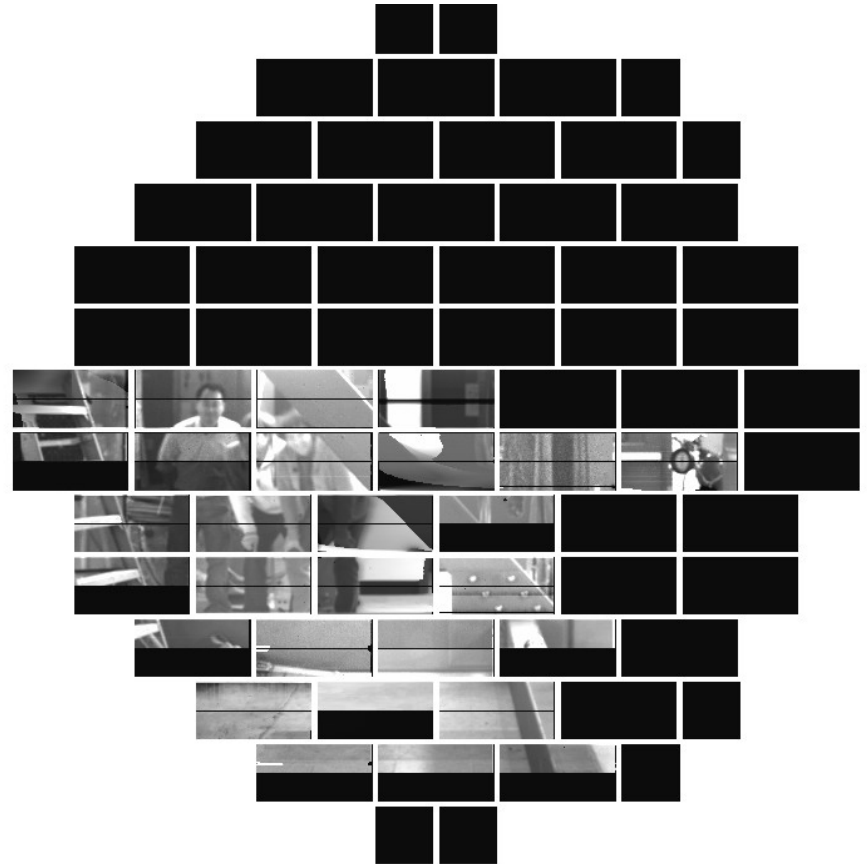
# Flatness of the MCCD focal plane

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- All CCD detectors need to be on the same plane so that they are all correctly focused.
- The DES specification for the flatness is all detectors are within a 60 microns envelope.



60 microns



Mosaic image taken from MCCDTV



# Methods for measuring flatness

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- Optics Based Method

Using optical method to measure the flatness of the CCD detectors. See the method using opto-NCDT by Tom Diehl

- Image Based Method

Imaging some pattern on the CCDs and then measure the flatness of the CCDs by deformation of the patterns measured from the images.

- Image based methods directly measure the “flatness” that we will see from the real observation.
- They are complementary methods to the Optics Based Method



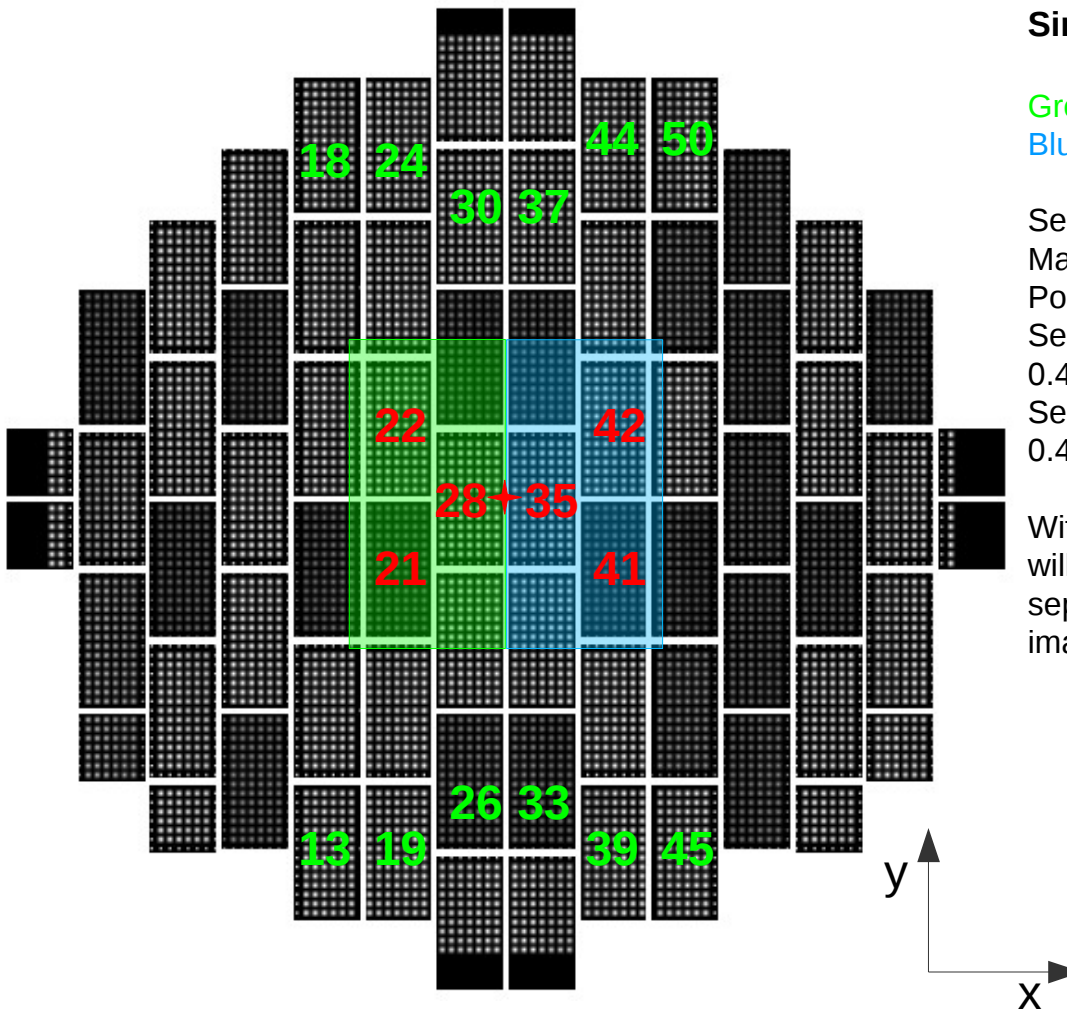
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# Method 1: “polka” dots projector

- We image a grid of dots on the full CCD focal plane and then extract the positions of the dots using sextractor.
- If there are offset among the detectors, the spacing of the grid dots will change.
- Looking at the distribution of the spacing among the nearest dots, we can see how much it is offset from the focal plane.



# Realistic Simulation



## Simulation parameters:

Green box: FP back by 4 pix

Blue box : FP forward by 4 pix

Separation between PH to FP: 150 mm

Magnification: 10.5

Position precision on image: 1 micron

Separation between neighboring dots on source:

0.4 mm

Separation between neighboring dots on image:

$0.4 \text{ mm} \times 10.5 = 4.2 \text{ mm} \sim 280 \text{ pixels}$

With this configuration, **4 pixel (60 microns) offset** will lead to **0.106 pixel** increase/decrease for the separations of neighboring pairs of dots on the image.

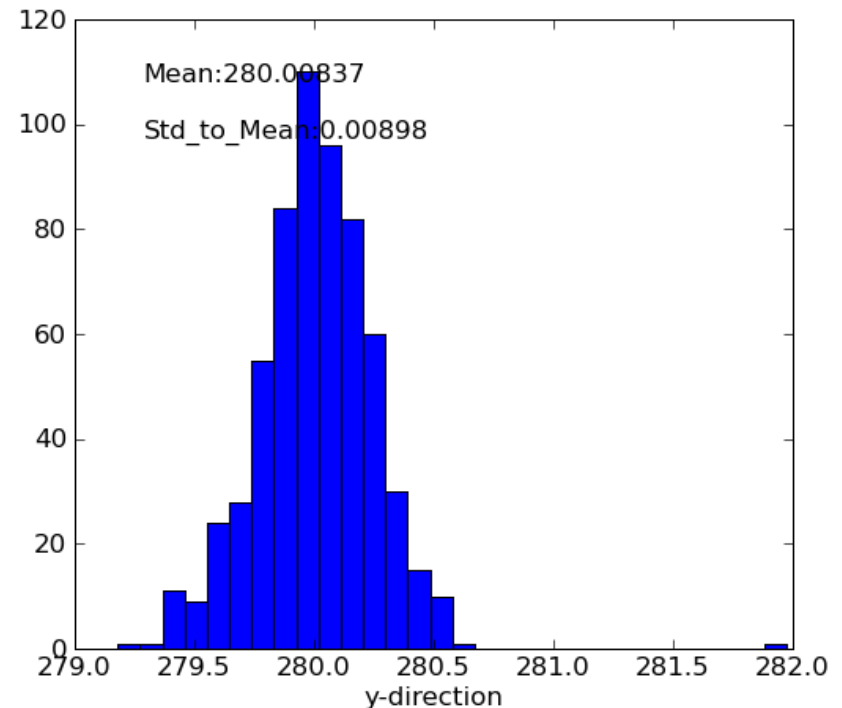
Thanks Huan and Nikolay for creating the simulated image



# Distribution of separations

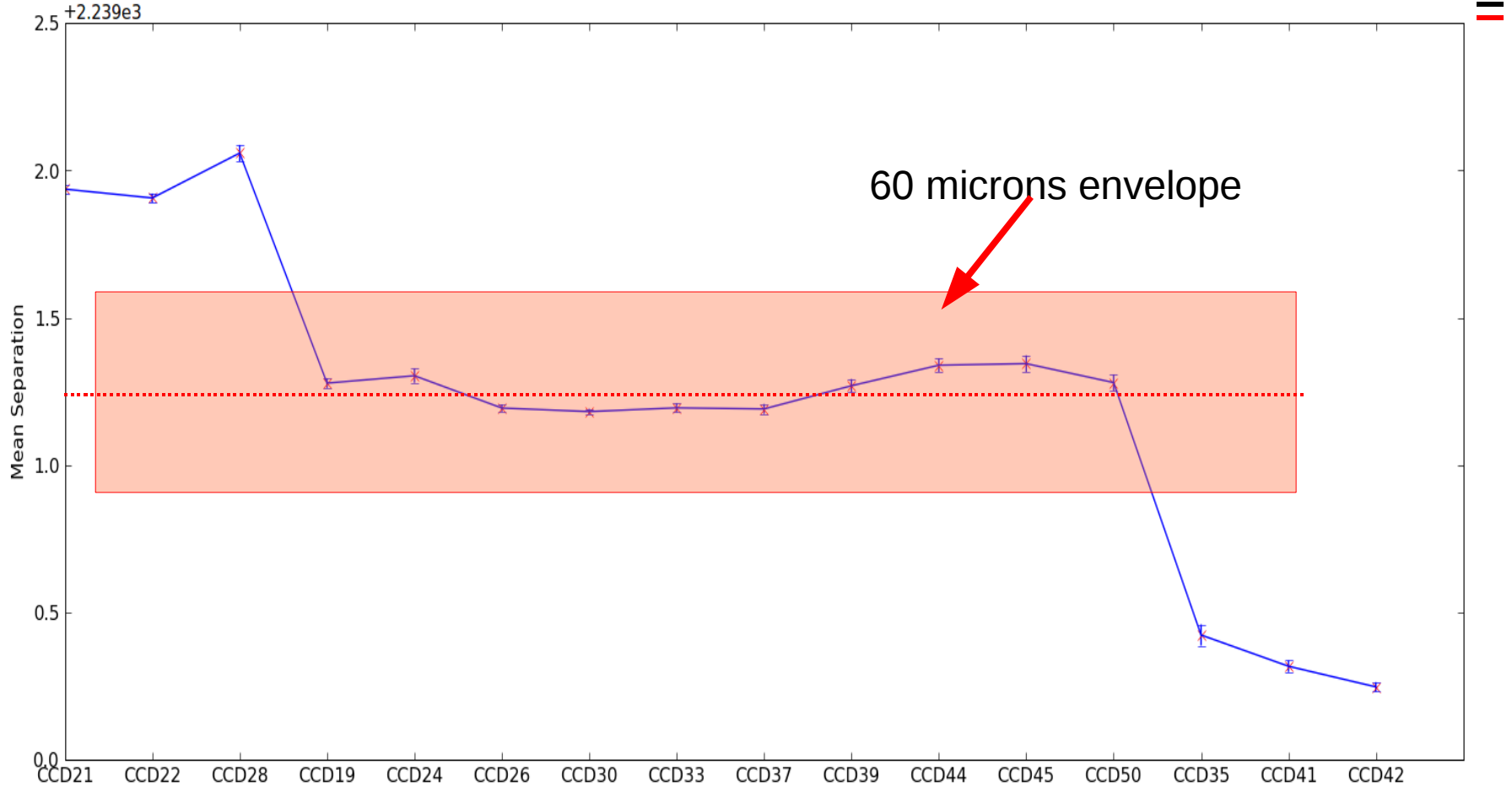
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- We use SExtractor to extract the objects on the simulated images.
- For a given Channel, the distribution of the separations between neighboring dots along y direction follow a distribution as show by the right figure.





# Flatness Results for Simulated Image



We look at the separations between 8<sup>th</sup> nearest dots. That means 4 pixels offset is converted to  $0.106 \times 8 = 0.848$  pixels difference in separations.



# Challenge of the polka method

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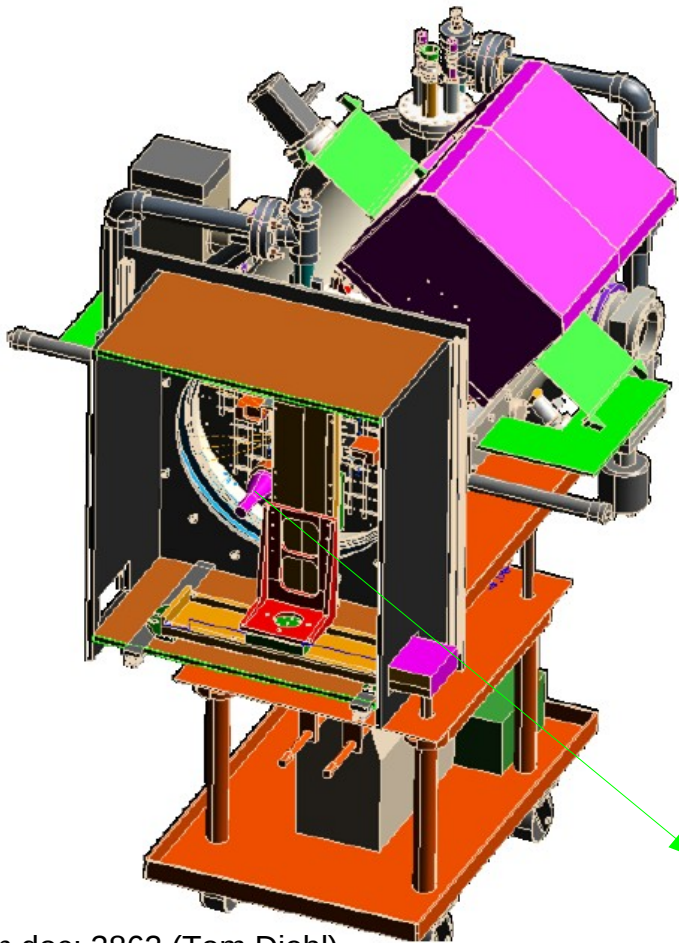
- The analysis from “polka” dots are very straightforward. However, it requires high precision on the positions of the source. i.e., the position on the source plate need to be  $\sim 0.1$  micron for our setup to achieve the quality of the measurement.
- We therefore have the method 2
- But the tools we developed here can be use to test the stability of the image when the imager is moved with the telescope simulator. This does not require high precision of the positions of the dots because we just measure the relative changes before and after it is moved.(I will introduce this at the last part)





## Method 2: Moving star projector by xy-stage

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- Using the existing instruments (see left figure)
- Using “star-projector”, we can project many “stars” on CCD. Record the image as **image1** and extract the positions of the “stars”.
- Move the star-projector along y(or x) direction for distance “d” and get another **image2** for “stars”, recording their positions too.
- On image1, calculate the difference of y (or x) coordinates of every star with respect to one star.
- On image2, cross matching the objects and calculate the difference of y ( or x) coordinates in a similar way.
- The change of separations will be turned into an estimator of the tilt of the plane.
- Repeat to get image3, ... and we will have many measurements on the tangent of the angle.

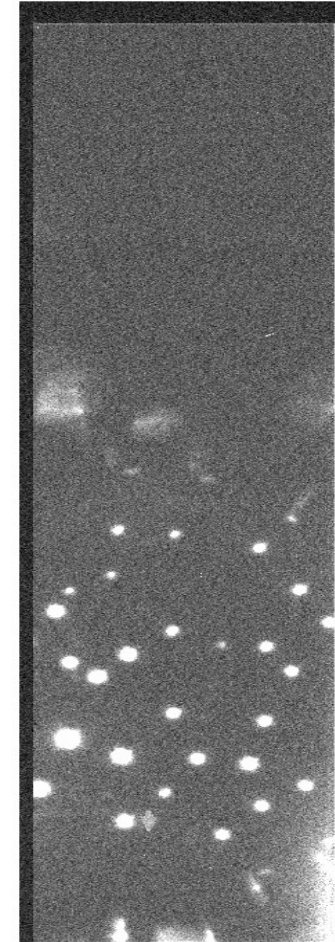
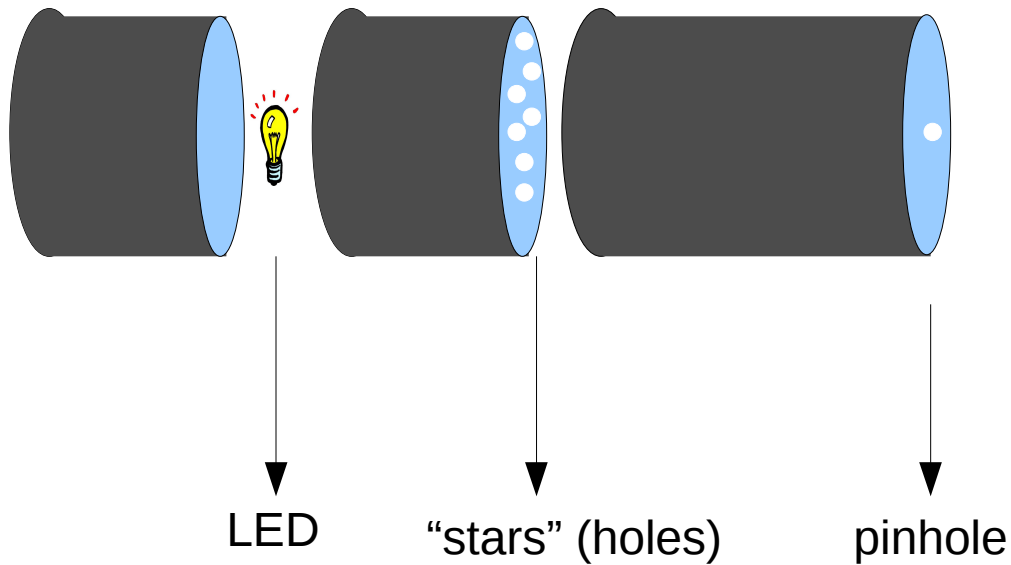
From doc: 3862 (Tom Diehl)

Replaced with star projector



# Star projector

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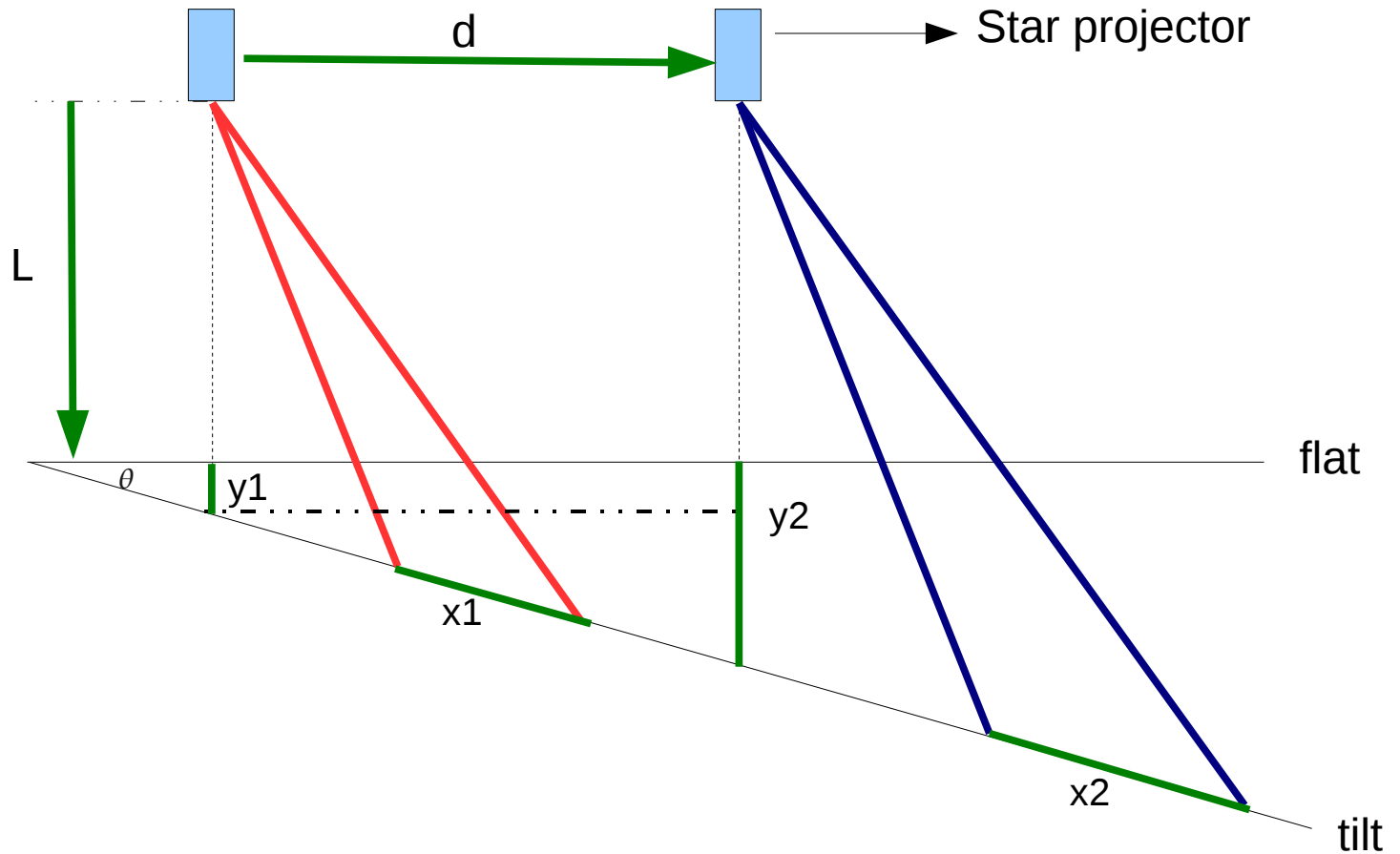


CCD Image from star projector



# Schematic

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# Geometric Relation

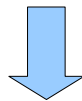
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From the similarity of triangles

$$\longrightarrow \frac{x_1}{x_2} = \frac{(L+y_1)}{L+y_2} \quad \longrightarrow \frac{x_2-x_1}{x_2} = \frac{(y_2-y_1)}{L+y_2} \quad \longrightarrow \frac{x_2-x_1}{x_2} \times L \left(1 + \frac{y_2}{L}\right) = (y_2-y_1)$$

$$\tan(\theta) = \frac{y_2-y_1}{d} = \frac{(x_2-x_1)}{x_2} \times \left(\frac{L}{d}\right) \times \left(1 + \frac{y_2}{L}\right)$$

$$y_2 \ll L$$



Eq.1

$$\tan(\theta) = \frac{(x_2-x_1)}{x_2} \times \left(\frac{L}{d}\right)$$

All Measurable



# Calibrate the x-y stage

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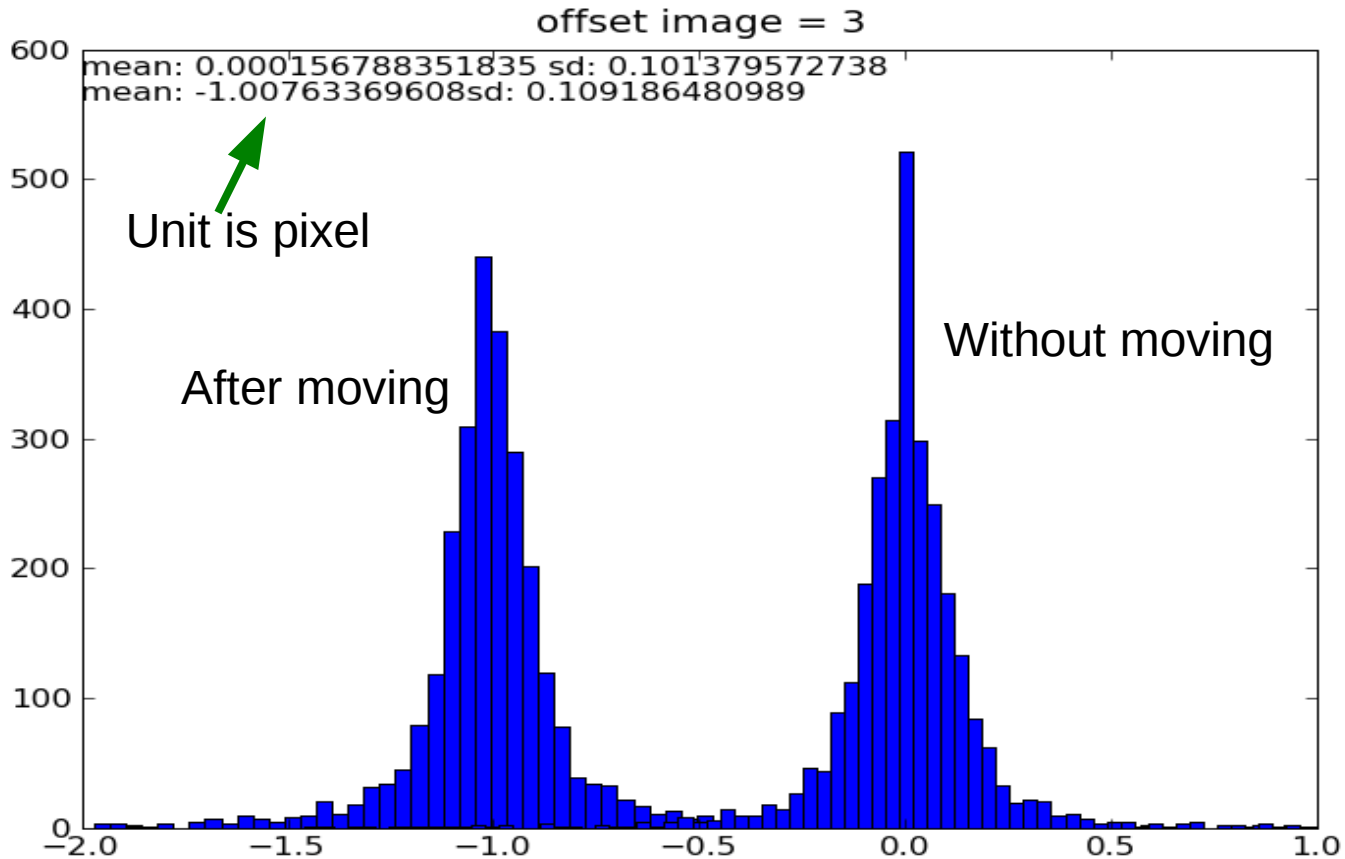
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- Before we start our measurement, we need to be sure that the x-y stage can produce the precision displacement and we can recover this displacement from image measurement.
- First, we take an image as reference and extract the “star” positions as reference positions.
- Second, without moving the star projector, we take another image. We extract the positions of the “stars” and calculate the difference between them and the reference positions.
- Next, we move the star projector and take another image. Repeat the step 2.
- Then, we can compare the differences of the positions.



# Move by 15 microns (1 pixel)

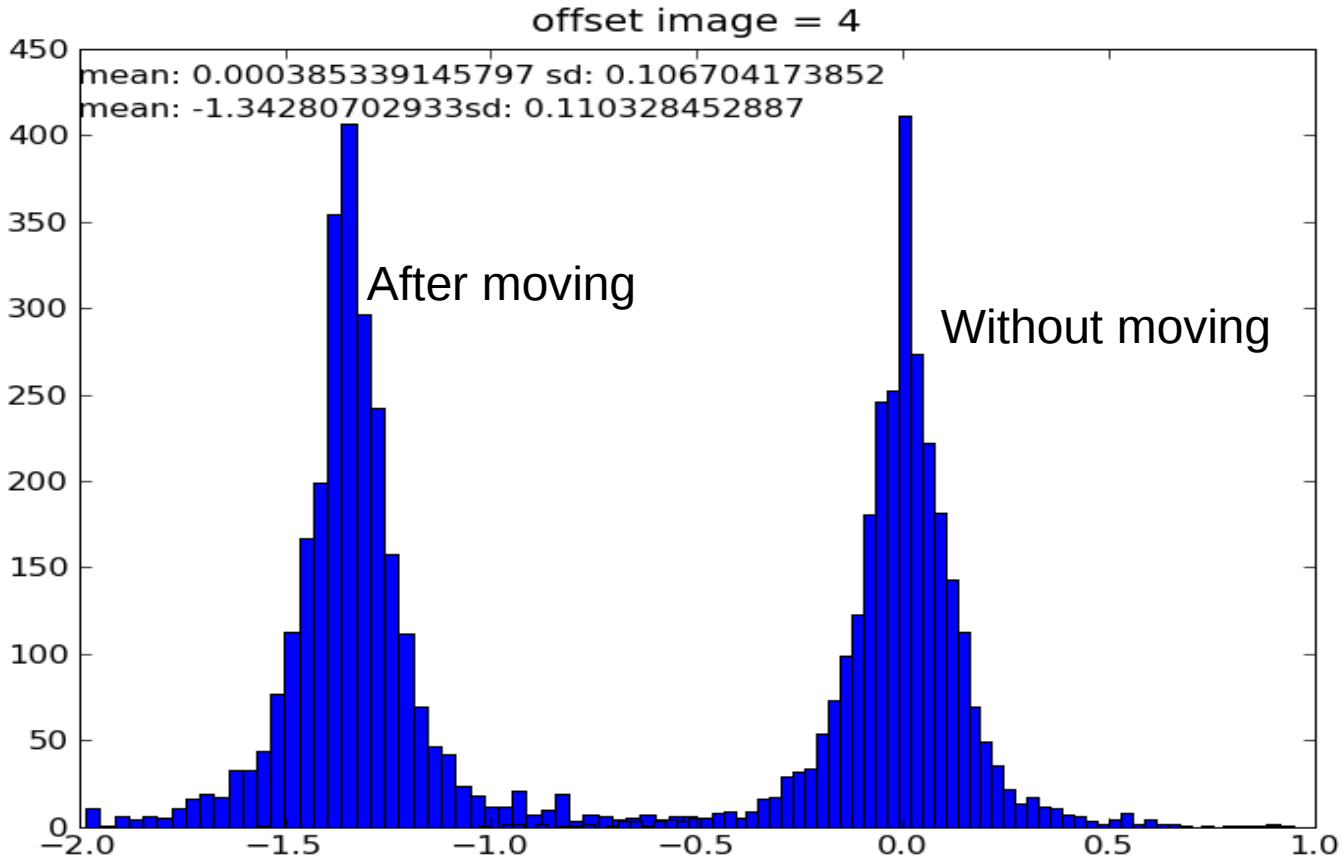
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# Move by 20 microns

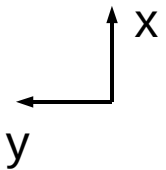
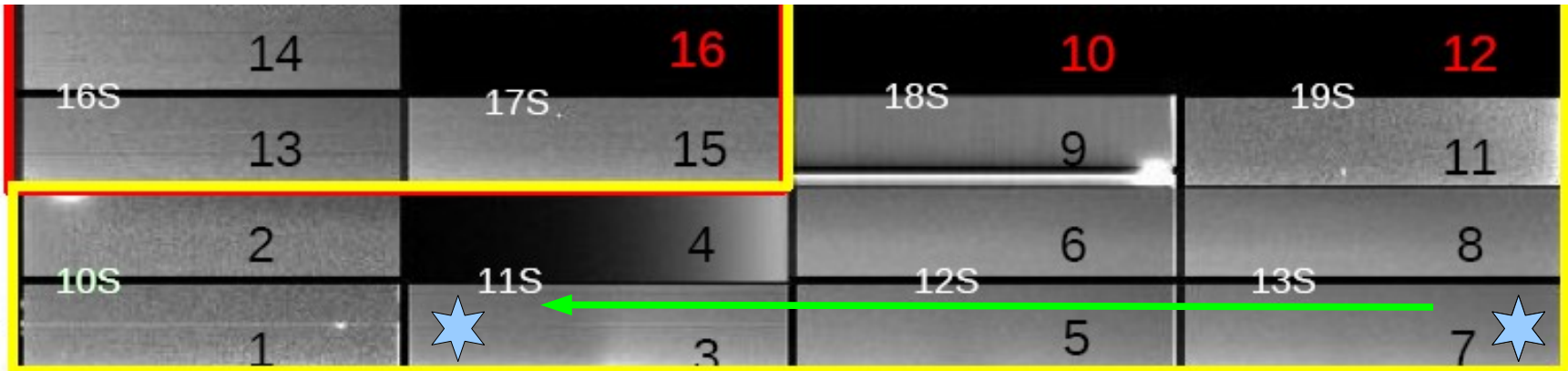
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# Implementation



Move 1mm per step

$d=1\text{mm}$   
 $L \sim 10\text{ cm}$

We use an x-y stage to move the star projector along the y direction

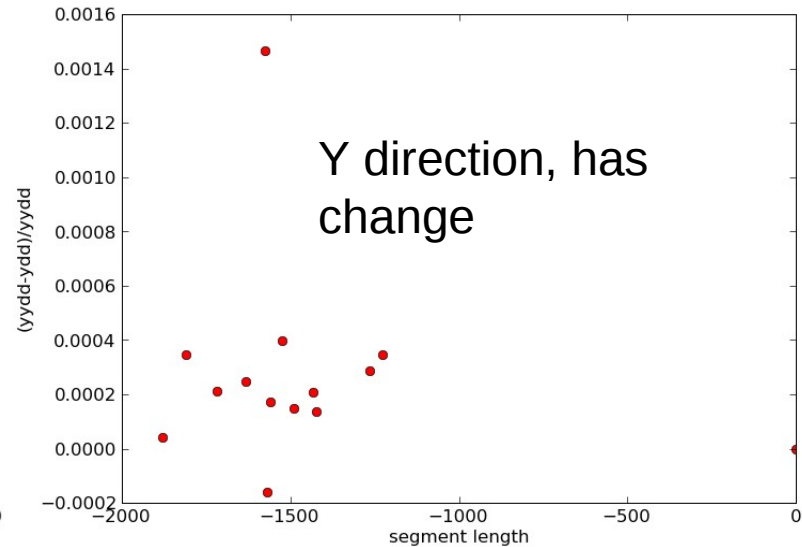
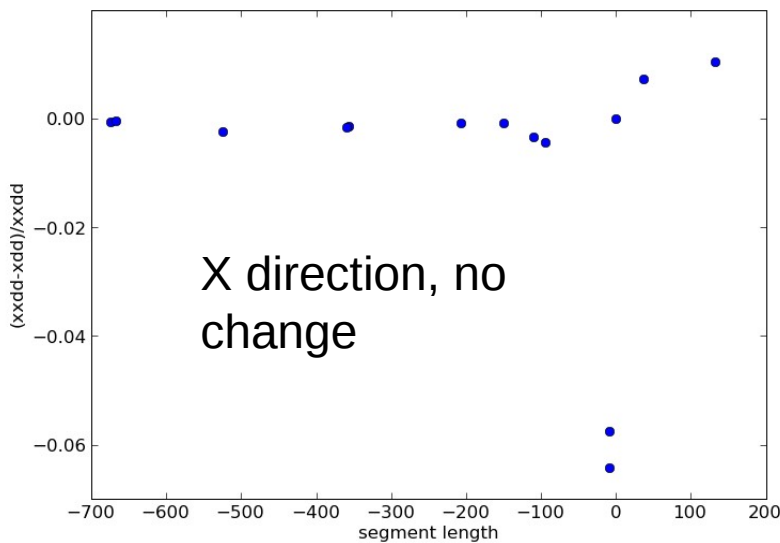




# One more cross-check with x direction

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- If the above approach really works, then in x direction, we will not expect a change in the length of the separations among pairs of stars.
- Using extension 7, we check this. See the following plot

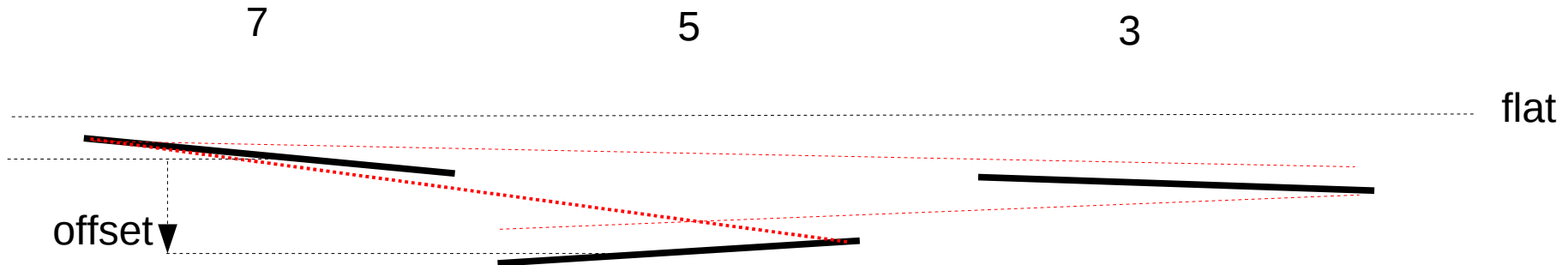


So, the method we are using do make sense.



# Results

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Angles:	Tangent:
7: 0.053	0.00093
5: -0.063	-0.00110
3: 0.0126	0.00022
7-5: 0.0784	0.00137
7-3: 0.0126	0.00022
5-3: -0.052	-0.00091

Based on the angles, the above is the possible configuration of the CCDs.

Offset 7-5:  $60000 \times 0.00137 \sim 82$  microns  
Offset 7-3:  $120000 \times 0.00022 \sim 26$  microns  
Offset 5-3:  $60000 \times (-0.00091) \sim -54.6$  microns

Note the uncertainty on Tangents are  $\sim 0.0002$ , corresponding to 12 microns. We can improve this by projecting more "stars".



# Summary of the two methods

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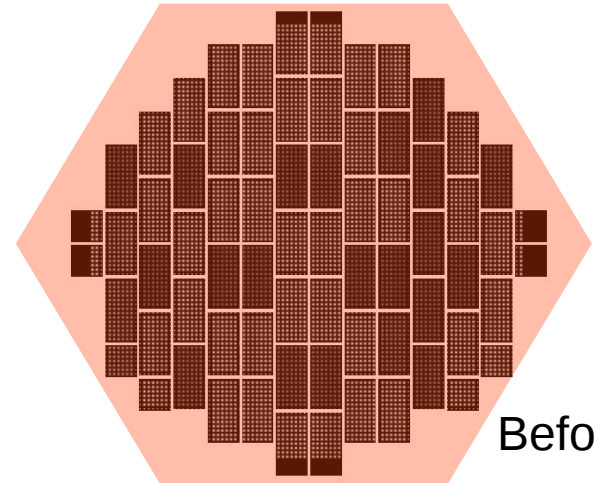
- We here show two image based methods to measure the flatness of the focal plane. They are direct measurements of the image quality.
- We are going to use the method 2 to measure the flatness as an independent cross check of the optical method by Tom Diehl.



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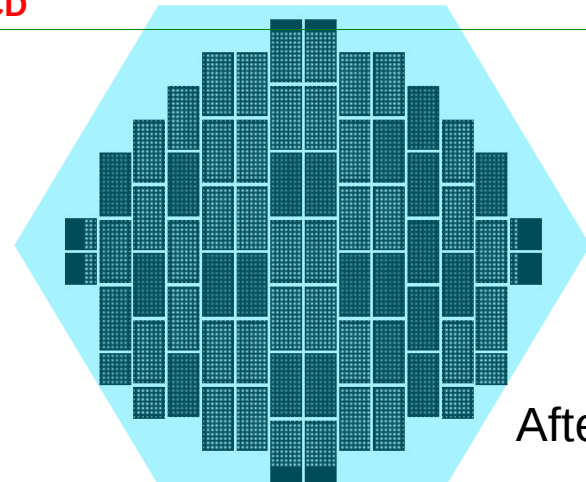
# Testing image quality in telescope simulator using polka dots projector

- The previous Method 1 can project a grid of polka dots on the full focal plane through pinhole.
- We can measure the relative changes of the polka dots positions when we move the imager
- We can measure the relative change of the photometry of the dots when the imager is moved.
- We have already developed the tools that can be used for this purpose.



Before move

**Relative astrometric and photometric change  
can be measured using our existing tools CCD  
by CCD**



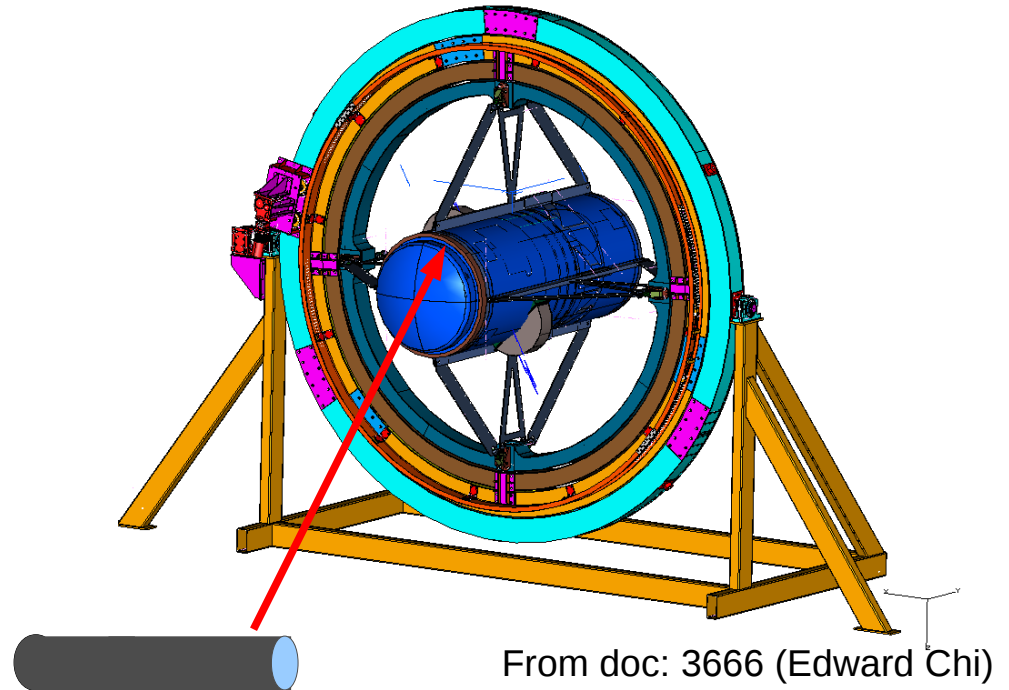
After move



# Our current plan for setup

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- Mount our polka dots projector on the cage (not the barrel)
- By this way, we will be able to measure the image stability and repeatability of the movements of the hexapod.



Polka dot projector