DECam DONUT Focus & Alignment

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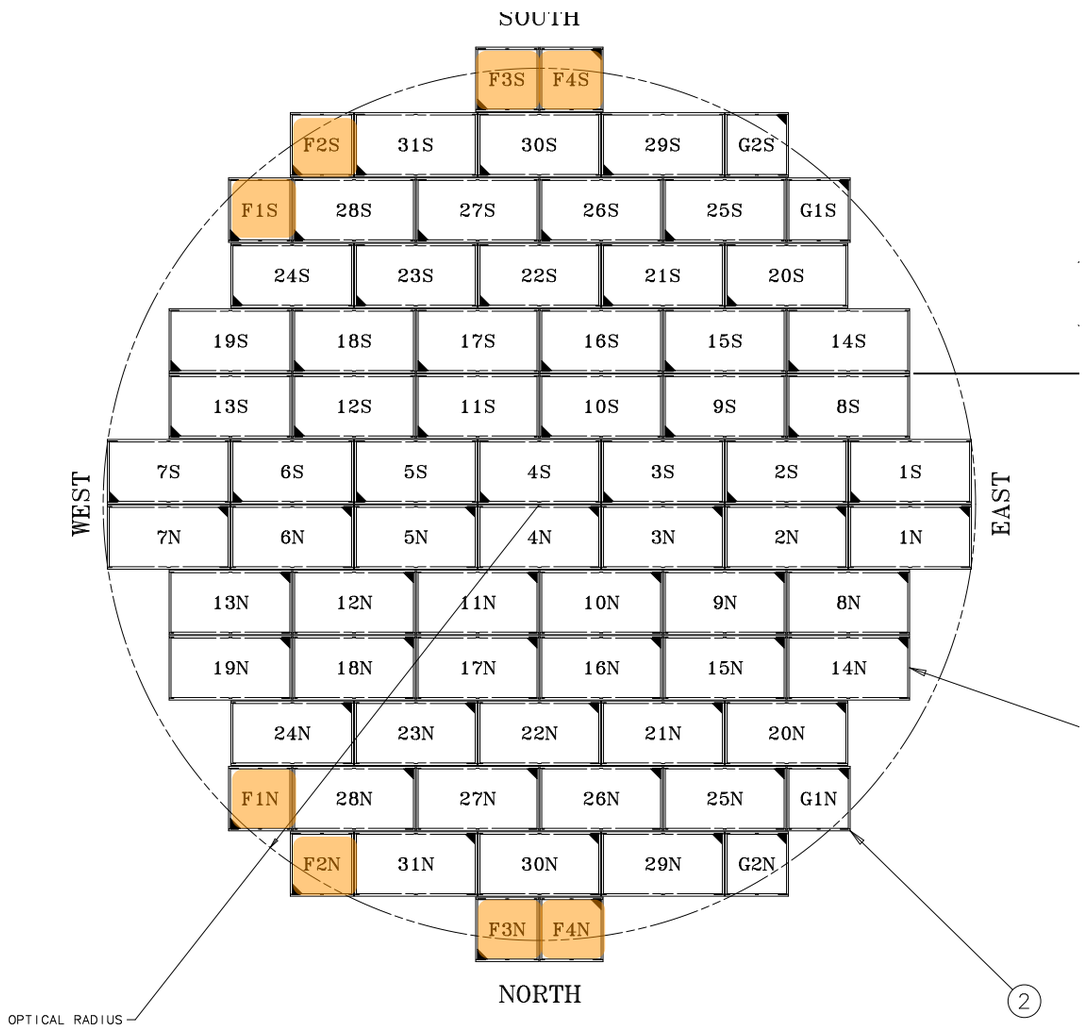
Image Quality Workshop

DECθm Focus & θlignment



- 8 CCDs (2Kx2K)
- 4 pairs on edge of focal plane
- 1.5mm above/below focal plane
- readout with science sensors
- Focus&Alignment (F&A) algorithm runs as part of SISPI
- stellar images (donuts) analyzed in time to adjust alignment and focus for N+2 image
- information about higher order aberrations for possible use to adjust mirror figure

Fitting Algorithm

- Model Wavefront at the pupil plane as a sum of Zernike terms

$$W(u,v) = \sum_{i=4}^{i<37} c_i Z_i(\rho,\theta)$$

- Calculate Donut image via Fourier Transform from pupil ⟹Focal plane

$$PSF(x,y) \sim \left| \mathcal{F}\left\{ P(x,y) e^{i\frac{2\pi}{\lambda}W(u,v)} \right\} \right|^2$$

- Convolute with smearing for Atmosphere, pixelate.

$$I(x,y) \sim PSF \otimes Atmos \otimes Pixel$$

- Use non-linear χ^2 fit to determine Zernike coefficients

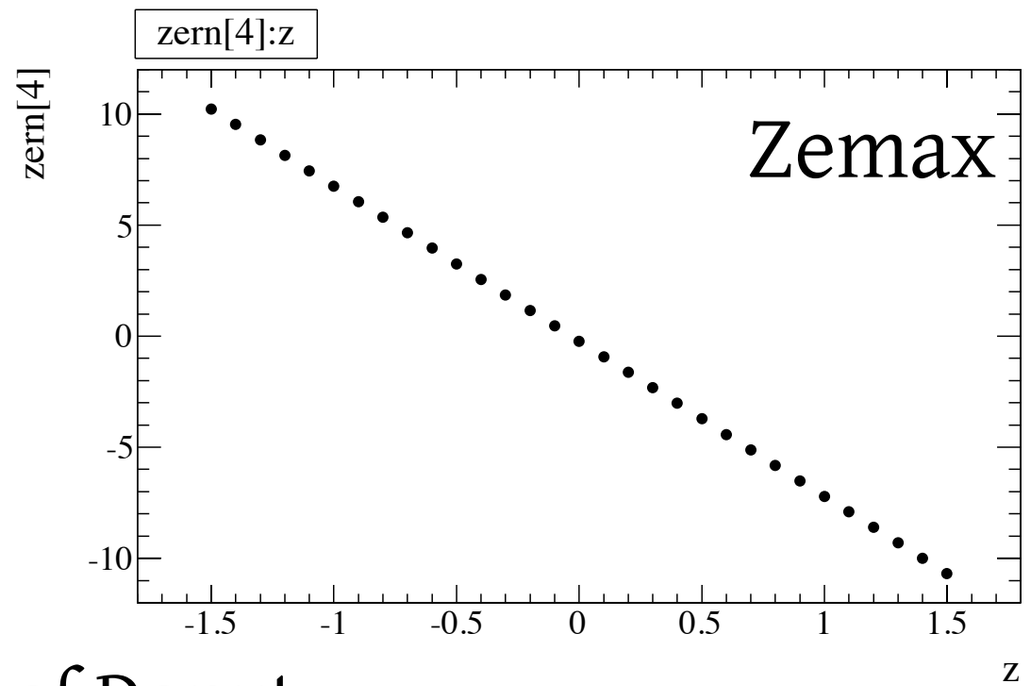
Zernike Expansion

Z 1	12.28460110 :	1		piston
Z 2	0.00000008 :	4^(1/2) (ρ) * COS (θ)		tilt x
Z 3	-0.46250619 :	4^(1/2) (ρ) * SIN (θ)		tilt y
Z 4	6.92547583 :	3^(1/2) (2ρ^2 - 1)		defocus (power)
Z 5	0.00000004 :	6^(1/2) (ρ^2) * SIN (2θ)		Astigmatism x
Z 6	0.06993887 :	6^(1/2) (ρ^2) * COS (2θ)		Astigmatism y
Z 7	-0.15628710 :	8^(1/2) (3ρ^3 - 2ρ) * SIN (θ)		Coma x
Z 8	0.00000000 :	8^(1/2) (3ρ^3 - 2ρ) * COS (θ)		Coma y
Z 9	-0.24016914 :	8^(1/2) (ρ^3) * SIN (3θ)		Trefoil x
Z 10	-0.00000008 :	8^(1/2) (ρ^3) * COS (3θ)		Trefoil y
Z 11	-0.11712697 :	5^(1/2) (6ρ^4 - 6ρ^2 + 1)		Spherical Aberration
Z 12	0.02619978 :	10^(1/2) (4ρ^4 - 3ρ^2) * COS (2θ)		Secondary Astigmatism x
Z 13	-0.00000001 :	10^(1/2) (4ρ^4 - 3ρ^2) * SIN (2θ)		Secondary Astigmatism y
Z 14	0.07663680 :	10^(1/2) (ρ^4) * COS (4θ)		Tetrafoil x
Z 15	-0.00000003 :	10^(1/2) (ρ^4) * SIN (4θ)		Tetrafoil y

- Focus: Z_4

$$Z_4 \approx \frac{\Delta z}{16\sqrt{3}F^2\lambda}$$

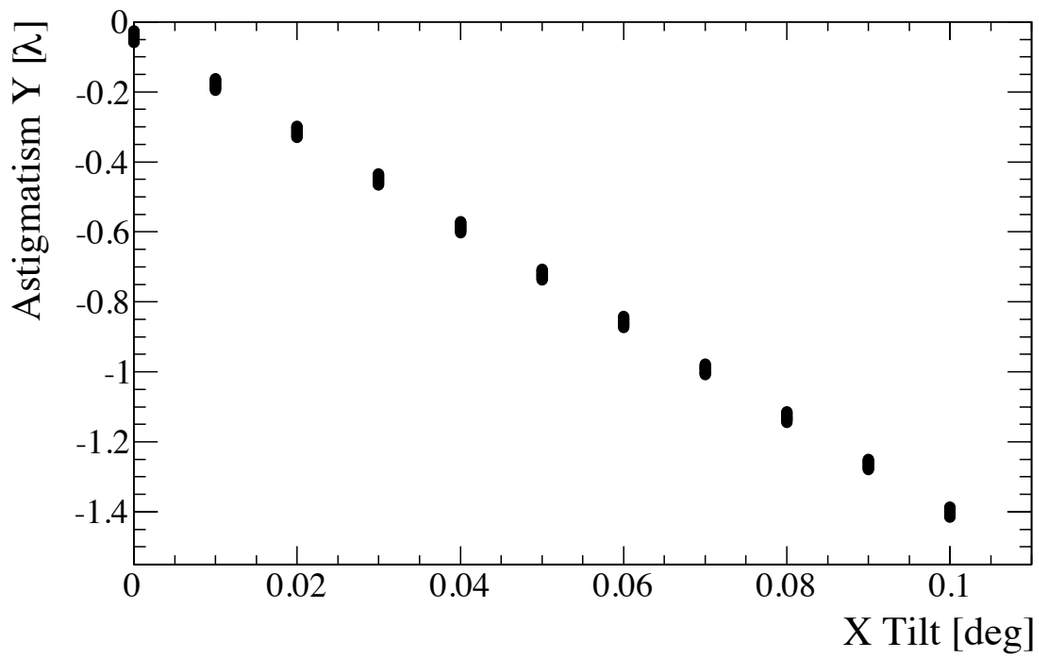
Zernike Coeff have units of λ

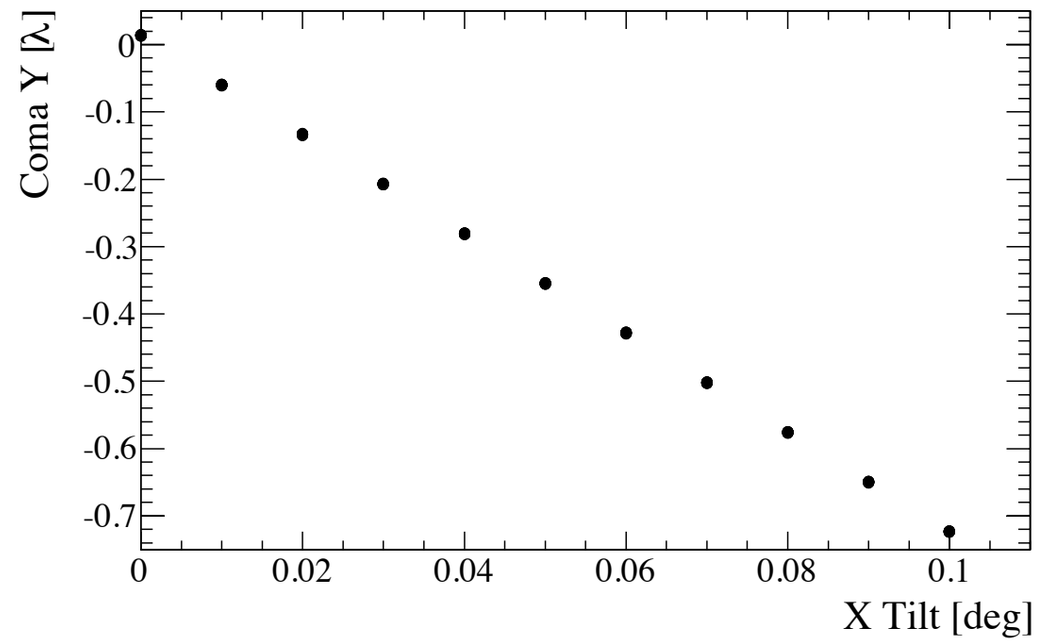


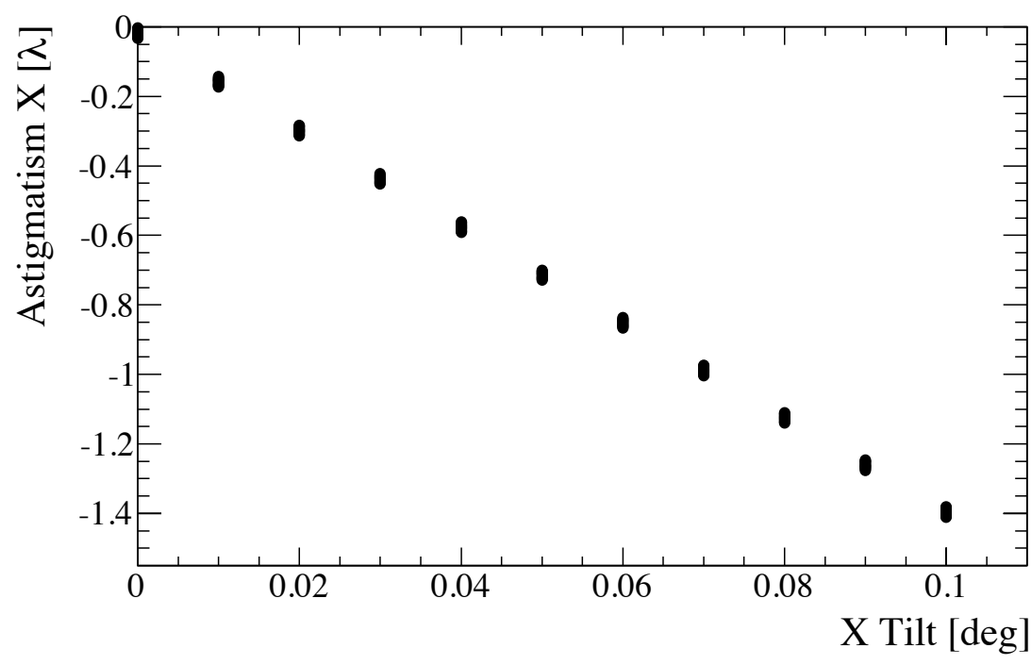
- Tilt: Z_2, Z_3 equivalent to x,y position of Donut
- Decenter?
- DECam Tilt and Decenter ⇒Astigmatism, Coma terms

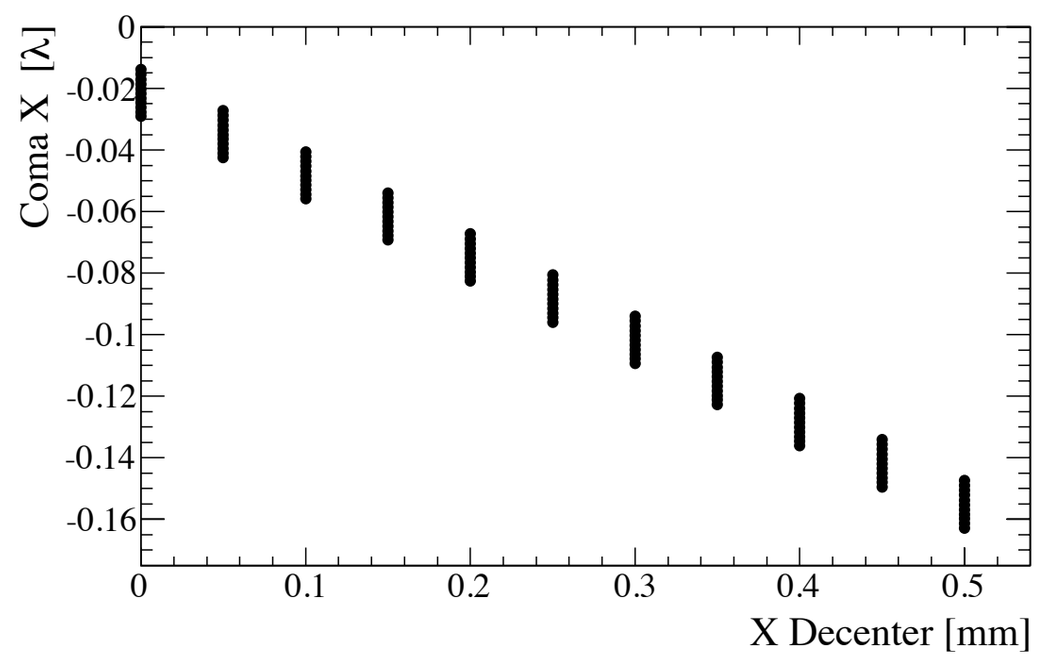
Study Tilt and Decenter

- Simulate tilt and decenter (x-view) of DECam (Zemax)



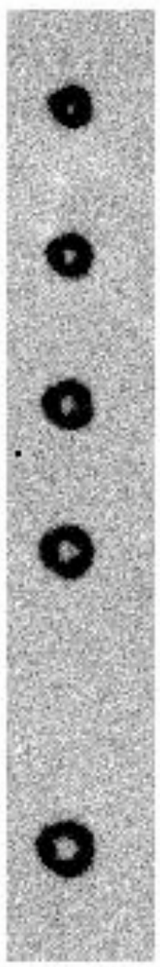


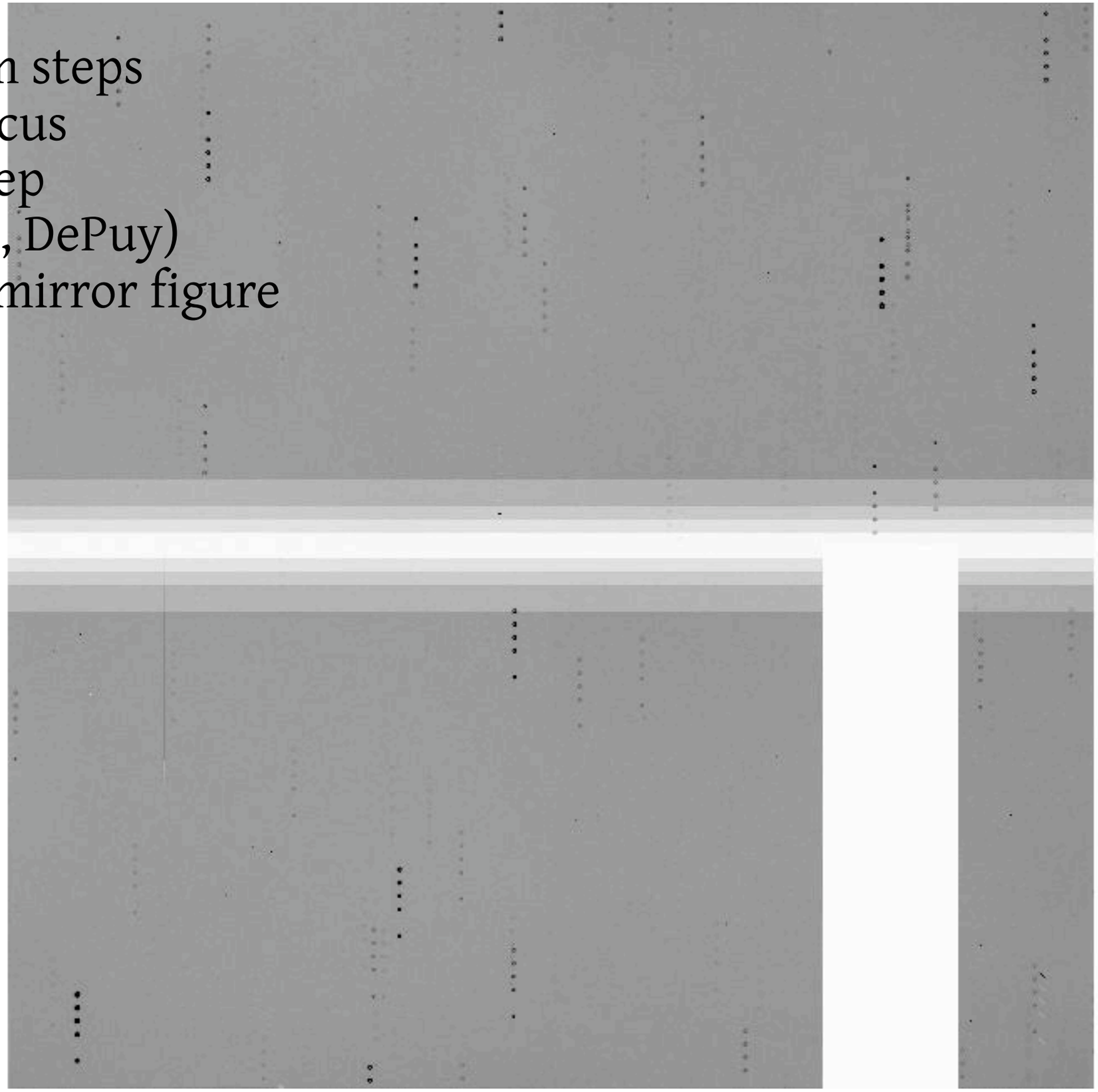




MosaicII donut images

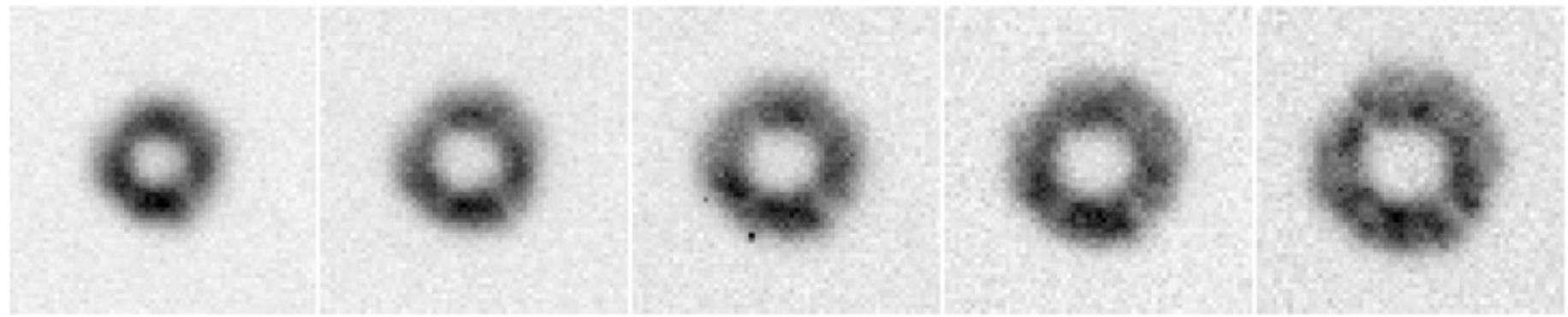
- 5 Focus settings, 100μm steps around 1.2mm from focus
- 10sec exposures per step
- taken in July 09 (Burke, DePuy)
- no LUT corrections of mirror figure





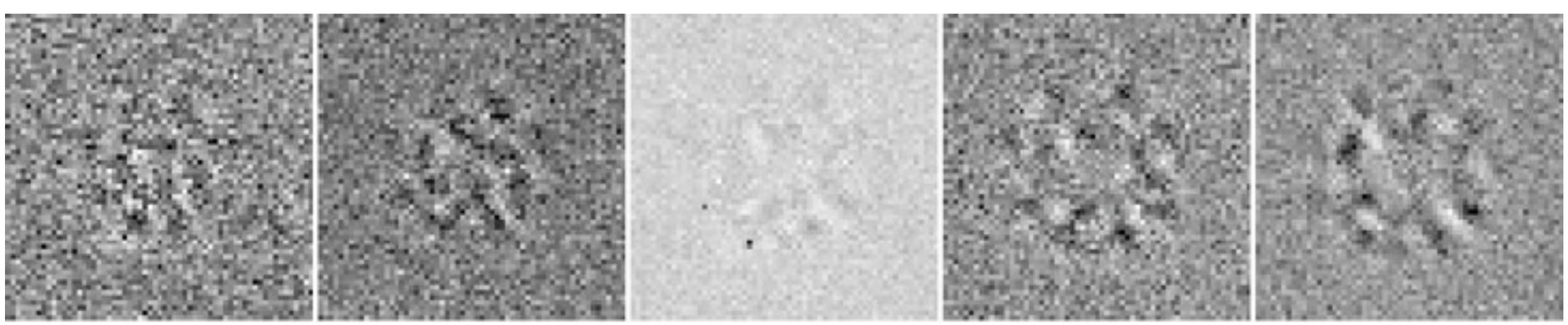
F&A Algorithm on MosaicII Donuts

- Fit in 2 passes
- First pass float Defocus & Atmosphere (r_0)
- Second pass fix r_0 and float 37-3 Zernike Coeff.
- Float x,y position, nPhotoElectrons, flat “bkgd” in both fits



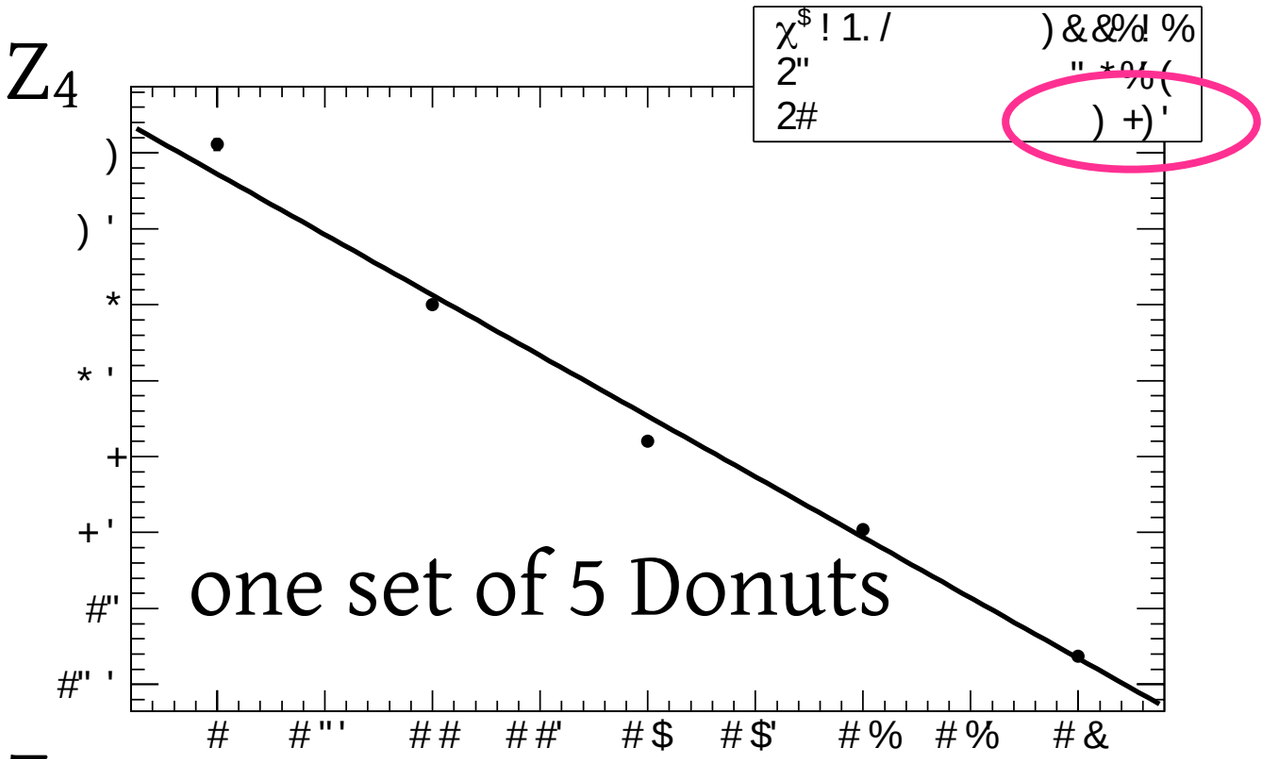
Donut

Fit

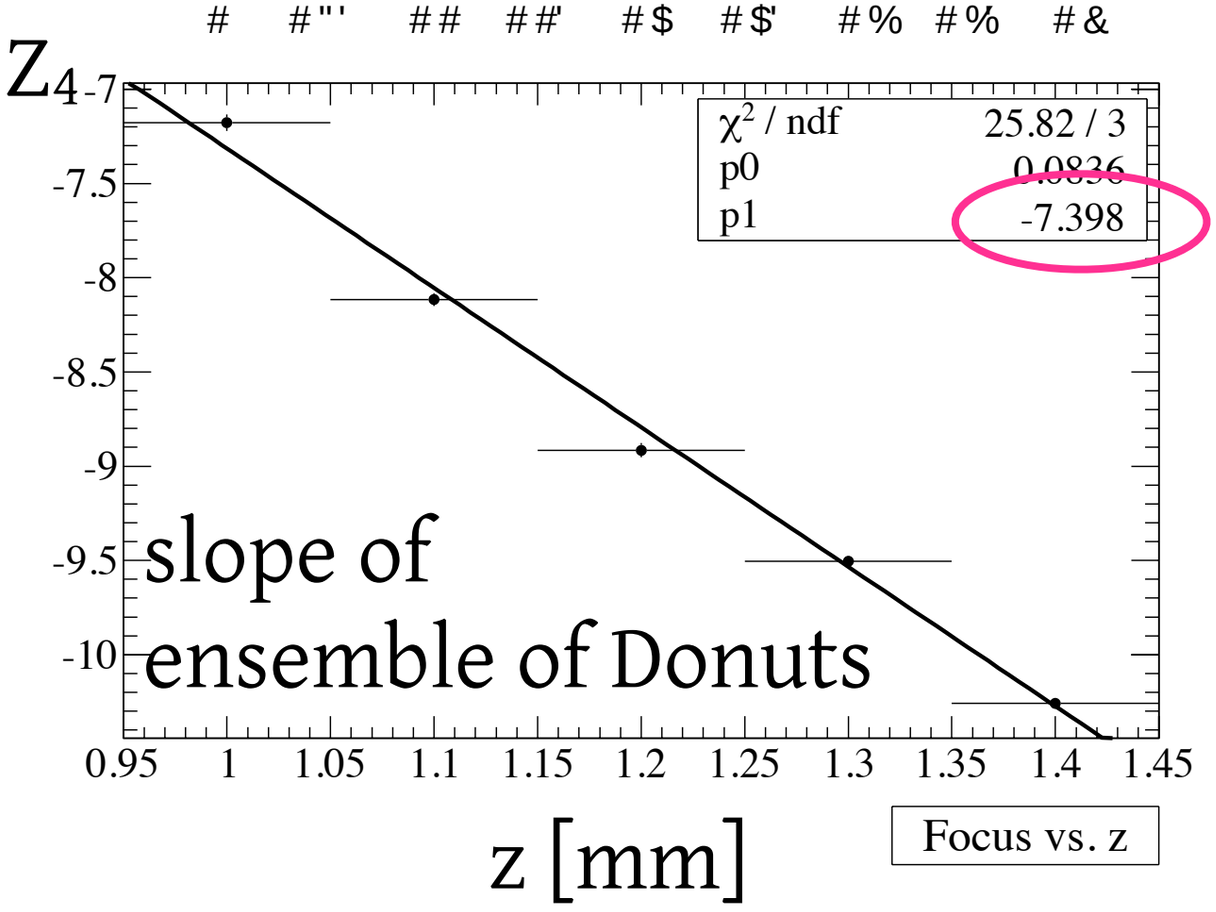


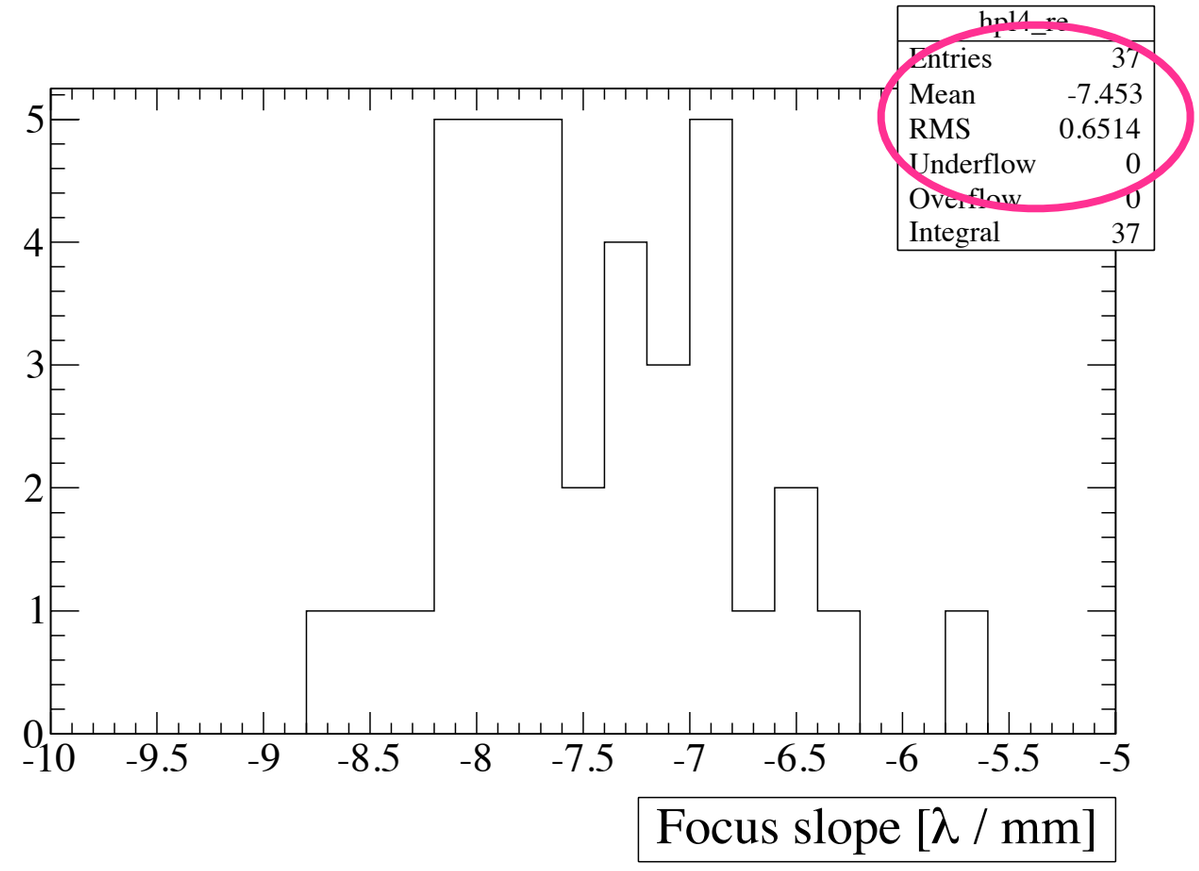
Residual

Defocus in MosaicII Images



expect slope of 6.7 [λ/mm]





Issues in MosaicII Images

- Higher frequency residuals in images, even with 37 Zernike terms
- 5 images of same star are similar and Zernike terms are roughly similar, but not in good agreement
- Defocus vs. z makes poor linear fits, especially for Donuts with more light
- ⇒ Images are only 10 second exposures - perhaps not long enough to average out Atmosphere or other stochastic effects

more Donuts with MosaicII

- multiple images per field - study repeatability of Zernike terms
- focus frames with 10-100 sec exposures - study minimum exposure and accuracy of defocus measurement
- focus frames for different Alt/Az - study changes in Zernikes
- introduce (small) known tilt or higher order aberrations in primary, via airpads - study calibration of Zernike terms

Details in F&A Algorithm

- FFT Grid size
  need 512x512 grid to cover entire Donut at 1.5mm out of focus but can scale Zernike terms by 2 to use 256x256 if needed, needs detailed study to check accuracy

- Algorithm speed (Optimized Python code on 2.2GHz MacBook)
  Fit to Defocus and r_0 with 256x256 : ~30 seconds
  Fit to Defocus and r_0 with 512x512 : ~120 seconds
  Fit to 15-3 Zernike terms with 256x256 grid: ~25 seconds
  Fit to 15-3 Zernike terms with 512x512 grid: ~100 seconds
  input r_0 from in-focus stars; cpu time depends on how close starting parameters are from minimum

- preFit analysis:
  need good starting points for r_0, nPhotoElectrons, Z_4, bkgd
- location of central obscuration depends on Focal plane position, parametrize for each F&A sensor
- complicated central obscuration from filter holders, spider etc.., need to model accurately to model donuts