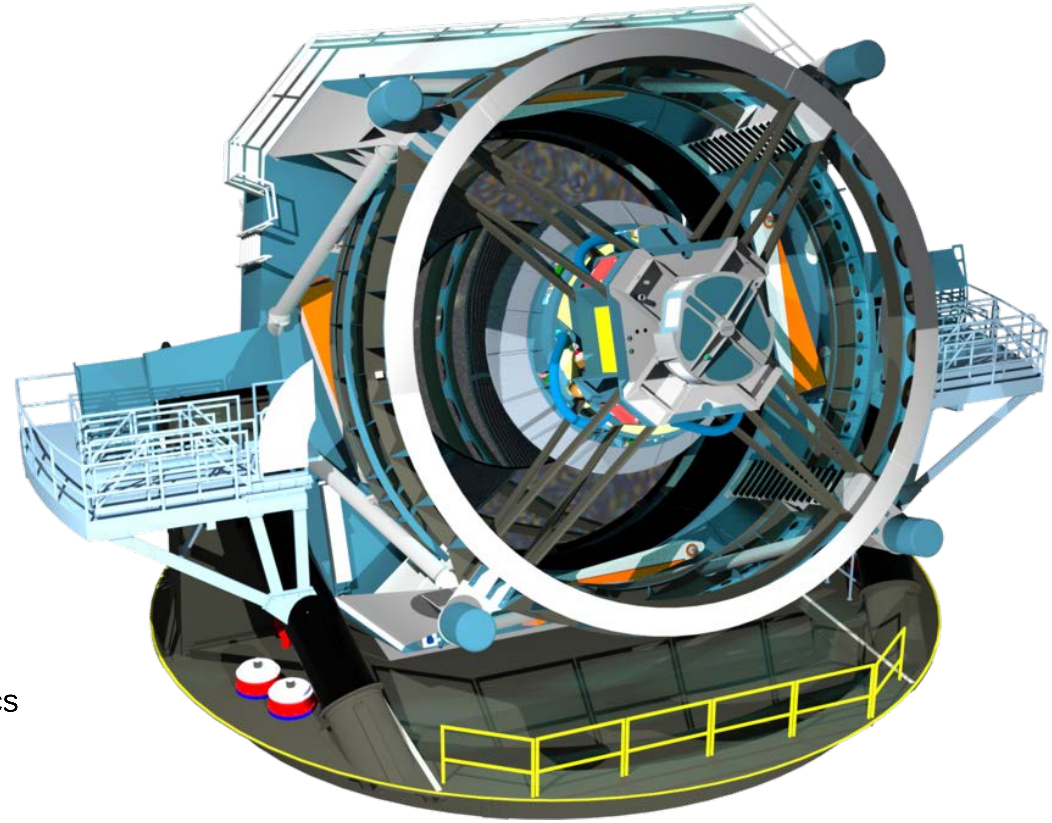
Fiber Positioners For LSST

Outline

- Different ways of placing optical fibers
- Mechanical Fiber Positioners as a solution
- Three Different Basic Types: Twirling Posts, Tilting Spines, Bugs
- Challenges at LSST*

*Assuming a Prime Focus Instrument w/ LSST optics



Tom Diehl (Fermilab)
Next Gen Spectroscopy with LSST
April 11, 2019 @ ANL

Acknowledgements

- Steve Kent, Kyler Kuehn, Joe Silber, Will Saunders, Michael Schubnell, Greg Tarle, Matthew Colless, Daren DePoy, Jennifer Marshall, Ting Li, Klaus Honscheid

How many spectra?

$$N_{\mathrm{Objects}} = N_{\mathrm{Fibers}} N_{\mathrm{Nights}} N_{\mathrm{Exp/Night}} W_{\mathrm{eather}}$$

- Some LSST Survey Characteristics
- 18,000 square degrees
- Mag limits
  - r<24.5 single epoch exp.
  - r<27.8 for 825 exp. Stacked => 20 Billion galaxies
- Acquiring 500M spectra demands high multiplexing. 20,000 is a reasonable number to start with.
- A Tough Problem:
  - DECAM Plate Scale (0.26 arcsec/15 microns): 0.1” position accuracy corresponds to 6um. 1’ target separation is 3.6 mm spacing
  - Fast reconfiguration, maximum throughput, highly reliable, cheap, easy to manufacture …

Plug Plates

- Plates are prepared in advance by drilling holes in the imaged locations of targets
- A person plugs fibers from a harness into the plate and an illumination trick is used to determine which fiber is in which hole
- A plate is useful only for one configuration and for a limited time at night
- If it costs ~$0.12 per plug to cast a plate ($50 for a plate of 5000 plugs), drill holes ($0.05 each), and have a person plug in fibers (one plate per 8hrs), then ½ billion object-visits costs ~$60M.
- A robot might make this reasonably economical but how do we stack and change plates? I didn't try to solve that.

SDSS

Rich Kron?

Pick & Place Robot

- AAΩ is a 492-fiber spectograph at Prime Focus of AAT
- Commissioned in 2006
- A robot picks up each fiber and places on the FP.
- Looks like there is a 45 deg mirror on the end of each fiber.
- They use two plates, observe on one, configure the next
- Limitation in #'s is due to space and complexity

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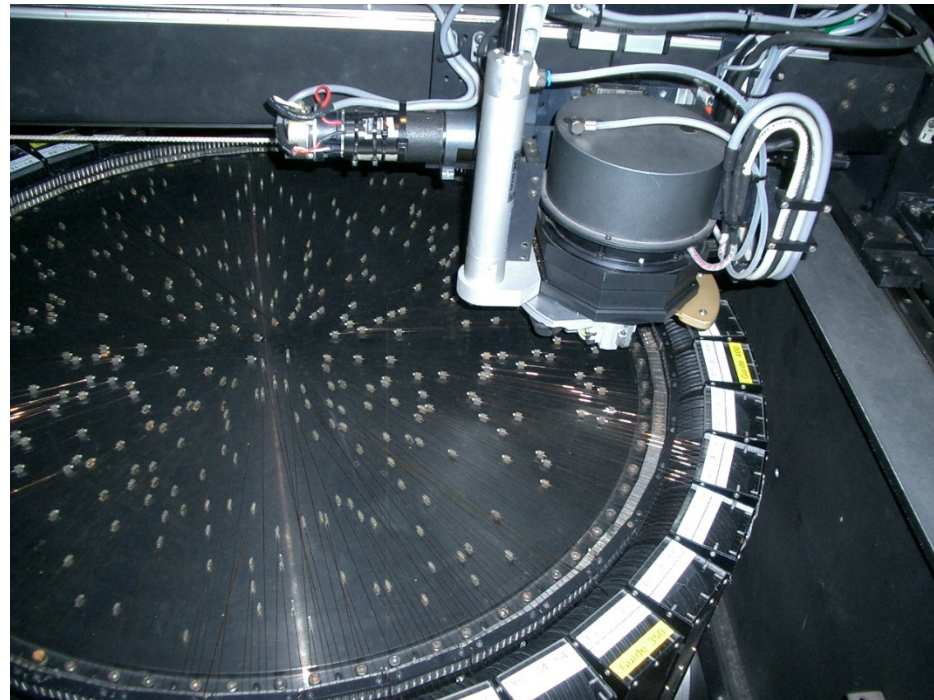
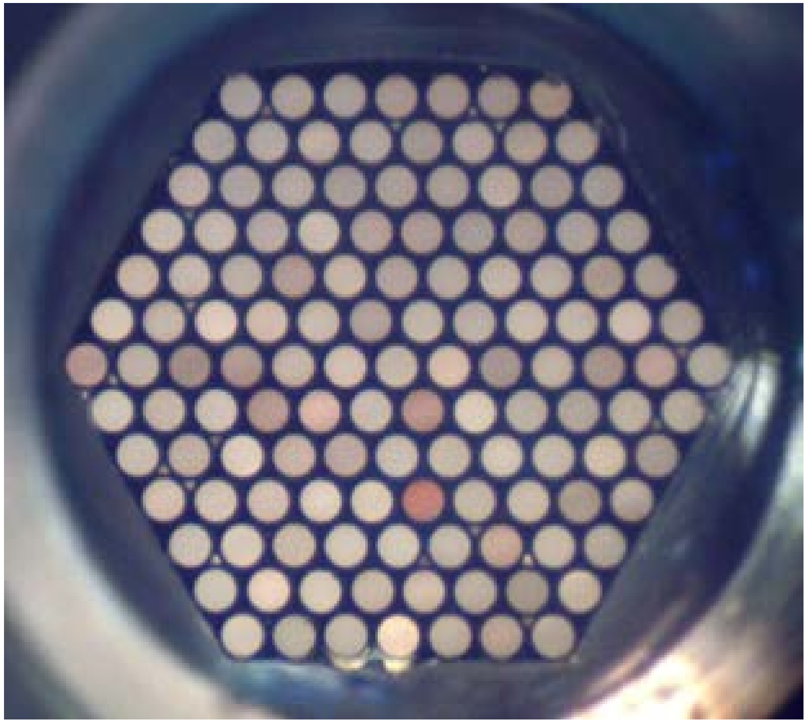


Integral Field Units
A bundle of optical fibers in a 2D array

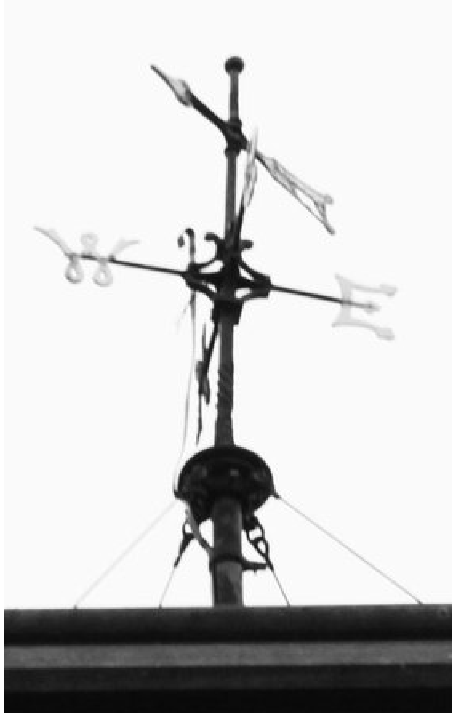
- 31M fibers arranged in a hex close-packed array would fully populate a 64 cm diameter focal plane.
- But then there's a sorting problem on the other end.
- The issues might include the length of fibers and the robustness of connectors.
- I didn't try to solve that.



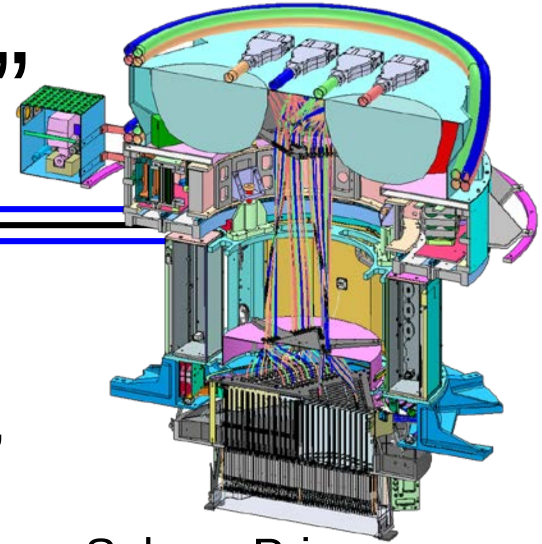
https://www.sdss.org/instruments/manga-instrument/

Mechanical Fiber Positioners
Move the Optical Fiber to the Object

- Twirling Posts
- Tilting Spines
- Bugs



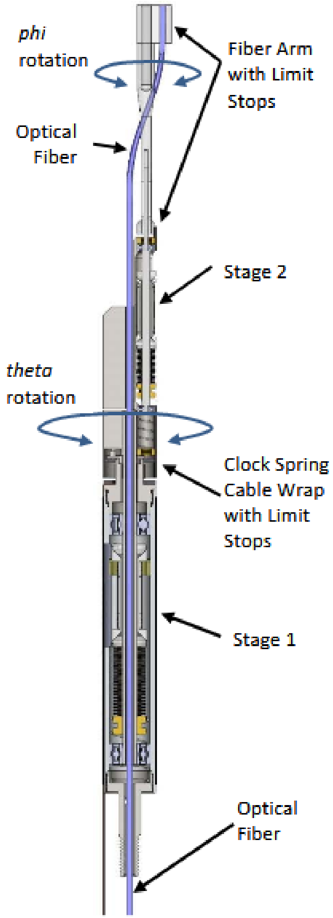
Cobra “Twirling Post”

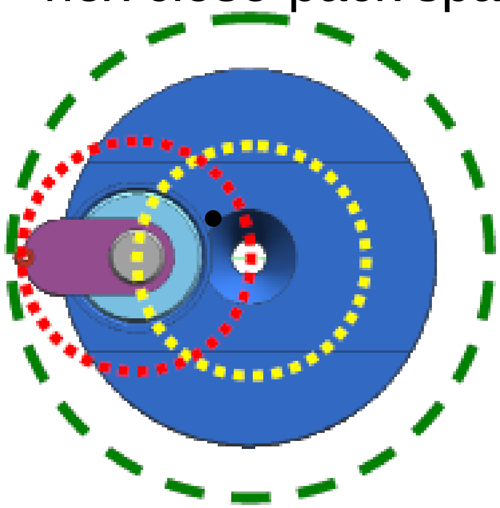


Subaru Prime Focus Spectrograph

★

- One Fiber Tip is held on an rotating arm at the top of a rotating post.
- Piezoelectric driven “wobbly motors”
- PSF Cobras ~ 7.7 mm diameter
- PSF will have 2400 F.P.s with 8mm hex close-pack spacing



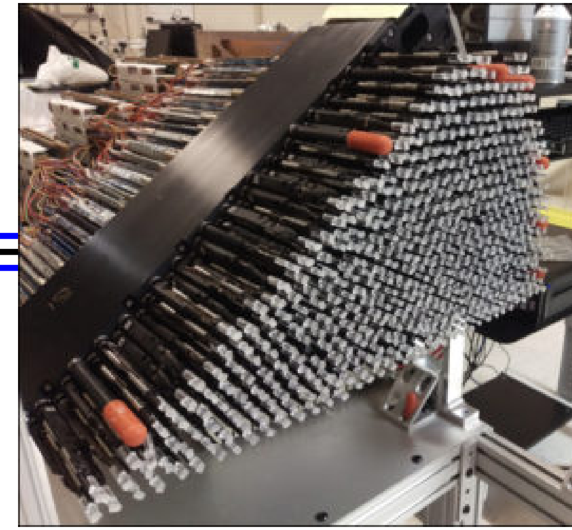


“Patrol Radius” 9.5 mm (I suspect that’s really the diameter)

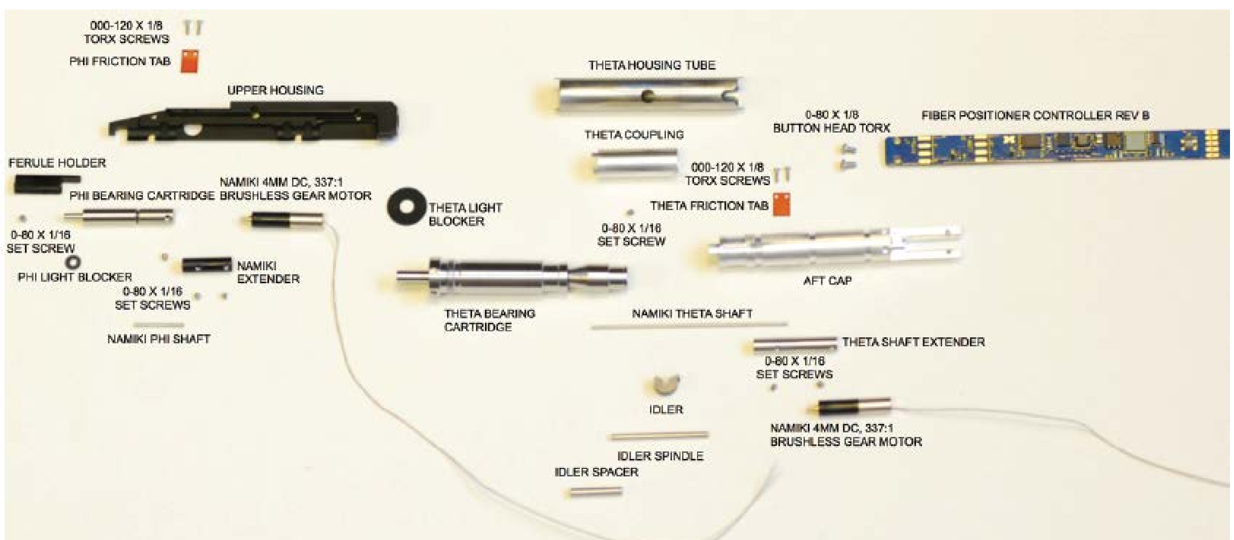
https://www.newscaletech.com/app-note-cobra-two-dof-fiber-optic-positioning-robot/
https://pfs.ipmu.jp/instrumentation.html

DESI “Twirling Post”

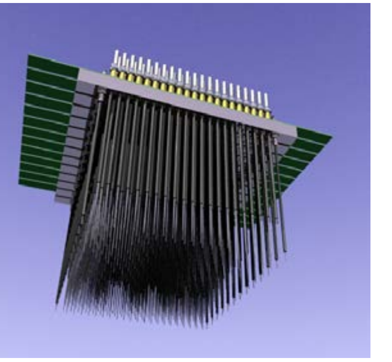
- Fiber is held on an rotating arm at the top of a rotating post.
- DESI F.P. ~ 8 mm diameter, 10.4 mm pitch, PR = 6 mm, 812 mm diameter focal plane.
- Big Focal Plane will have 5000 F.P.s
- Lots of wee moving parts including two DC Brushless Gear Motors



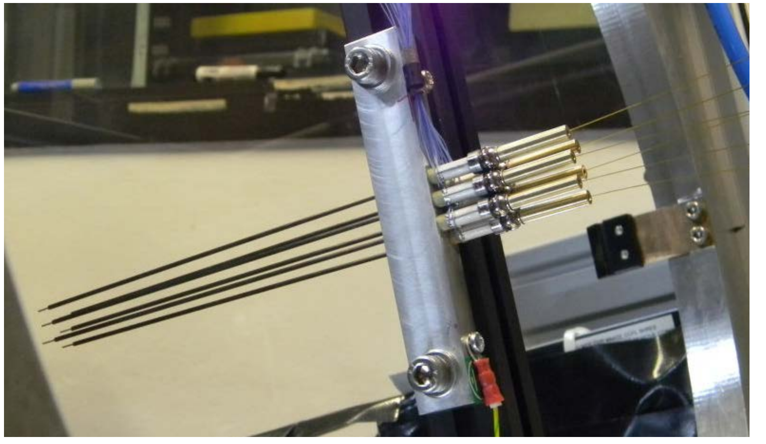
DESI Petal (one of 10)
5000 F.P. 1 cm pitch

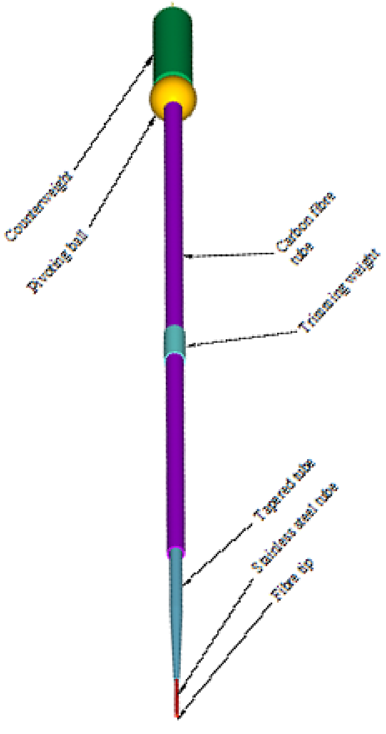


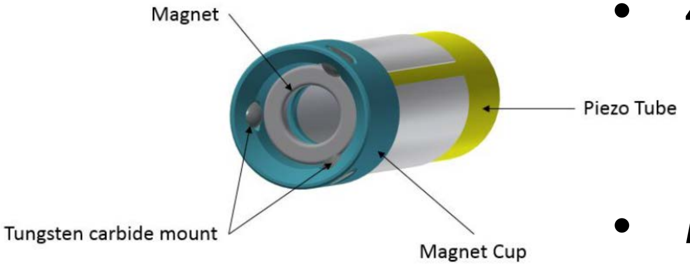
“Tilting Spines”



400 fiber FMOS Echidna
is still on the Subaru

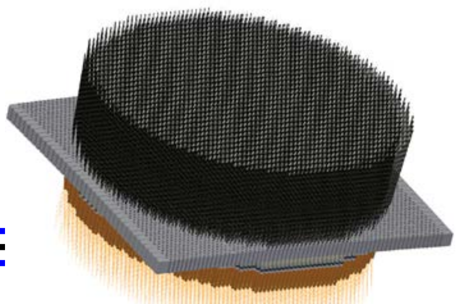






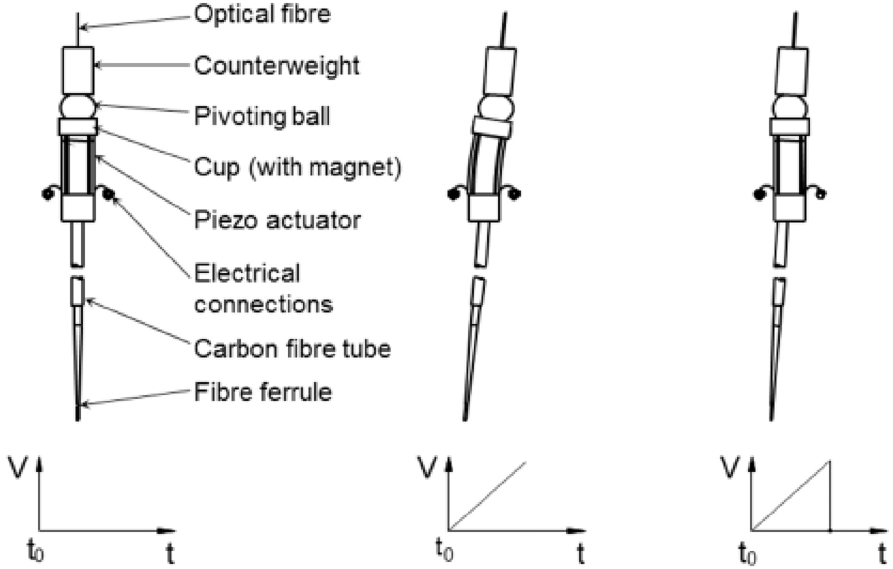
- FMOS (400), 4MOST (2436), *DESpec (4000), MSE (4332)*
- Piezo tube and magnetic cup fits over the ball on the spine. One moving part.
- 4MOST soon to go online?
  - 2 minute configuration time
  - 9.5 mm pitch, 11.8 mm patrol radius
- *DESpec/MSE* even smaller pitch: 6.7/7.6 mm
- Could put more than one fiber in a spine

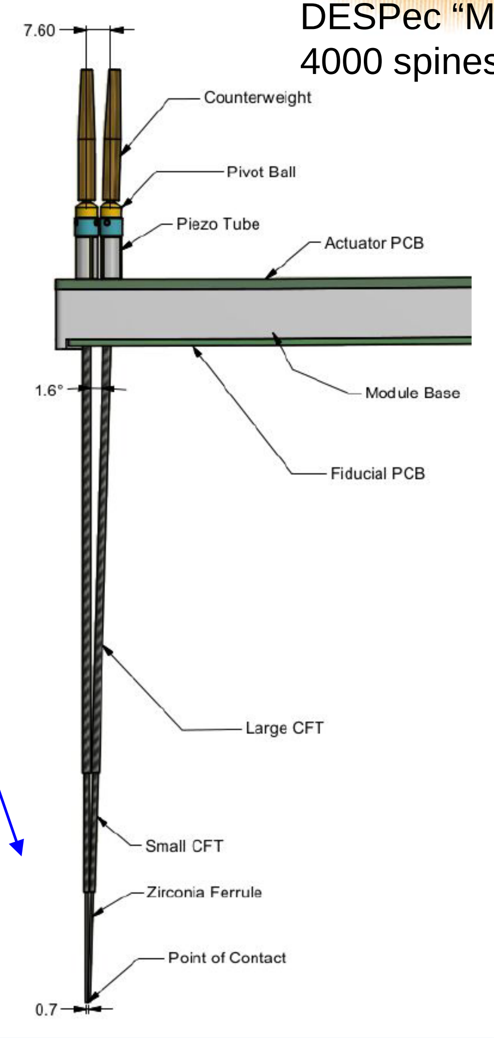
Tilting Spine Movement



DESPec “Mohawk”
4000 spines

- Uses ~100V sawtooth wave on piezos to bend and unsnap the base. The ball slips in the cup and sticks, thus nudging the tip a little. Apply the pulse a bunch of times to get the desired position.
- Spine Tips can be located to 0.7 mm from each other





Will Saunders et al., “MOHAWK …” Proc. SPIE 8446, 84464W (2012).
A. Sheinis et al., Proc. SPIE 9151, 91511X (2014).

Tilting Spines
New Piezo Design (2016)

- Same spine. New piezo geometry. Still “slip-stick” movement
- Now low voltage and more precision.

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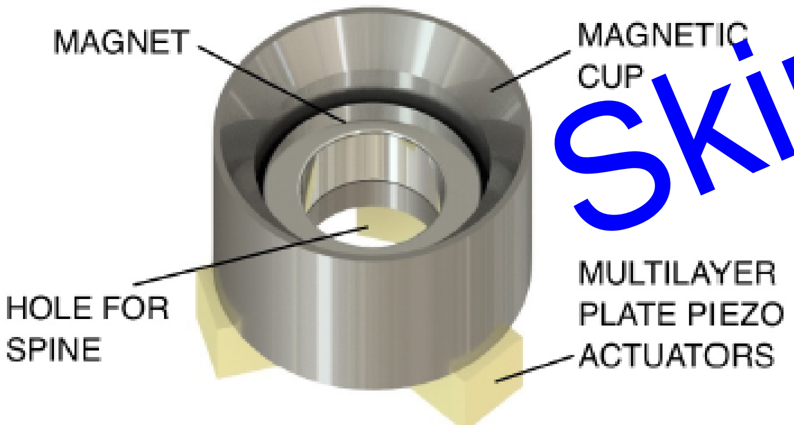
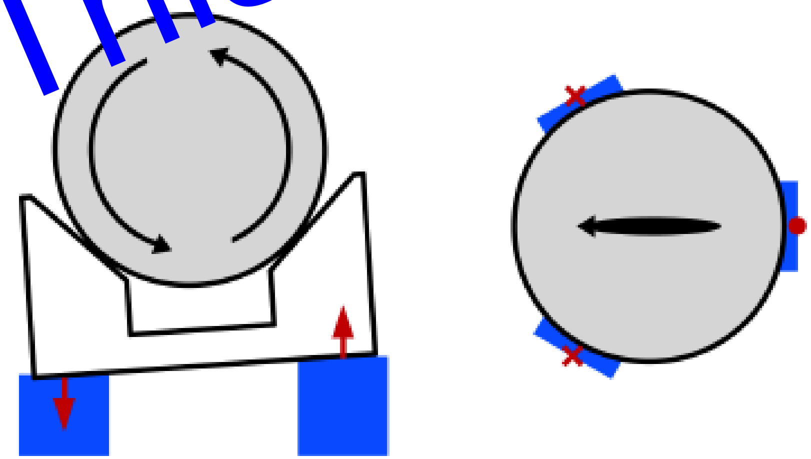


(a) 3D model of new motor design



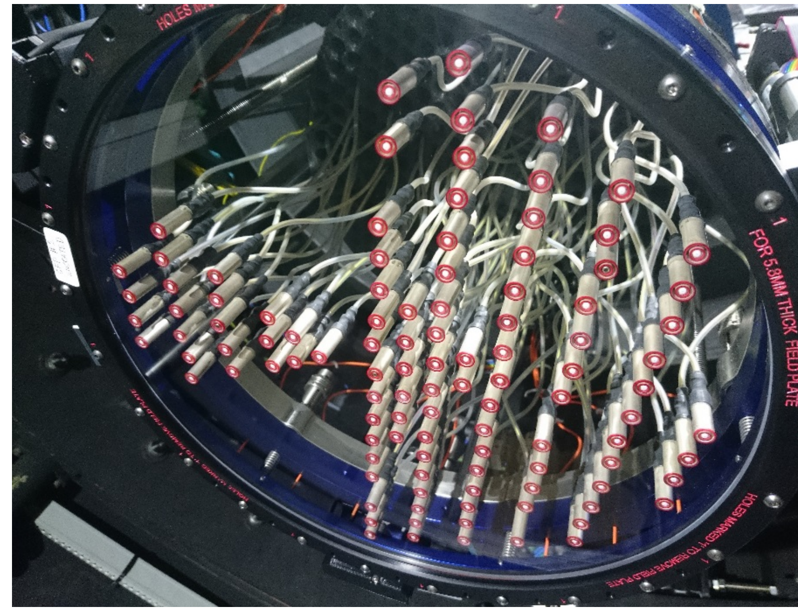
(b) Exaggerated diagram showing actuator forces

Jaime Gilbert & Gavin Dalton, “Echidna Mark II: one giant leap for 'tilting spine' fibre positioning technology”, Proc. SPIE 9912, 992012 (2016).

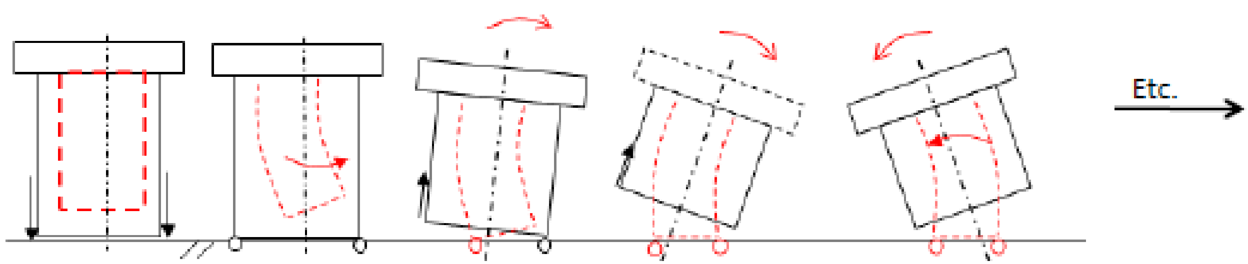
- June & July 2018 discussions with Will Saunders (AAO) & Kyler Kuehn (AAO) suggest that 5 to 6mm pitch is possible. R&D needed here.

StarBugs

- A positioner that carries a fiber close to a glass focal surface. Held to the glass by a slight vacuum.
- Uses concentric piezos to perform a lift & step motion so that the bug can “walk”.
- Bug Footprint ~ 10 mm
- Can have different size bugs, multiple fibers, mini-IFUs …
- Difficult to make them much smaller?

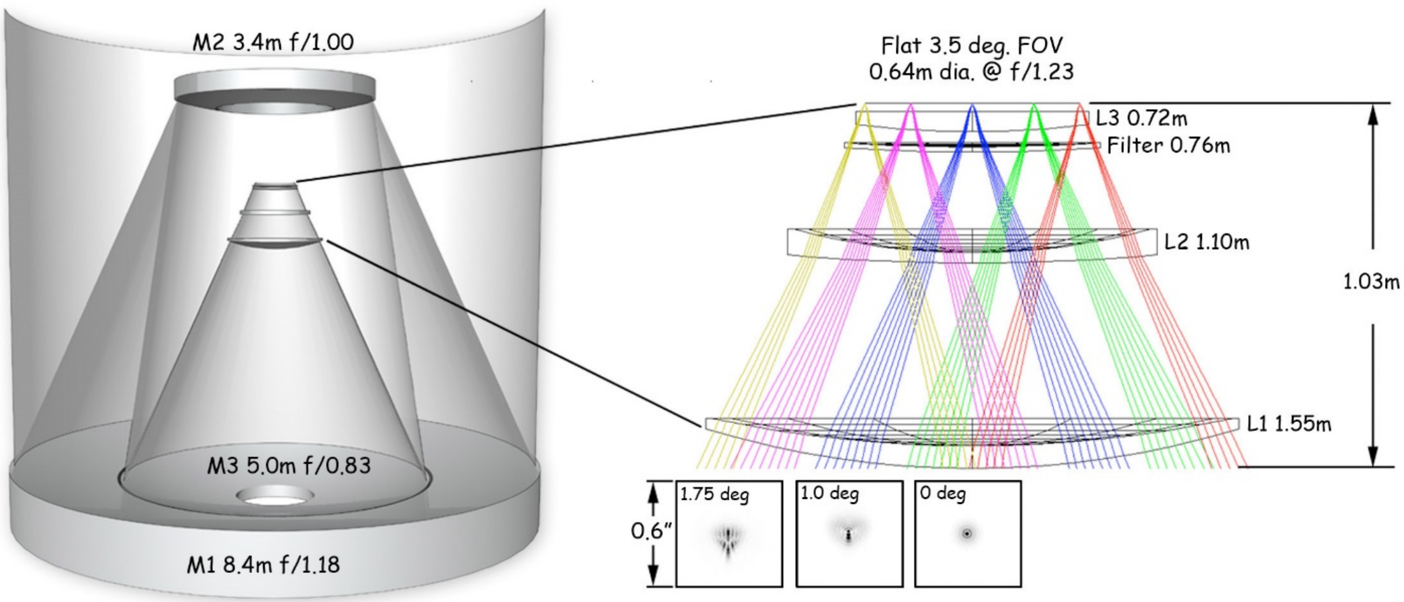


TAIPAN instrument soon to have 150-300 fibers

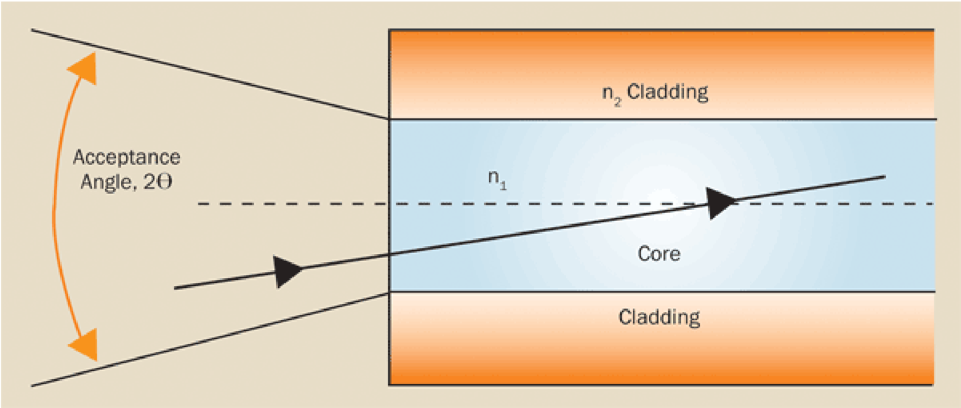


LSST Imaging Camera Optics (Wikipedia)

- LSST
  - 8.4m (6.7m) mirror w/ a hole in the center
  - 9.6 square-degree FoV
  - Focal plane is flat & 64 cm diameter
  - ~6 deg edge non-telecentricity
  - Plate scale is 50.9 microns per arcsec



Application to LSST
Problem: f/1.2 beam



$$NA = \sqrt{(n^2_{core} - n^2_{cladding})} = \sin\theta$$

η Core = 1.5
η Cladding = 1.485
θ=12.2 deg

- Fibers transmit light through total internal reflection.
- For f/1.2, θ= 24.6 deg
- For f/2.3, θ= 12.5 deg
- For LSST we'll need to put a lens on each fiber tip (See Chris S., probably).
- Better throughput with beams with f #'s of ~3+ (next slide)

https://www.photonics.com/Articles/Fiber_Optics_Understanding_the_Basics/a25151

Throughput & FRD vs. F Ratio

- F. Ramsey Tested Focal Ratio Degradation and throughput vs input focal ratio and output focal ratio for various diameter fibers.
- Bigger fibers => more throughput.
- Concludes f/3 to f/4 is ideal.

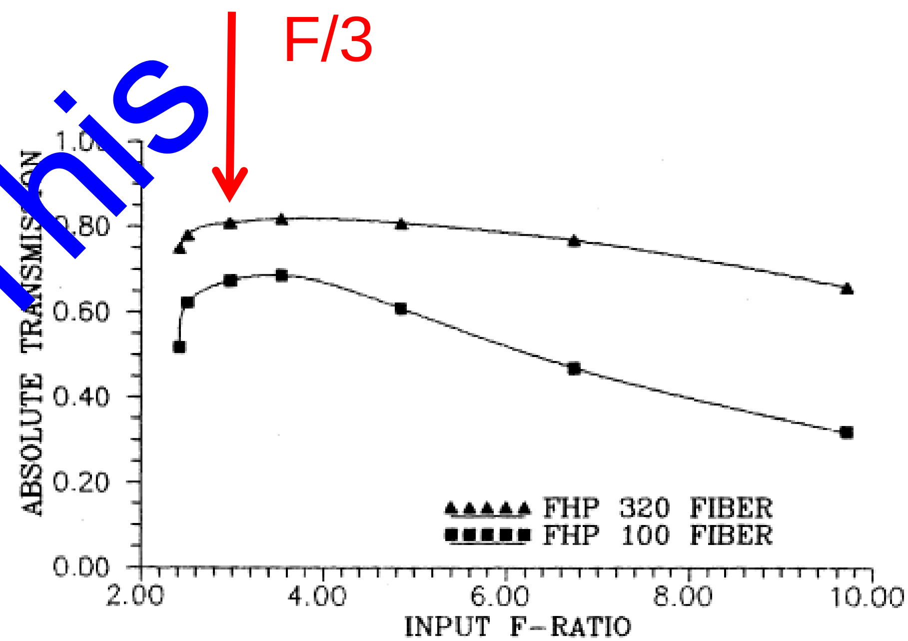


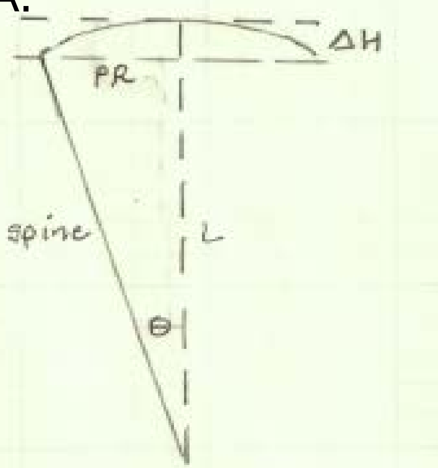
Fig. 7 The vertical axis is the absolute transmission into a aperture equivalent to the input f-ratio given on the horizontal axis. Both the FHP320 and FHP100 fibers are shown.

F. Ramsey, "Focal ratio degradation in optical fibers of astronomical interest" , Proceedings of the Conference Fiber Optics in Astronomy, 1988.

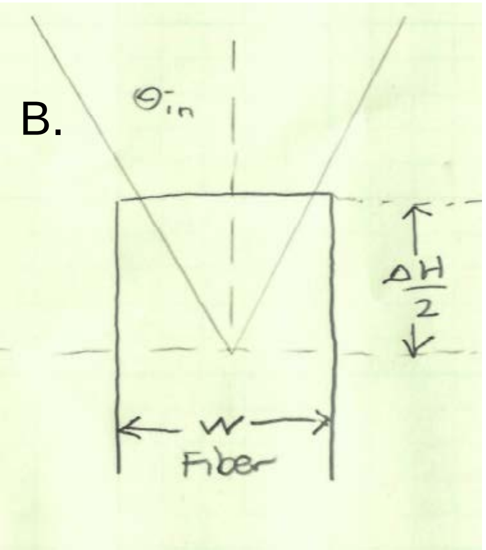
Also see Will Saunders SPIE paper on DESpec Mohawk

Tilting Spines Defocus w/ Tilt
How bad is f/1.2?

A.



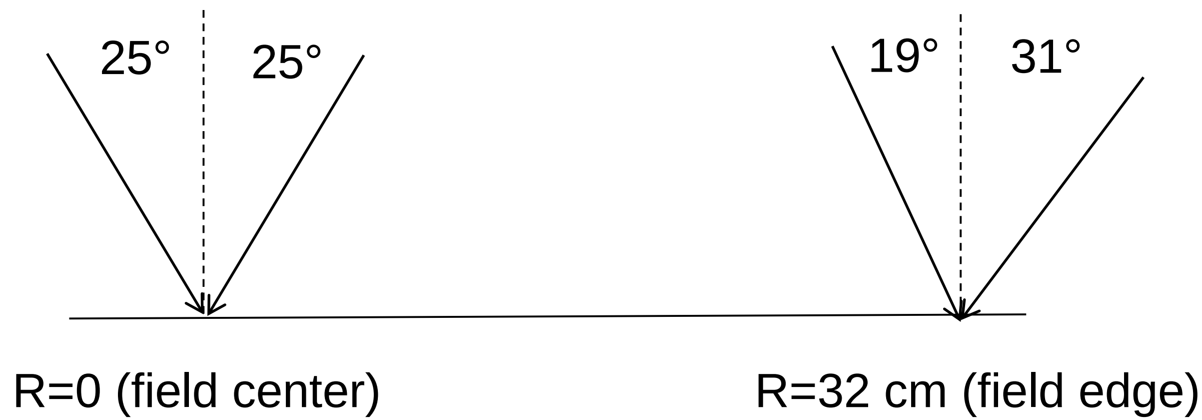
B.



- A. The fiber tip moves in an arc. If the spine is tilted, the fiber tip is not in the focal plane.
  - For L=250 mm spine with Patrol Radius 8 mm (6.7mm pitch), $\Delta H = 128\ \mu m$.
  - So we put a focal plane $\Delta H/2 = 64\ \mu m$ below the top of the non-tilted fibers.
- B. LSST has f/1.2 incoming beam (skip the lenslet for this estimate)
  - For $\Delta H/2 = 64\ \mu m$ and $\Theta_{in} = 25°$, the radius of the out of focus spot is 29 μm.
  - That's smaller than the fiber radius. This is OK.
  - Implication for the minimum diameter of the fibers. And the mechanical assembly tolerances.

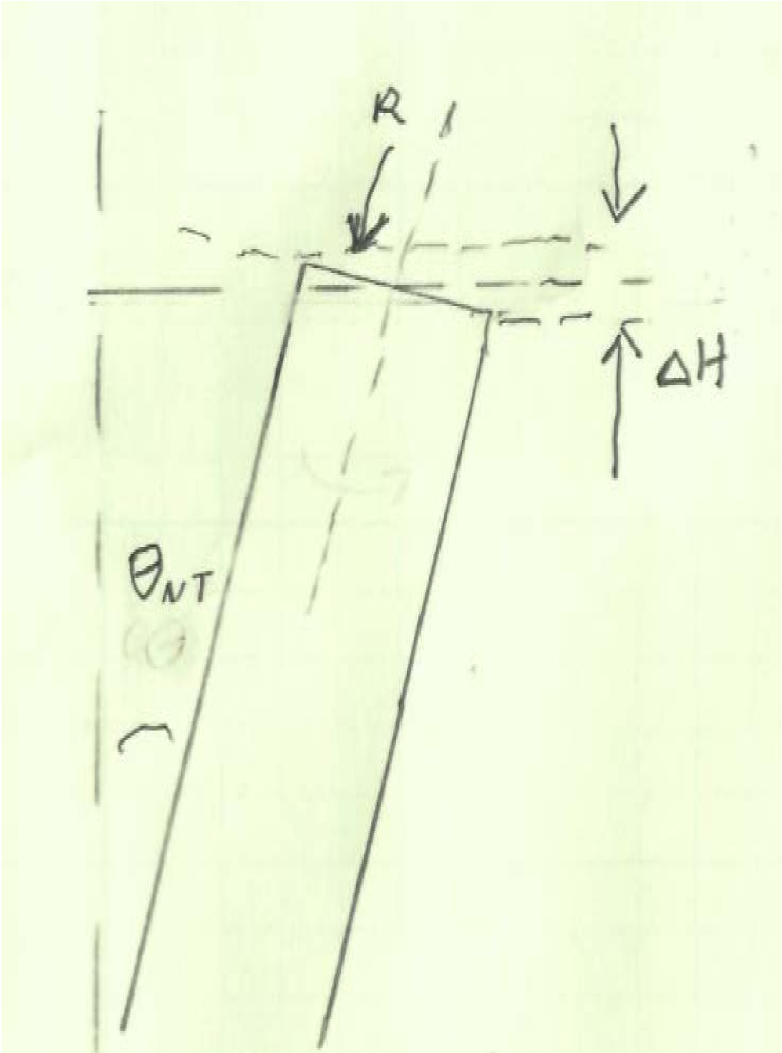
Application to LSST
Problem: not telecentric (Steve Kent)

Small deviation from normal incidence at outer radius



- The incoming beam has a 6 (8?) deg tilt at the edge
- But the focus is planar
- The fiber positioner support plate might array the positioners at different angles, but maintaining the plane of tips of the fibers.
- Fancy machining for the “Focal Plane Support Plate” could do that.
- You might think you would want to, except …

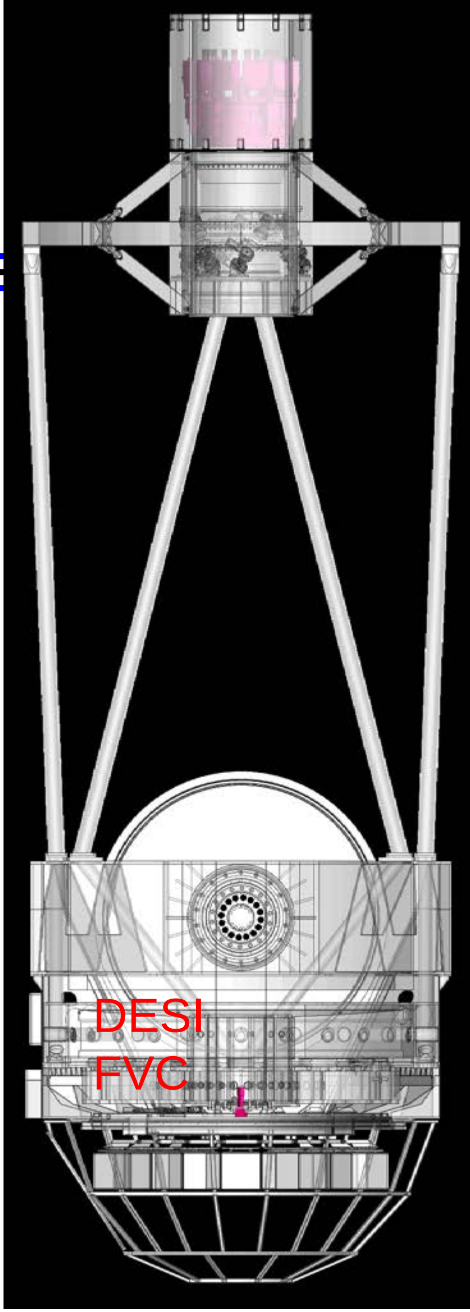
Effect of Non-Telecentricity for on Focus for Both Twirling Posts & Tilting Spines, if set to accommodate the non-telecentricity



- At R=0 this isn't a problem.
- At the edge of the FP, with 6 deg. non-telecentricity, and a patrol radius R of ½ cm, then $\Delta H/2 = R\sin(\Theta) = 522\ \mu m$.
- Spot size when we are that far out of focus has radius > 240 μm. We lose ~3/4 of the light unless the fibers are that big.
- Similar for spines.
- Maybe better to stay normal to the focal plane and take the non-telecentricity loss. See lenslets. Maybe they help.

More Fiber Positioner Components & Technical Design Considerations

- Fiber Positioner Support Plate
- Positioner Control Electronics
  - Power requirements
  - Thermal control
- Guide and Focus CCDs
- Fiber View Camera to measure the current fiber position during configuration (backlight the fibers)
  - Metrology Fibers on the support plate
  - Fiber View Camera might be located in the central hole of the primary?
  - Complicated because the LSST optics has a secondary and a tertiary mirror !!!
  - More complicated with a lenslet on it?



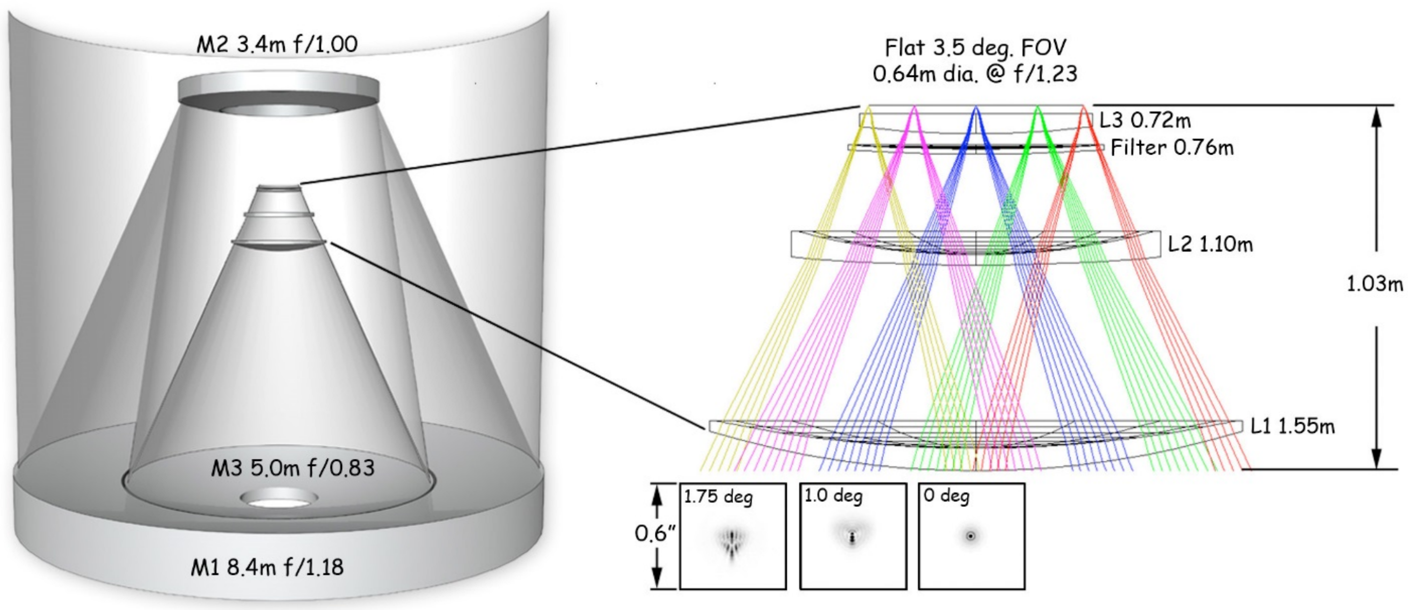
Summary

- I described three main types of fiber positioners: Tilting Spines, Twirling Posts, and Bugs.
  - All 3 types have been or about to be used on real instruments.
  - To fit 20,000 of them on a 64 cm diameter focal plane, we'll do R&D that scales down the radial space that each positioner takes up.
  - Tilting spines advantages: smaller, easier to make, allows denser targets, could put a few fibers in spine if desired.
  - Twirling Post advantages: no tilting out of plane, so a little more throughput (small effect) than spines
  - Bugs Advantage: easy to see how to make mini-IFUs
- The LSST optics and corrector provide complications
  - f/1.2 beam requires fibers have lenslets on them
  - Non-telecentricity at focal plane coupled with flat focus surface will cause light losses at larger radii. Maybe a no go to align the positioners to the incoming beam.
  - How do (can) we make a fiber view camera work?
- Perhaps we should break the assumption that we have same corrector optics.

Extra Slides

Implementation Details

LSST Optics

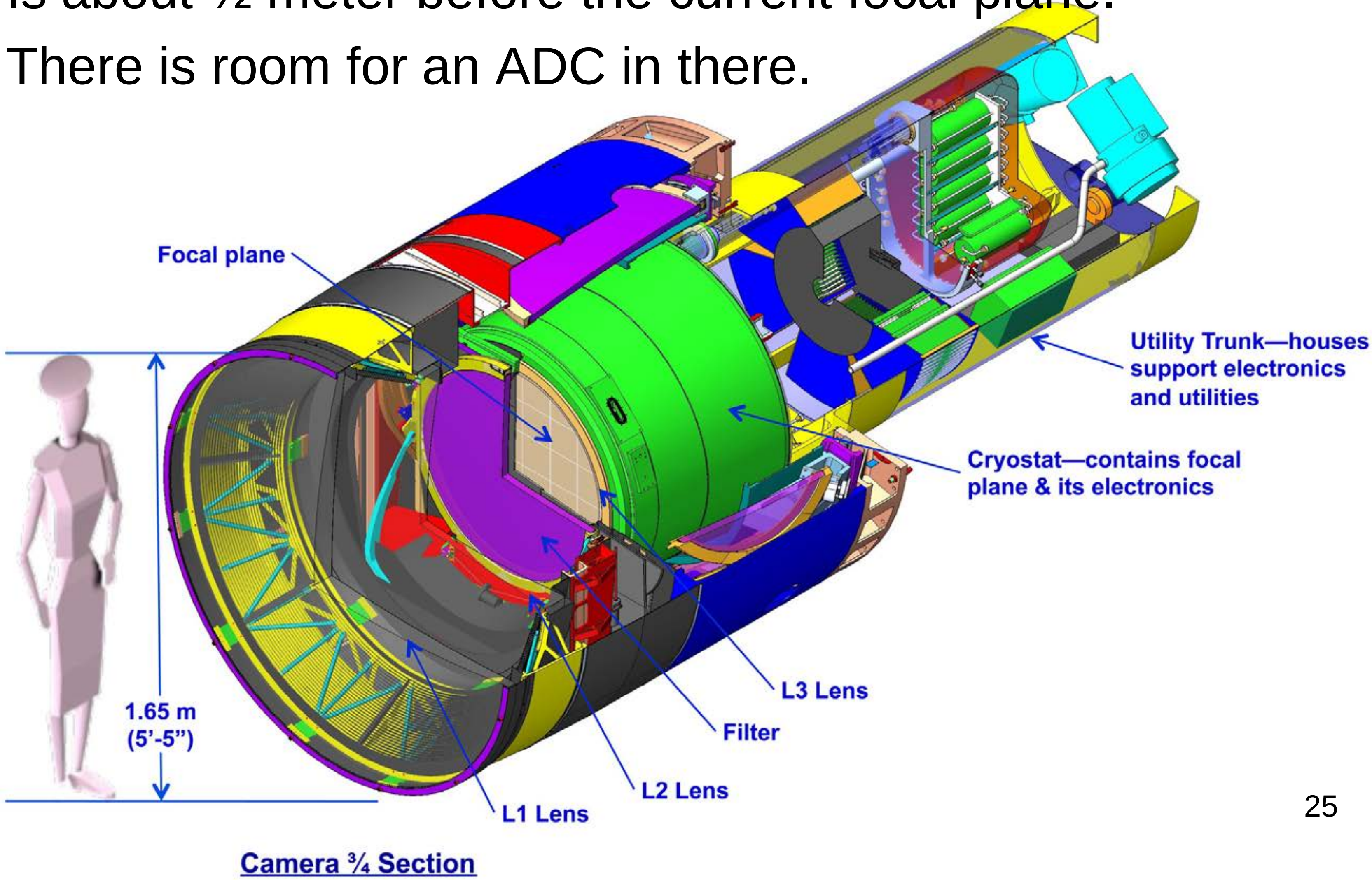


Filters go in between L2 and L3.

It looks like there is ~a 15 inch gap between L2 and L3.

Space After L2

- Is about ½ meter before the current focal plane.
- There is room for an ADC in there.



Lenses After L2

- The Lens L3 is also the Dewar window. We get to replace L3 with a different L3.
- I note the DEWAR window is pretty thick. That’s because it has to not break under 14 psi. We don’t need for it to be so thick.
- There is also about 1” of space behind L3 in front of the focal plane.
- We get to put 2 lenses in that space, if that would help.