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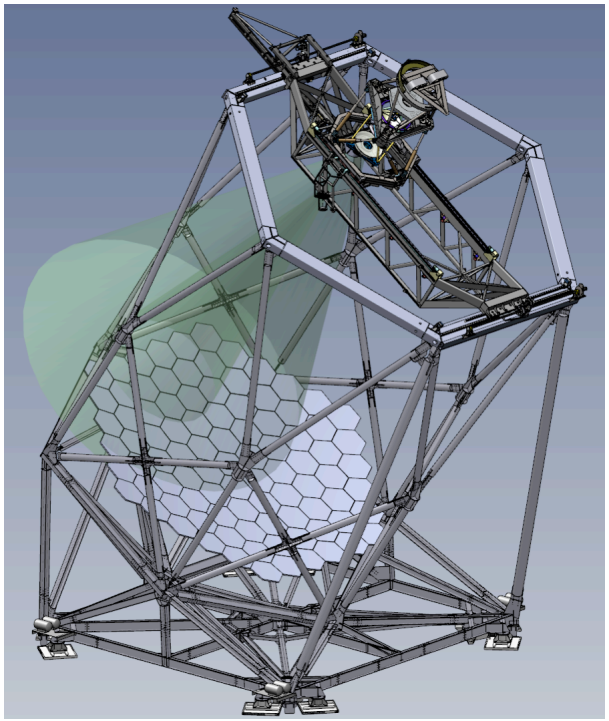
# HET Tracker Test Plan Review:
## Mount Models



Tuesday, March 8

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# Mount Models: Overview

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- What coordinates do I have to give to the control system to get where I want to go?
- The transformation from the theoretical coordinates to those coordinates is the “Mount Model”.

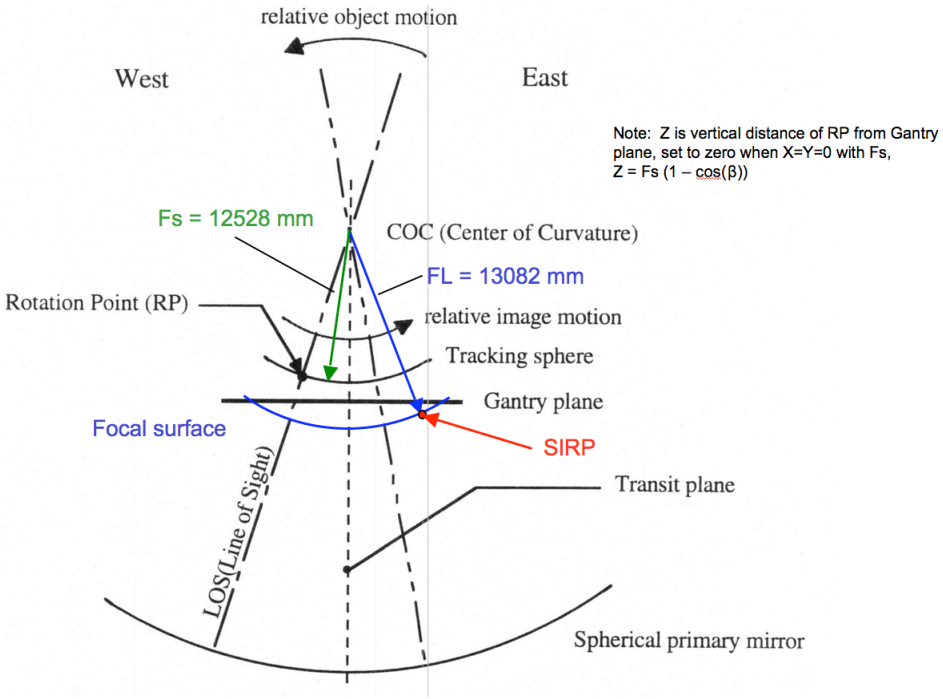
- Mount models help us satisfy two requirements:
  - Set tracker initial position to within capture range of metrology

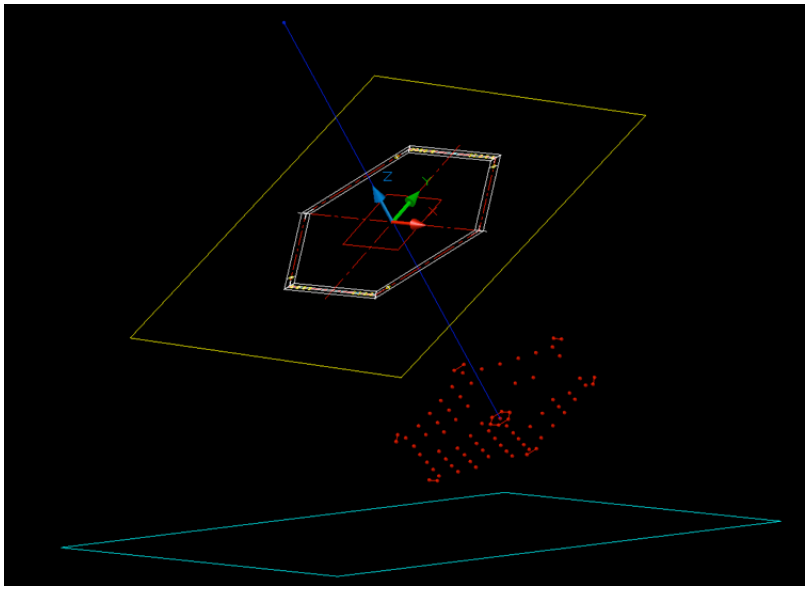
| | Defocus | Decenter | Tip/Tilt | Rho |
|---|---|---|---|---|
| **ACAM** | | 2.9′ x 2.9′ | | |
| **GCAM** | | 22.6″ x 22.6″ | | |
| **DMI** | ±20000 μm | | ±25″ | |
| **TTCAM** | | | ±75″ | |
| **WFS** | ±50 μm | ±50 μm | ±20″ | ±20″ |

  - Maintain position between metrology updates, to within IQ spec

# Coordinate Systems: ITF

- The ITF is a mathematical construct, defined by COC and PM center
  - and not an actual, measureable reference frame in and of itself
- X = Y = 0 on optical axis of primary mirror
- Fs parameter defines location of the tracking sphere relative to COC
- All coordinates are “ideal”, as for a perfect tracker



**Ideal Tracker Frame (ITF)**
1) **X**, **Y**, and **Z** axes are orthogonal
2) Positive direction for the **X**, **Y**, and **Z** axes is as shown by the arrows
3) **W** axis passes through the M1 COC and SIRP, and is positive towards the M1 COC
4) Beta (**β**) is the angle between the **W** axis and the **Z** axis
5) Theta (**θ**) is the angle between the **Z** axis and the projection of the **W** axis onto the **YZ** plane
6) **θ** rotates about an axis that is parallel to the **X** axis
7) Phi (**φ**) is the angle between the **Z** axis and the projection of the **W** axis onto the **XZ** plane
8) **φ** rotates about an axis that is parallel to the **Y** axis
9) Rho (**ρ**) is rotation about the **W** axis
10) Positive direction for **θ**, **φ**, and **ρ** is based upon the right-hand rule

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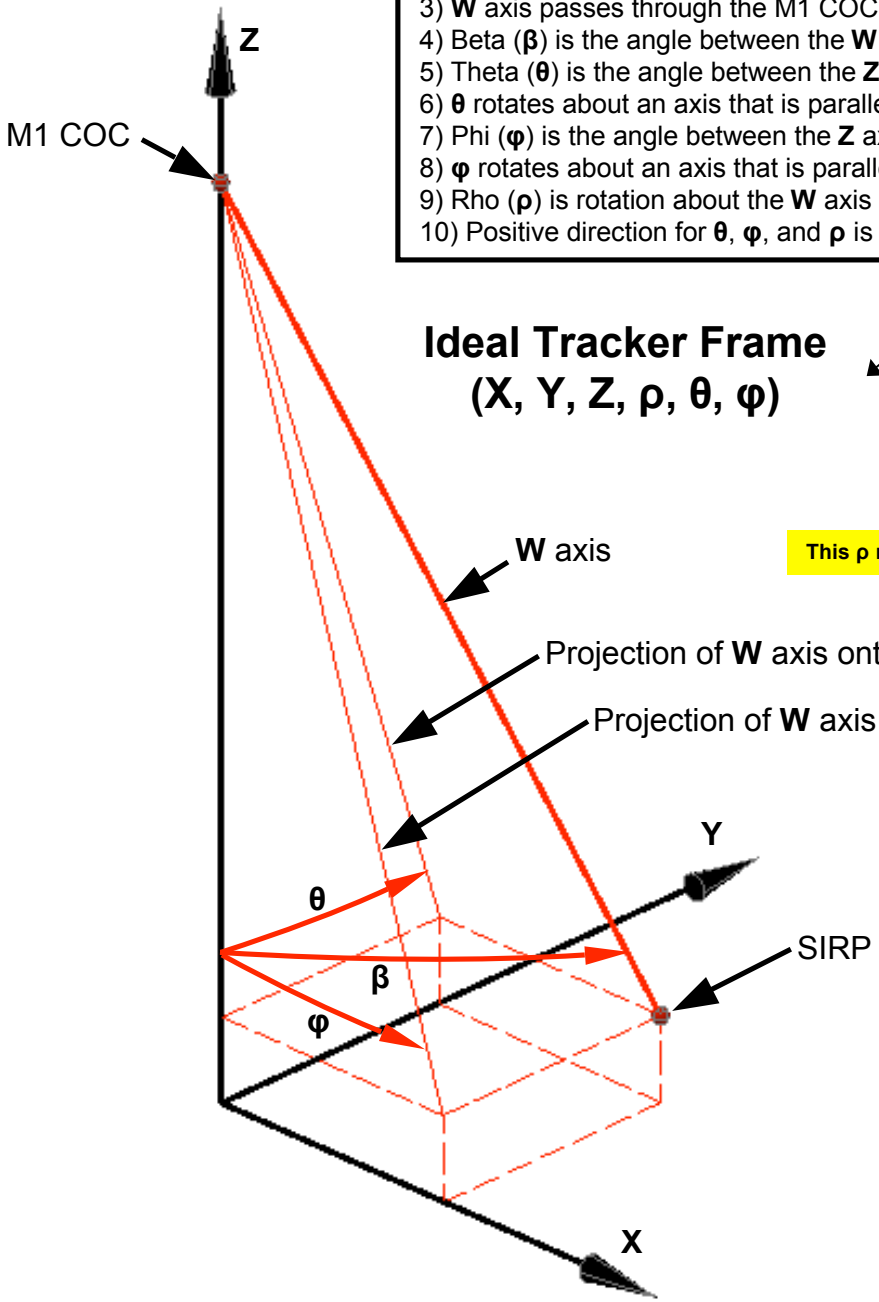
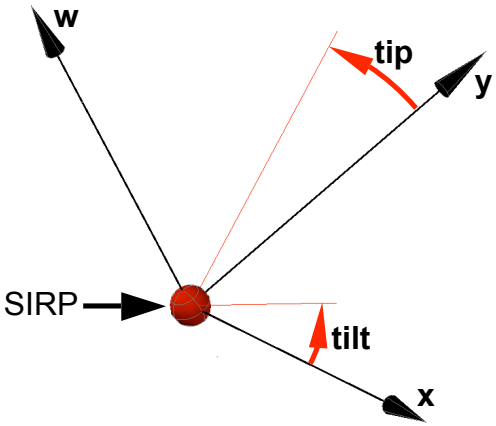
## Ideal Tracker Frame
## (X, Y, Z, ρ, θ, φ)

**This ρ relates to the real rho stage**

**This ρ relates to the WFC optical axis**



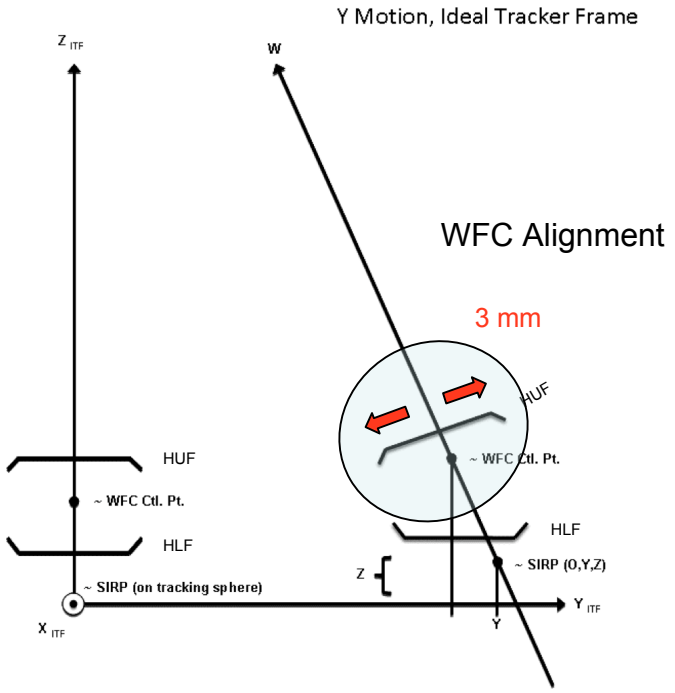

## SIRP Frame
## (dx, dy, dw, dρ, tip, tilt)

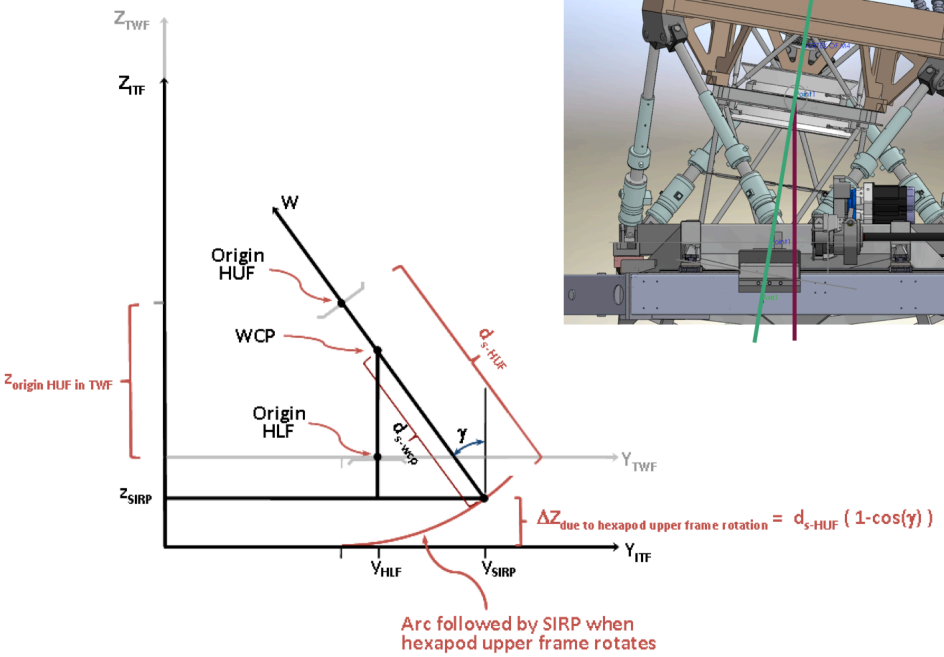



**SIRP Frame**
1) **x**, **y**, and **w** axes are orthogonal
2) **w** axis is coincident with the WFC's optical axis
3) Positive direction for the **x**, **y**, and **w** axes is as shown by the arrows
4) **tip** is rotation about the **x** axis
5) **tilt** is rotation about the **y** axis
6) Rho (**ρ**) is rotation about the **w** axis (not the same as **ρ** in ITF)
7) Positive direction for **tip**, **tilt**, and **ρ** is based upon the right-hand rule
8) When **β** = 0 and **ρ** = 0 the **x** and **X** axes are parallel to one another
9) When **β** = 0 and **ρ** = 0 the **y** and **Y** axes are parallel to one another

# Coordinate Systems: Tracker Frames

- Real, physical coordinate systems (measured against ref points)
  - Hexapod Upper Frame (HUF) - attached to PFIP strongback
  - Hexapod Lower Frame (HLF) - attached to X/Y carriage
  - Tracker Working Frame (TWF) - origin @HLF origin when X/Y @midpts
  - Top Hexagon Frame (THF) - interface between tracker and telescope



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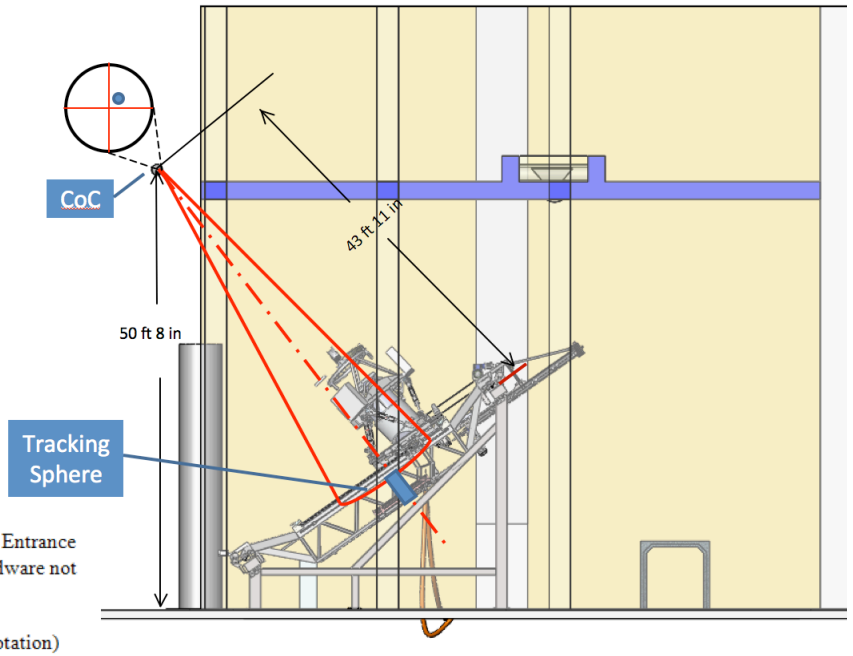
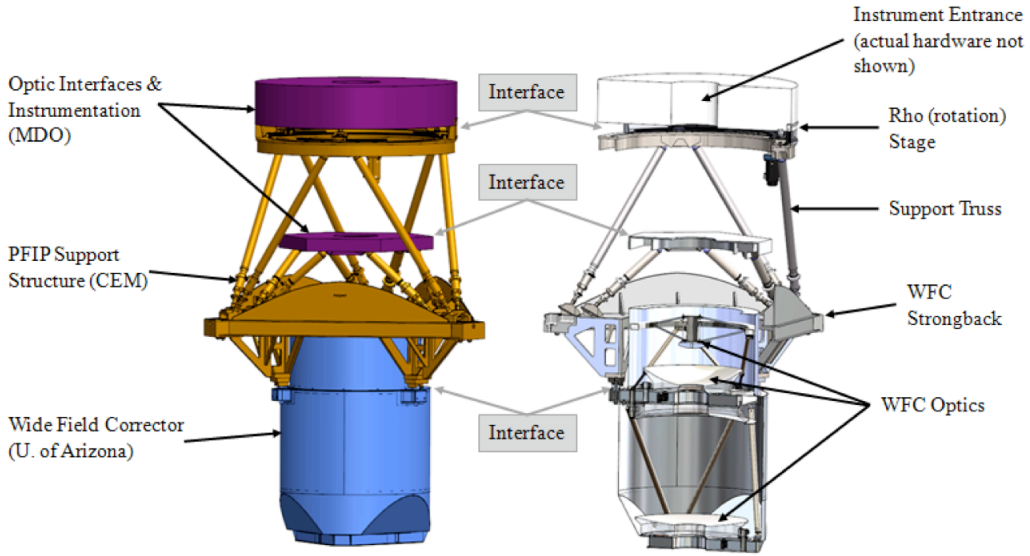
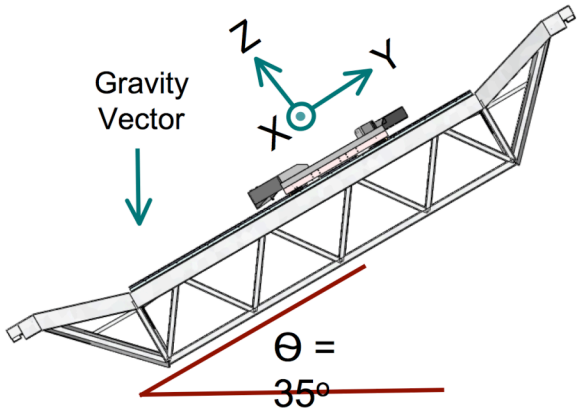
# Transformations

- ITF to TWF
  - Work out from coords of COC and PM center in TWF
- SIRP to TWF
  - Via WFC to PFIP (HUF)
    - Initially from Arizona



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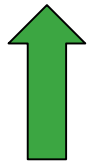
# Key Mount Models

- Mechanical
  - Axis Straightness and Orthogonality
  - Rail Sag (remeasure at HET)
  - Rail Curl (remeasure at HET)
  - Upper Hex Deflection (remeasure at HET)
  - Hexapod Characterization (e.g. joint positions)
  - Relationship of WFC to PFIP (UA/CEM FEA, refine on sky)
  - Focal Plane Assembly Deflection

Measure in lab



Implement in Tracker

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Implement in TCS

- Astronomical
  - Pier Tilt
  - Tube Tilt

Measure at HET

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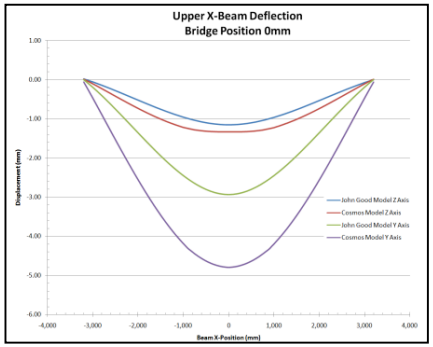
# Strategy

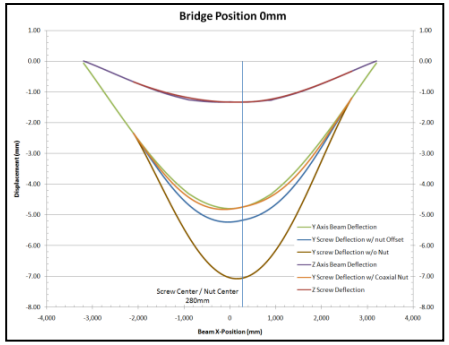
- Hide mechanical details of Tracker from TCS
- Keep astronomical parameters out of Tracker
- Deconvolve physical effects as much as possible
- Measure each separately
- Measure as much as possible in the lab
- At the telescope, measure as much as possible during the day, in closed dome
- Leave the minimum to be resolved with on-sky measurements
  - e.g. simple offsets in azimuth and elevation as a function of azimuth
  - too much degeneracy otherwise

# Rail Sag: Z as a function of X,Y

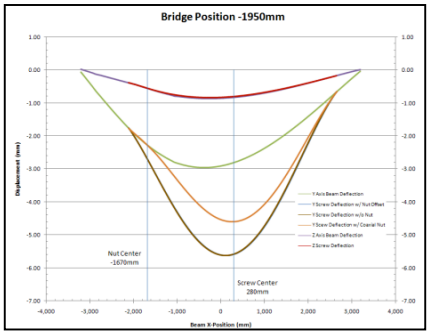
Upper X-beam Z and Y deflections with bridge at center of travel (0mm)



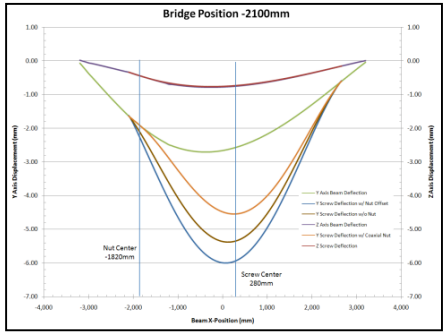

**X-beam and screw deflections with bridge at center of travel (0mm)**

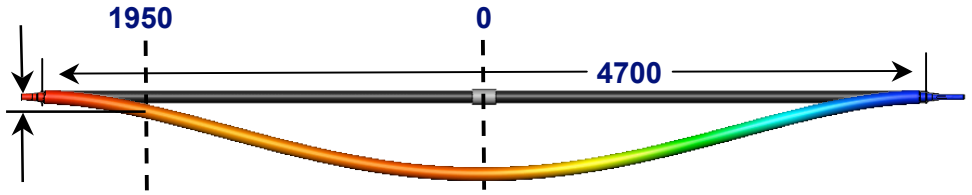



X-beam and screw deflections with bridge at end of free travel (1950mm)



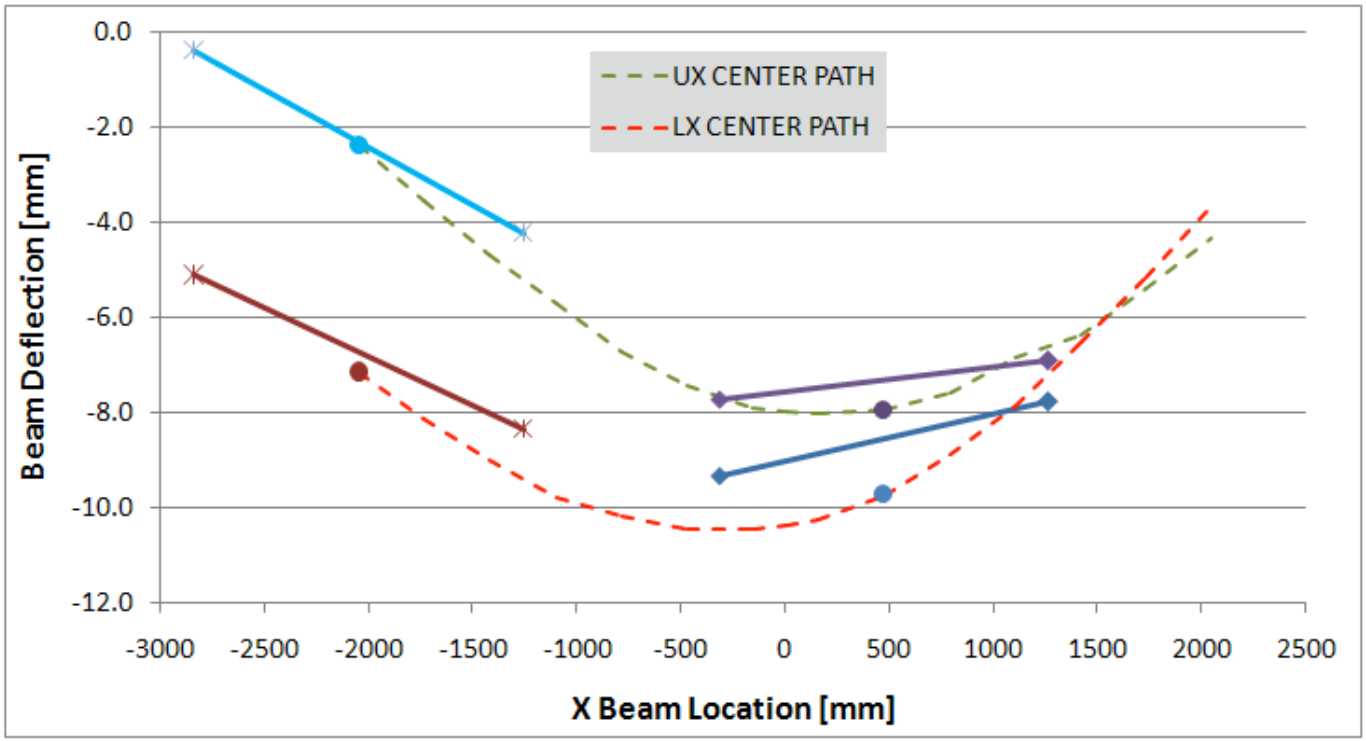

**X-beam and screw deflections with bridge at end of overtravel (at bumpstop – 2100mm)**



# Rail Curl

- Upper hex beams (UX & LX) deflect under tracker payload
- Different deflections of UX & LX causes tracker bridge to twist
  - Resulting in Theta/Phi corrections as a function of X,Y



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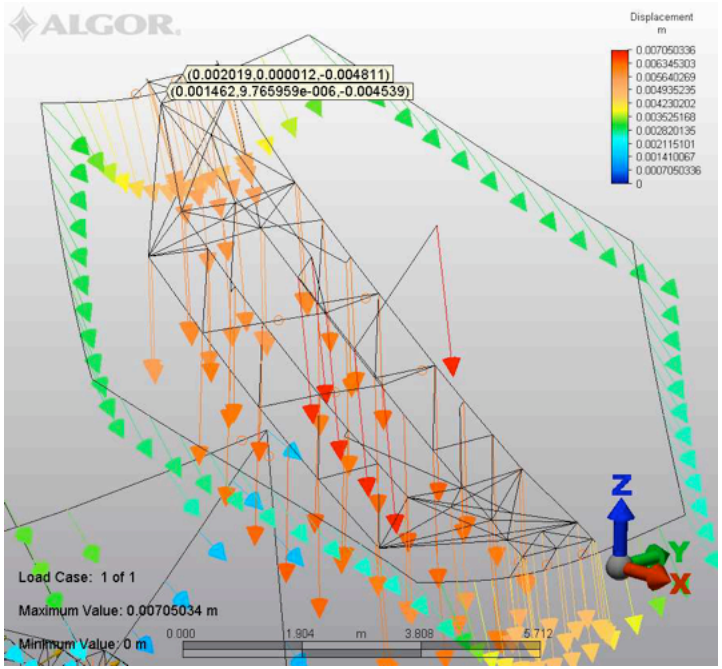
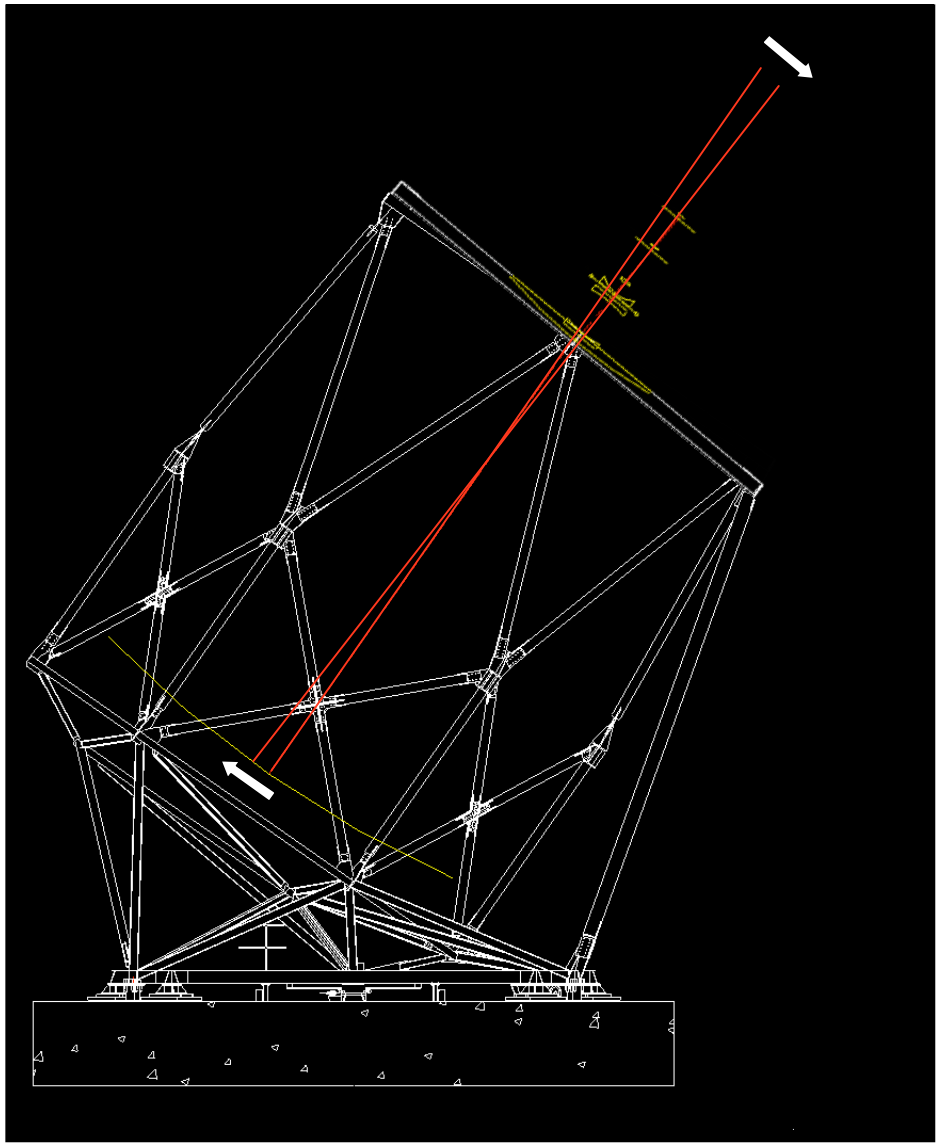
# Upper Hex Deflection

- TWF moves relative to ITF
- Taken up by an explicit transformation of ITF to TWF
- Can vary with Tracker X,Y



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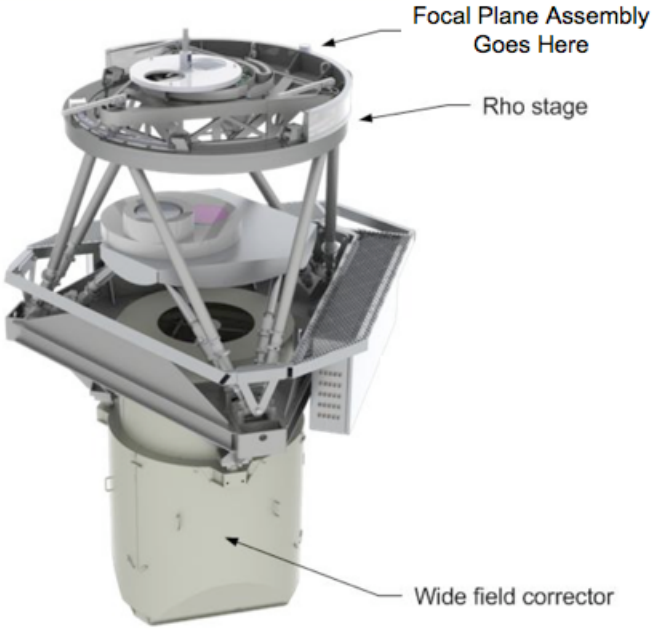
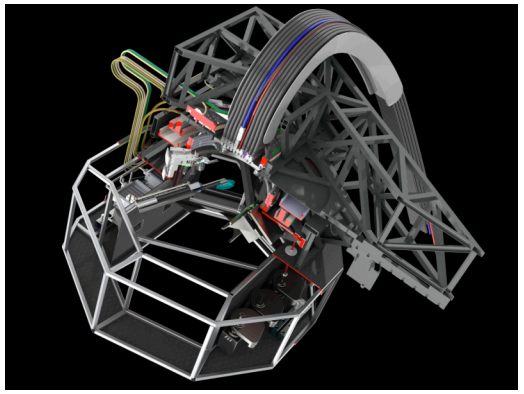
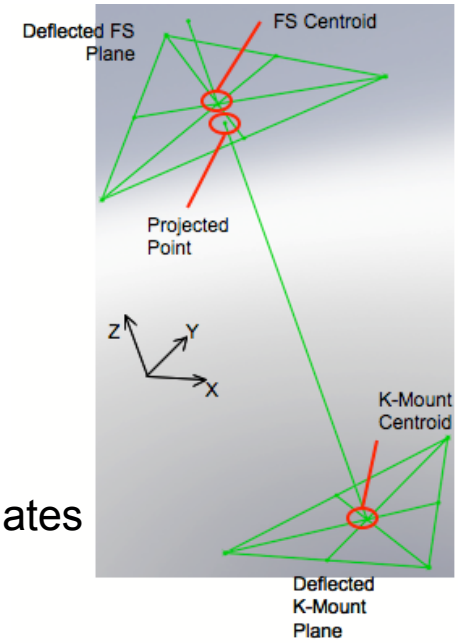
# Deflection of Focal Plane Assembly






- Decenter
  - Σ PFIP, WFC deflections & rho runout ≤ 400 μm p-p over track
- But very small between metrology updates
- Model FEA results as X/Y offsets
- Defocus
  - Σ PFIP, WFC deflections & rho runout ≤ 100 μm p-p over track
  - Only 10 μm of corrector focus, very small between metrology updates
- Residuals from FEA model can easily be guided out

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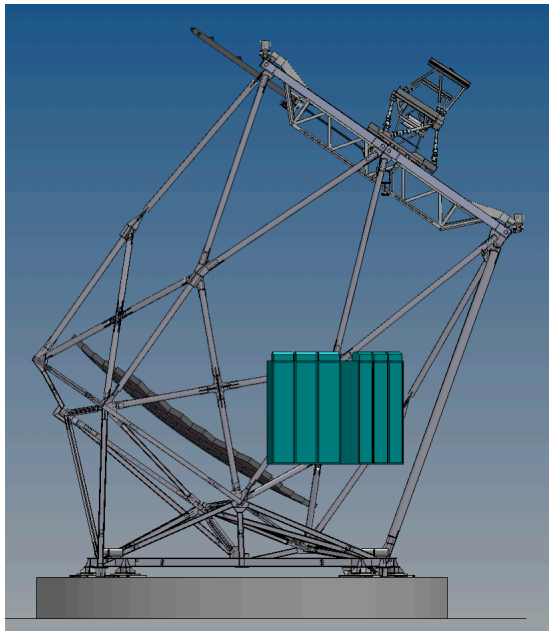
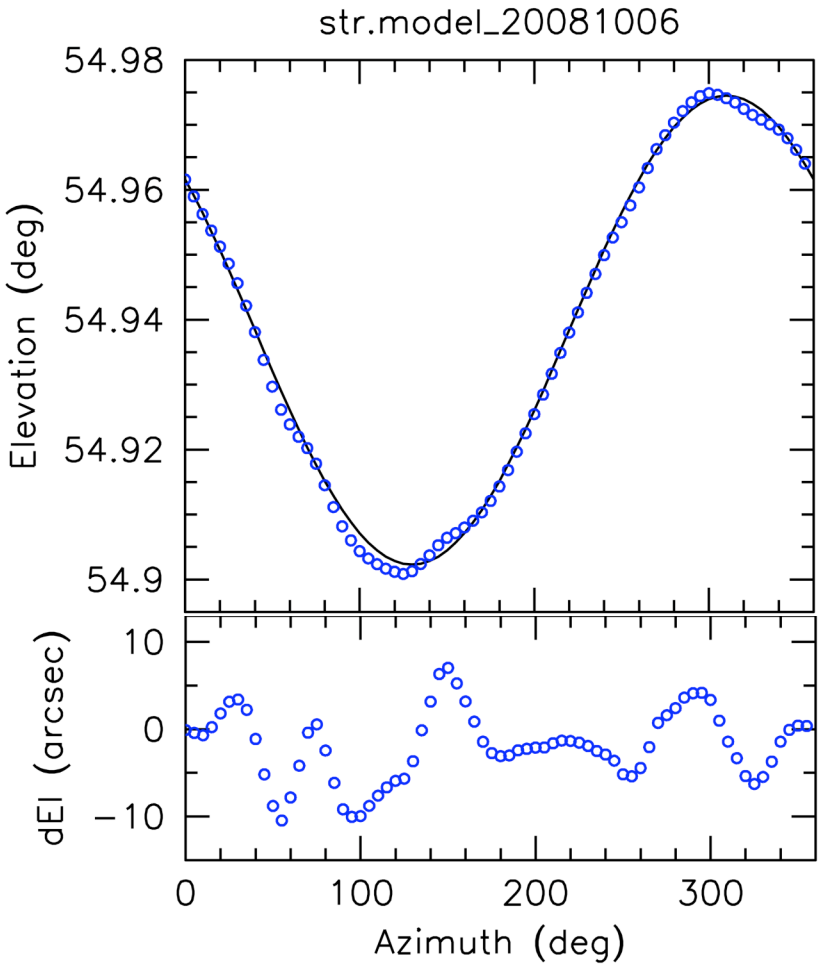
# Pier Tilt

- Pier is not quite level
  - Cosine dependence on Azimuth, 260 arcsec peak to peak
- Pier is not flat
  - Deviations of ±10 arcsec
  - Handle with lookup table





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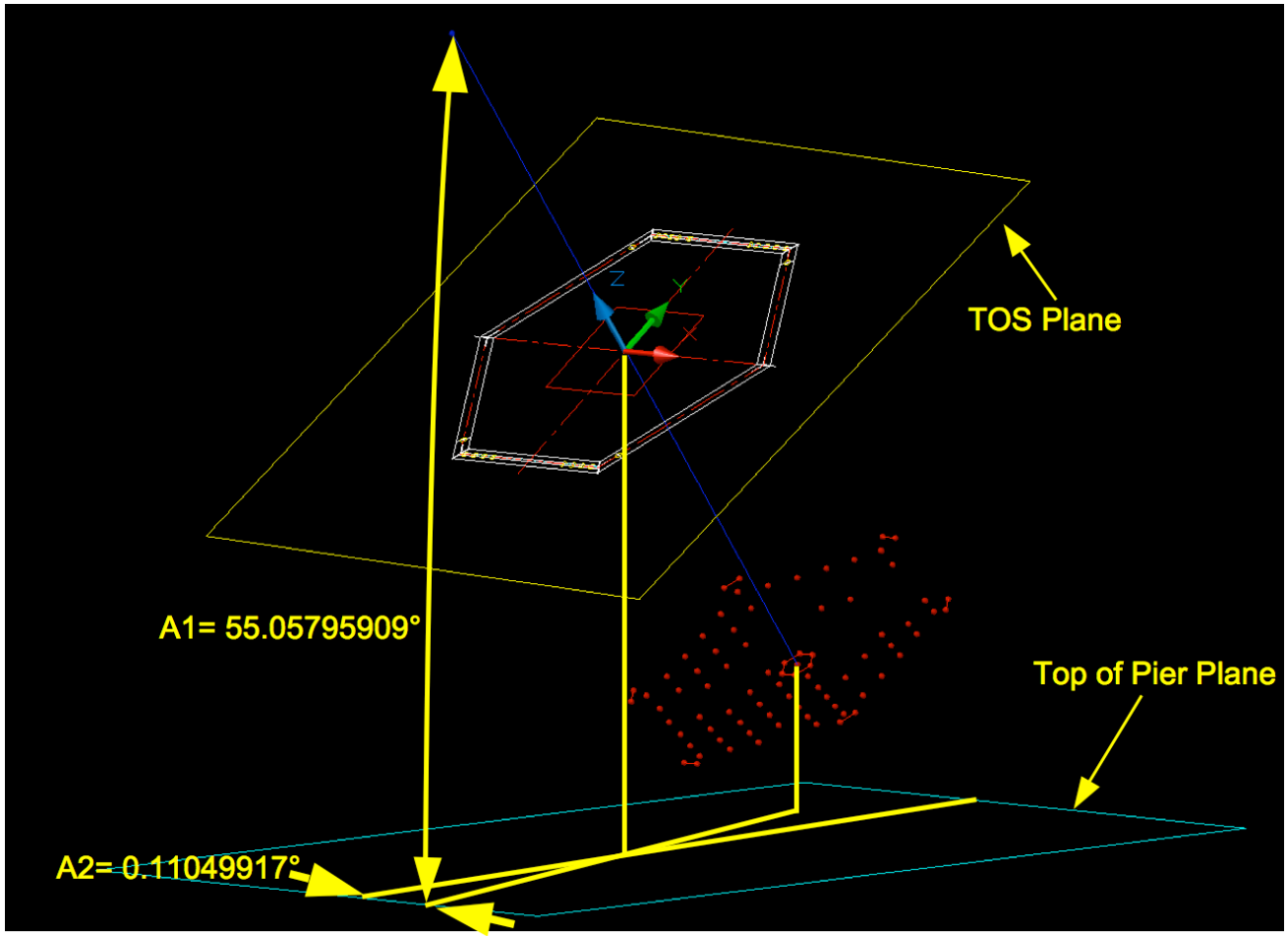
# Pier Tilt

- Sokkia measurements from CCAS
  - note the sign difference in the elevation offset



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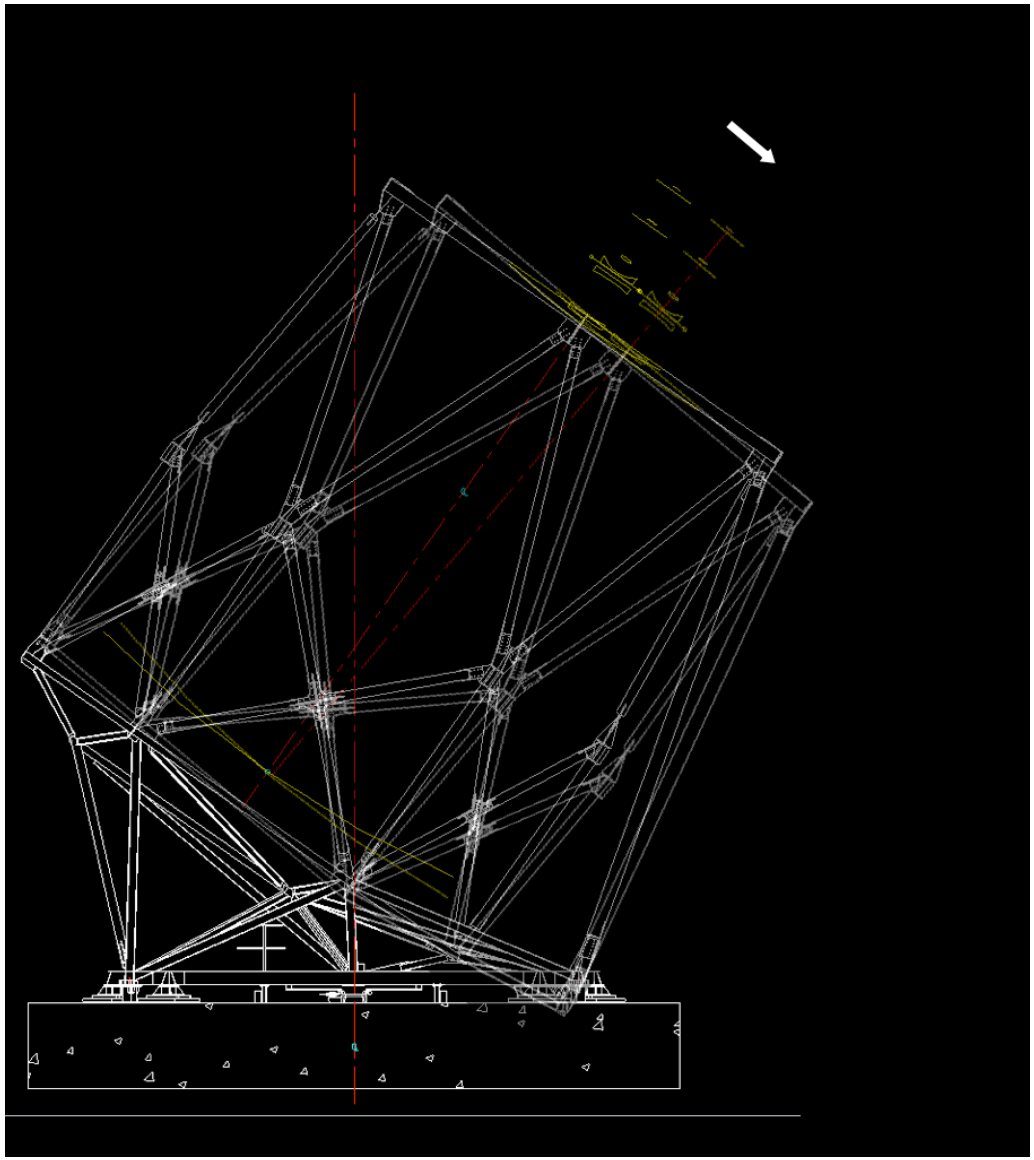
# Tube Tilt

- Telescope tips as a solid body
- This tip is not seen by the transformation of TWF to ITF
- Amounts to a pointing offset on sky, i.e. a change in telescope elevation and azimuth
- Can vary with Tracker X,Y

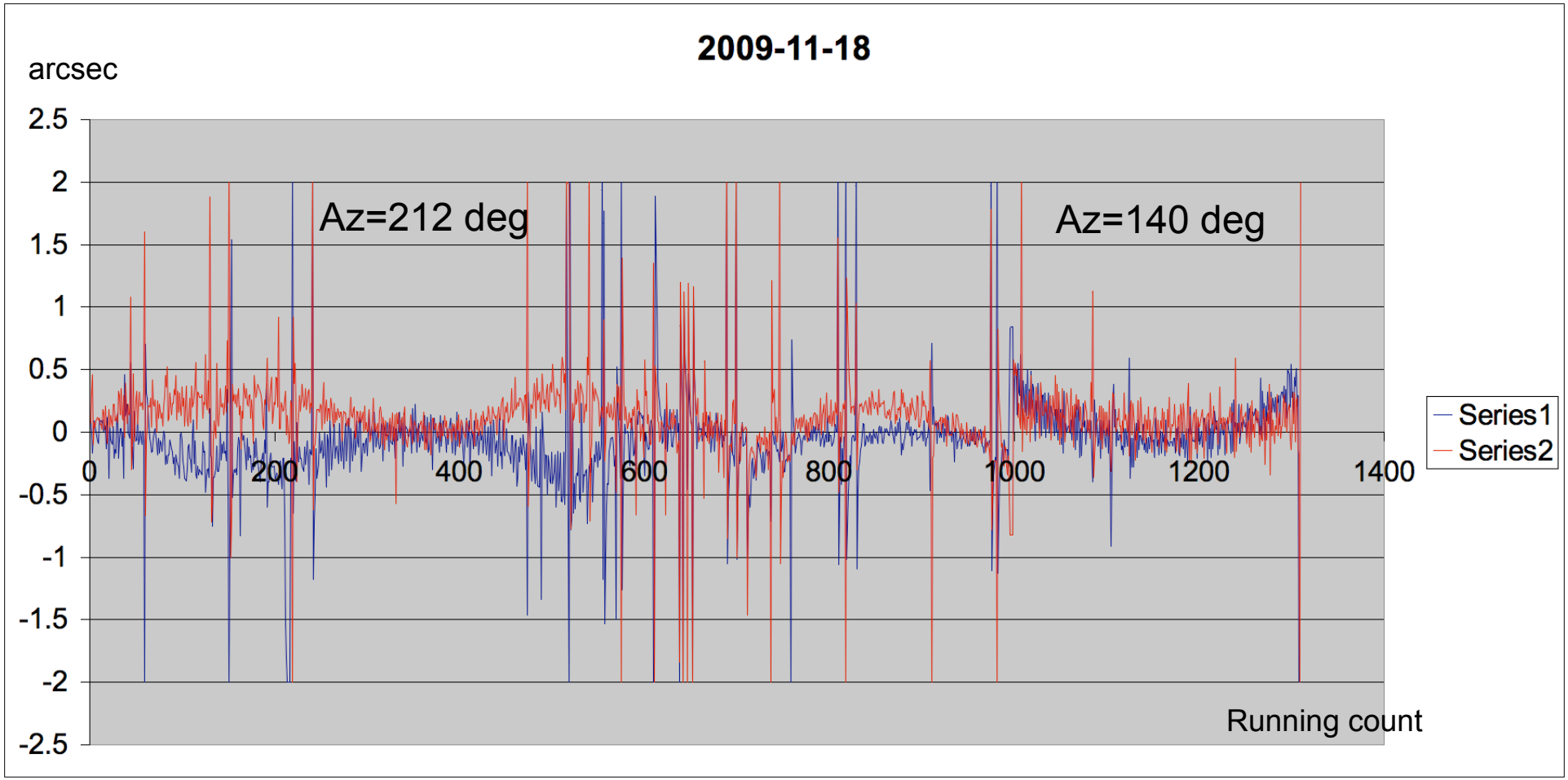


# Coming Attractions: Refinement at HET

- On telescope
  - Relate WFC optical axis to the PM optical axis with alignment telescope
  - Determine zeropoints for tracker and metrology systems
  - Measure COC, PM center as seen from tracker to relate TWF to ITF
  - Measure Upper Hex Deflection with laser tracker, mapping TWF to ITF
  - Use DMI and TTCam to refine Rail Sag and Rail Curl models
  - Re-measure pier tilt and pier flatness with laser tracker
- On sky
  - Determine offsets for guide/WFS/Acq cameras, DMI and TTCam
  - Refine WFC deflection map as a function of tracker X/Y
  - Refine FPA deflection map as a function of tracker X/Y/Rho
  - Map guide/WFS probe positions over FOV
  - Measure pointing offsets and hence elevation/azimuth offsets as f(az)
  - Photometric calibration of guide cameras

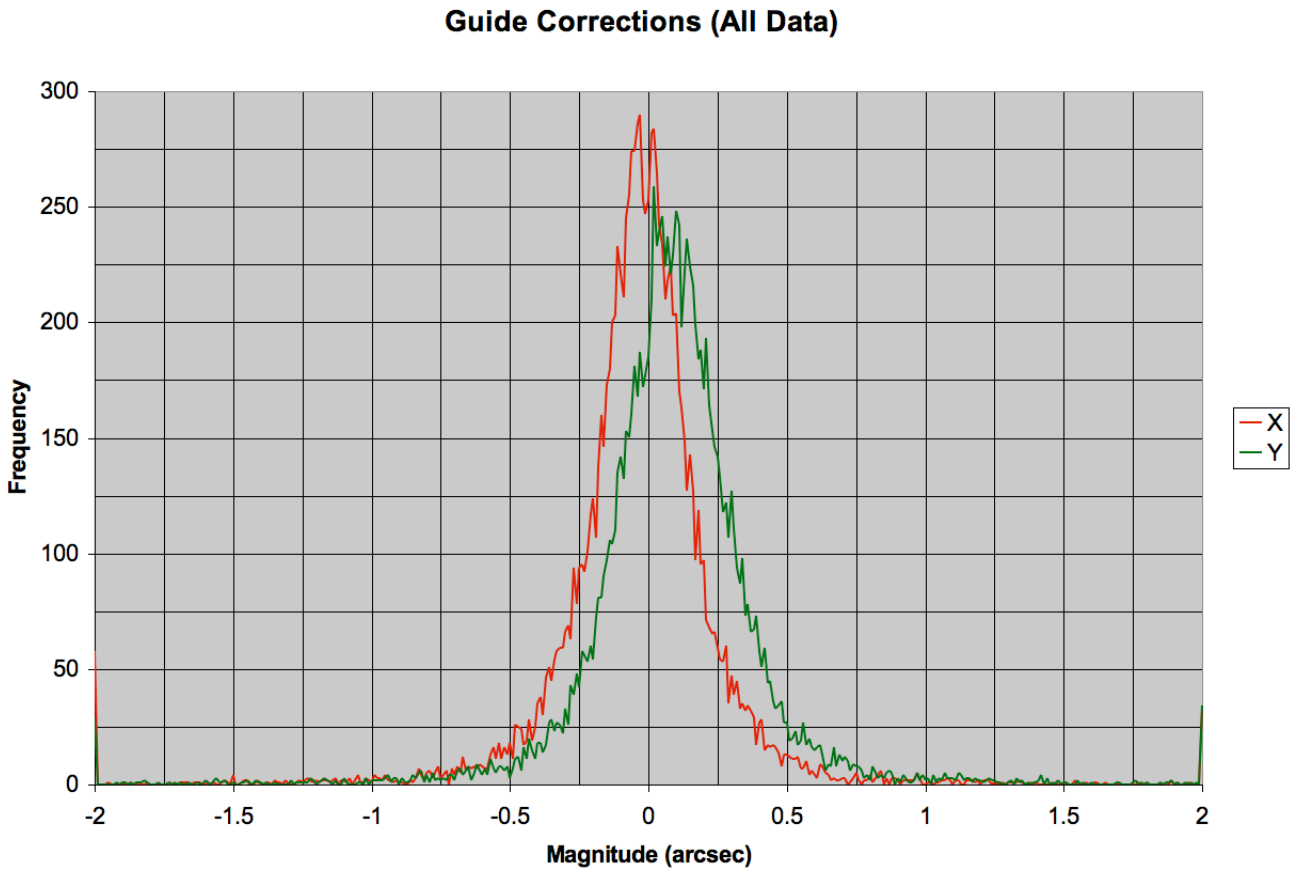
# Guide Corrections Trend Analysis

- Variation along track, changing with azimuth => geometry problem



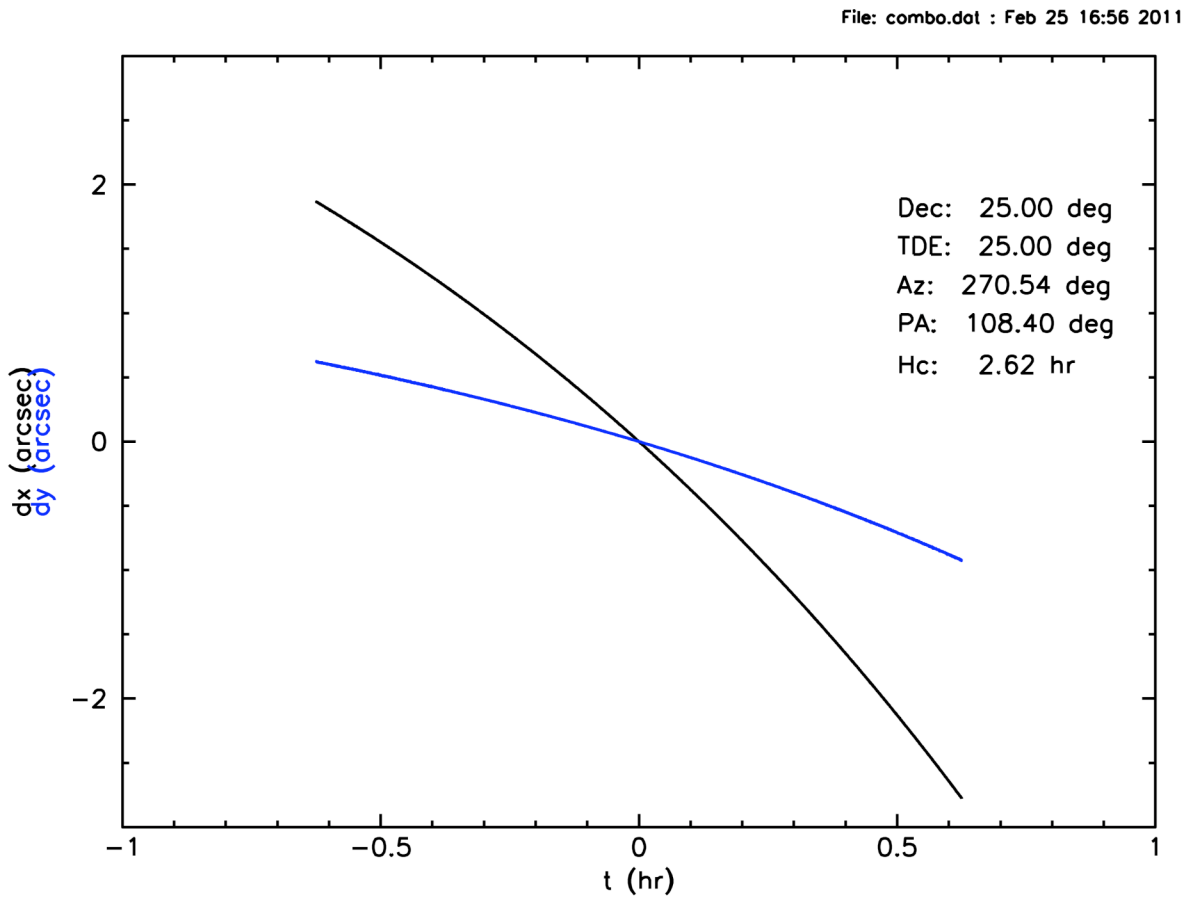
# Guide Corrections Trend Analysis

- If measured corrections do not scatter about zero, we have a drift



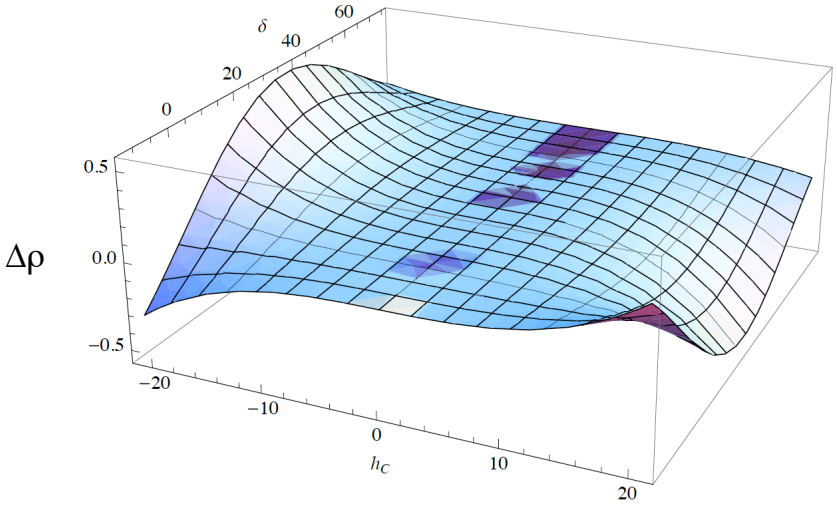
# What's New This Time?

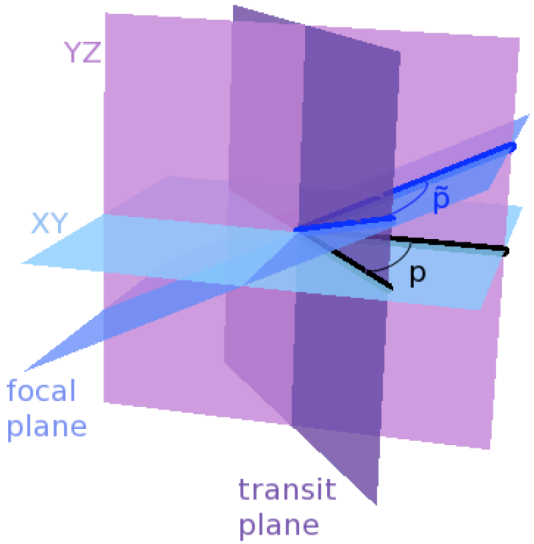
- Improved trajectory calculations: non-constant Declination
  - From atmospheric refraction; matters most when due East or West

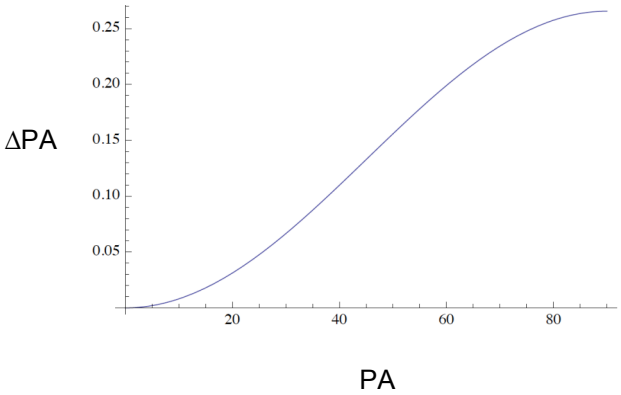


# What's New This Time?

- Improved trajectory calculations:
  - Corrected rho
  - Parallactic angle projected onto the focal plane




All angles in degrees

# What's New This Time?

- Better handling of corrections
  - No longer treat focus interchangeably with Z
  - No longer treat tip/tilt about SIRP interchangeably with Theta/Phi
  - Option to recompute trajectories on the fly
    - DMI, TTCAM, and WFS guarantee that we are on the correct sphere
    - Guider offsets show that we are pointing in the wrong place
    - So we offset along the sphere
      - i.e. recompute trajectory for a new RA/Dec position
  - Predictive guiding to measure and take out drift on the fly
    - Send extrapolated corrections between metrology system updates

- Better handling of mount models
  - Explicit transformation from ITF to TWF
  - Initial zero of ITF-to-TWF transformation each night against PM
  - Then position offsets in each pointing amount to offsets in Alt/Az
  - Preserve these zeropoints across tracks and from night to night