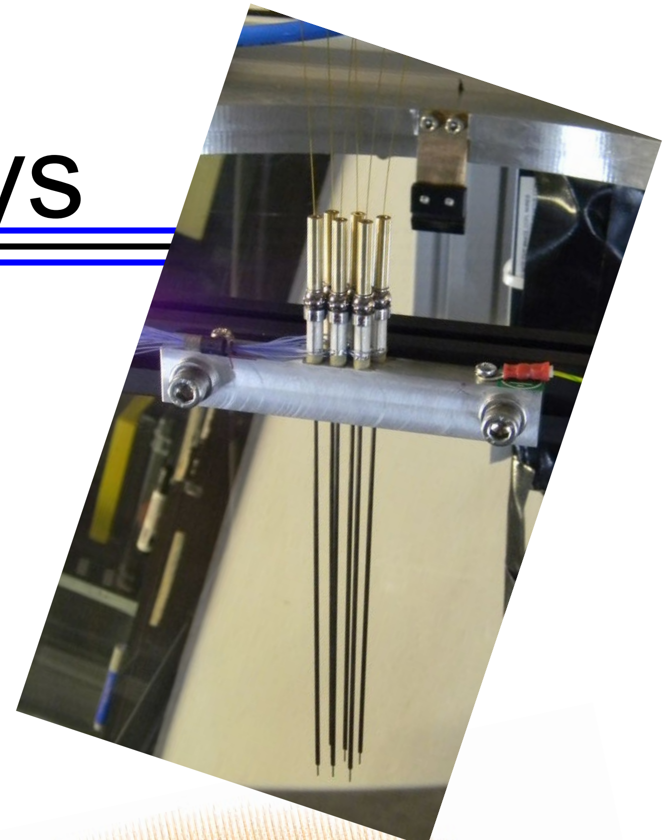
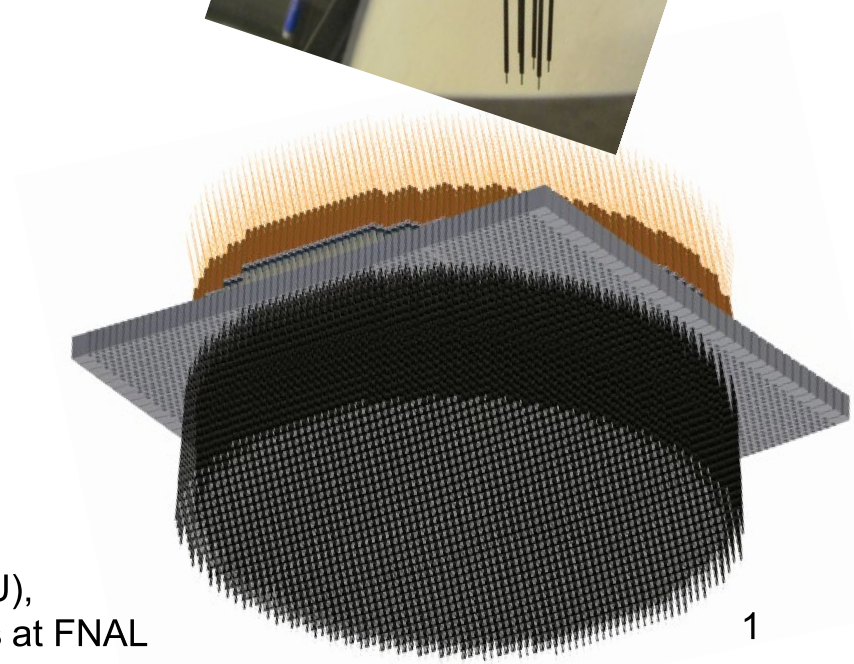
Fiber Positioners For Cosmic Surveys



- Stage V DE science goals
- Telescopes & Instrumentation: Collecting a spectrum onto a optical fiber
- Mechanical Fiber Positioners as a solution for collecting 100M to 1B galaxy spectra
- R&D Direction



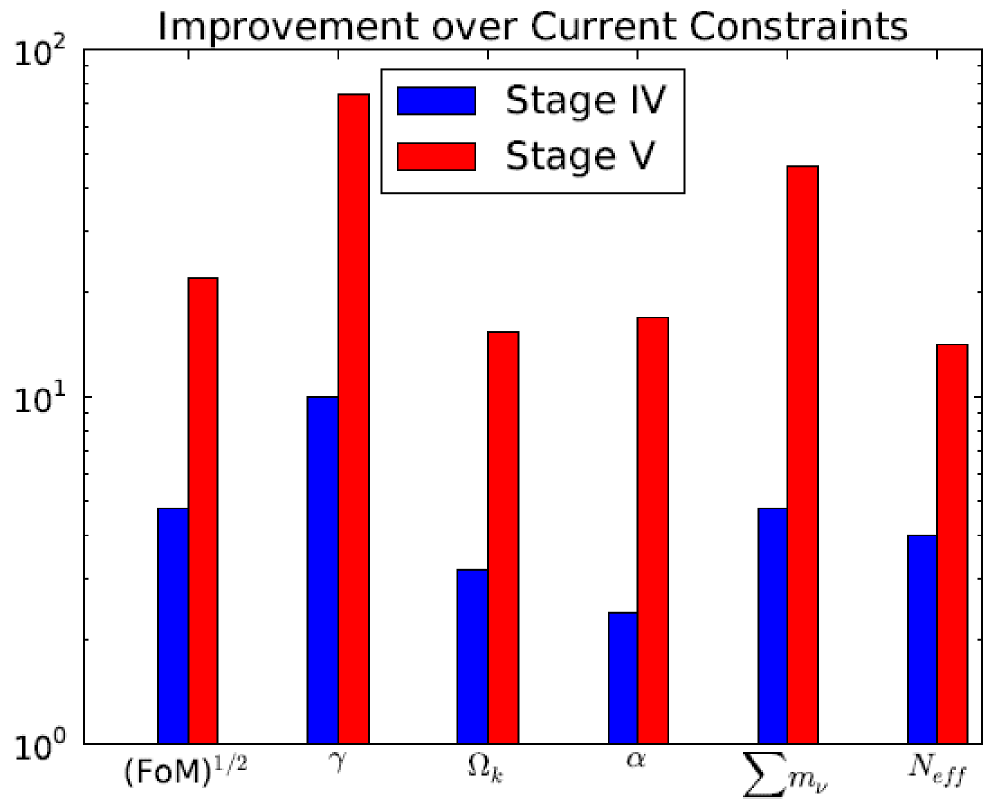
Tom Diehl (FNAL)
CPAD 2019, Madison
December 10, 2019

With M. Soares-Santos (Brandeis), J. Marshall (TAMU),
M. Schubnell (UM), K. Kuehn (AAO/Lowell Obs.) and others at FNAL

Cosmic Visions Dark Energy “Stage 5” Science

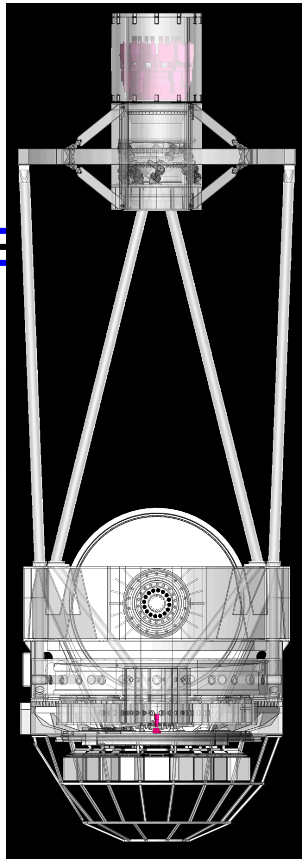
- Following up LSST targets with spectroscopy improves constraints on fundamental parameters, some by a factor of 10.
- Big gains from extending the redshift range past z=1.
- Currently operating surveys expect to collect spectra of O(20M) objects.
- Stage V hopes for O(1Billion) spectra.
- Parallelism is key to achieving this # of spectra

arXiv:1604.07626

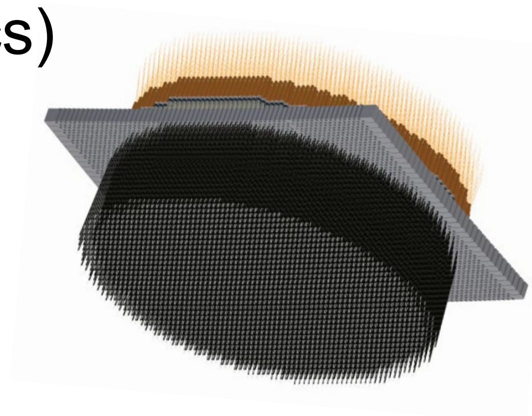


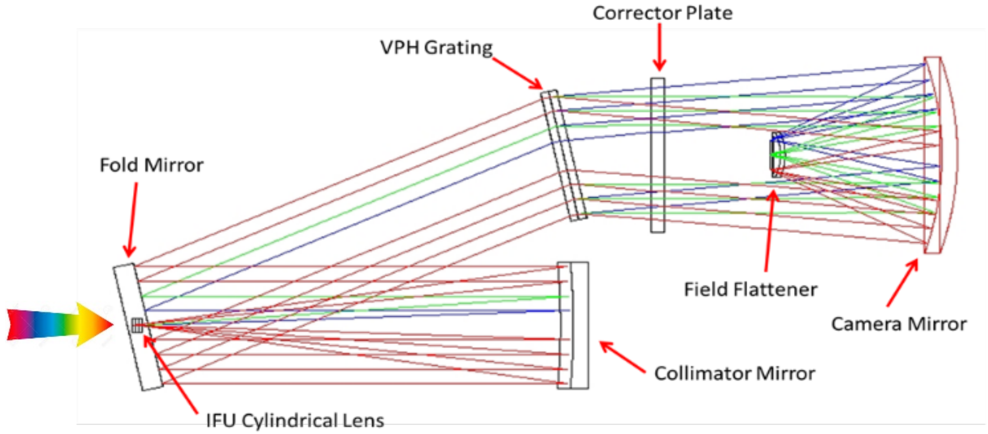
Even after the currently planned surveys finish operating, we can make revolutionary discoveries with future surveys; one indication of the power of these surveys is the projected order of magnitude improvements in parameter space.

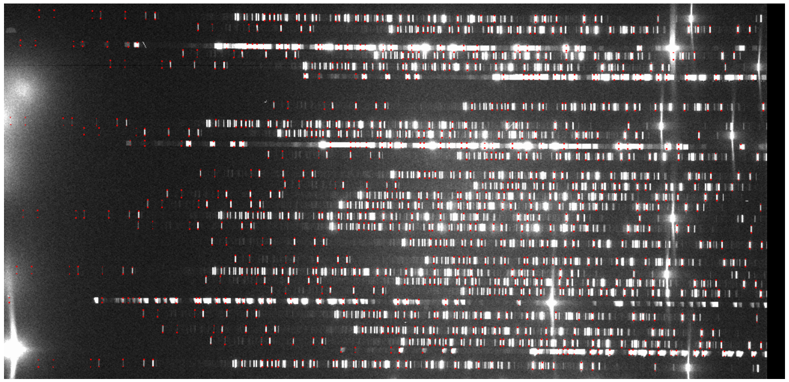
Collecting Spectra
We do it with telescopes!



- A Telescope (Wide Field Optics)
- Array of Optical Fiber(s) to collect individual object's light. Scale ½ m to 1 m diameter
- # Spectrographs, R>3500
- Detectors, CCD's, IR …





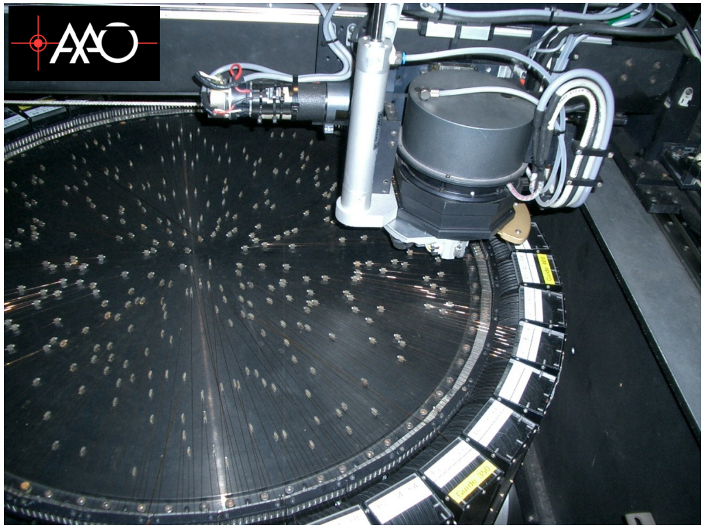


Design of Telescope, Focal Plane, Spectrograph Optics are tightly coupled

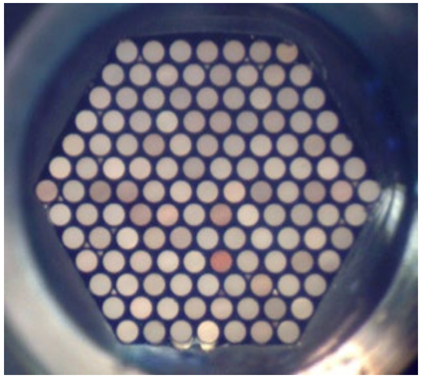
Past solutions are uneconomical and/or technically unfeasible for this problem

SDSS Plug Plates

Pick & Place Robot instead of a person



Integral Field Unit (IFU)



“Robotic” Fiber Positioners Move the Optical Fiber to the Object

- Walking Bugs
- Twirling Posts
- Tilting Spines

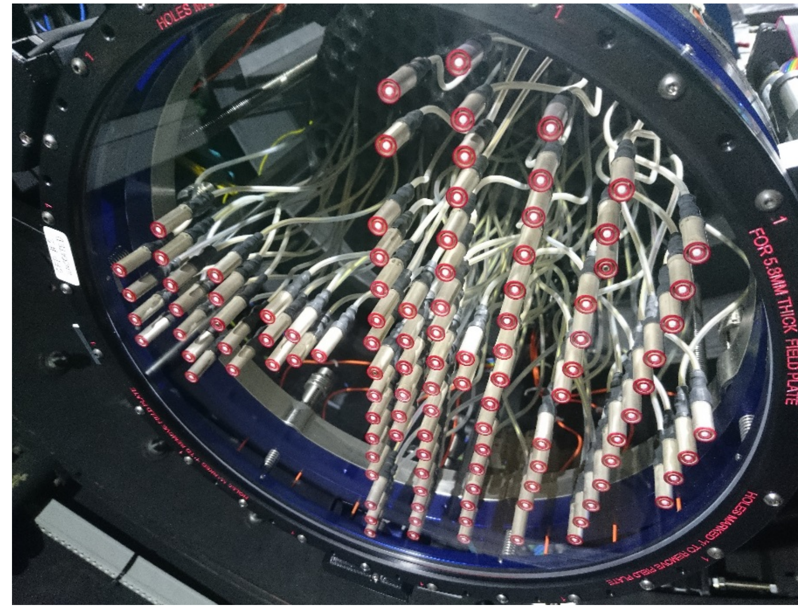
Typical Specifications for collecting spectra with a FP

From DESI Technical Design Report (2015)

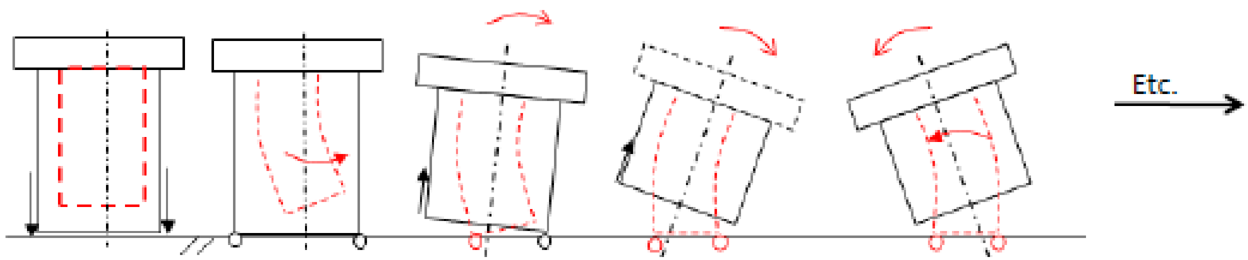
Specification:	My comment:
• **Horizontal Position Accuracy < 5 um**	(plate scale is 71 um/arcsec)
• Lifetime moves > 372,000	(812 mm diameter focal surface)
• Peak (Mean) Power < 3W	(waste heat in vicinity of optical path)
• FRD max < 0.4 deg w/ f/3.75 beam)	(spectrograph optics)
• Vertical mounting error < 20 um	(implications for focus/spot size)
• Tilt Error max < 0.1 deg	(I didn't understand this one)
• **Reconfiguration Time < 45 s**	(so no effect on duty-cycle)
• Mass < 50 g	(I didn't see one for space/size)
• Operational Temperature -20C to +60C	(!)
• Fiber Handling Radius > 50 mm	(so the fibers aren't damaged)

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 or bigger
- Can have different size bugs, multiple fibers, mini-IFUs …
- Can’t make them much smaller



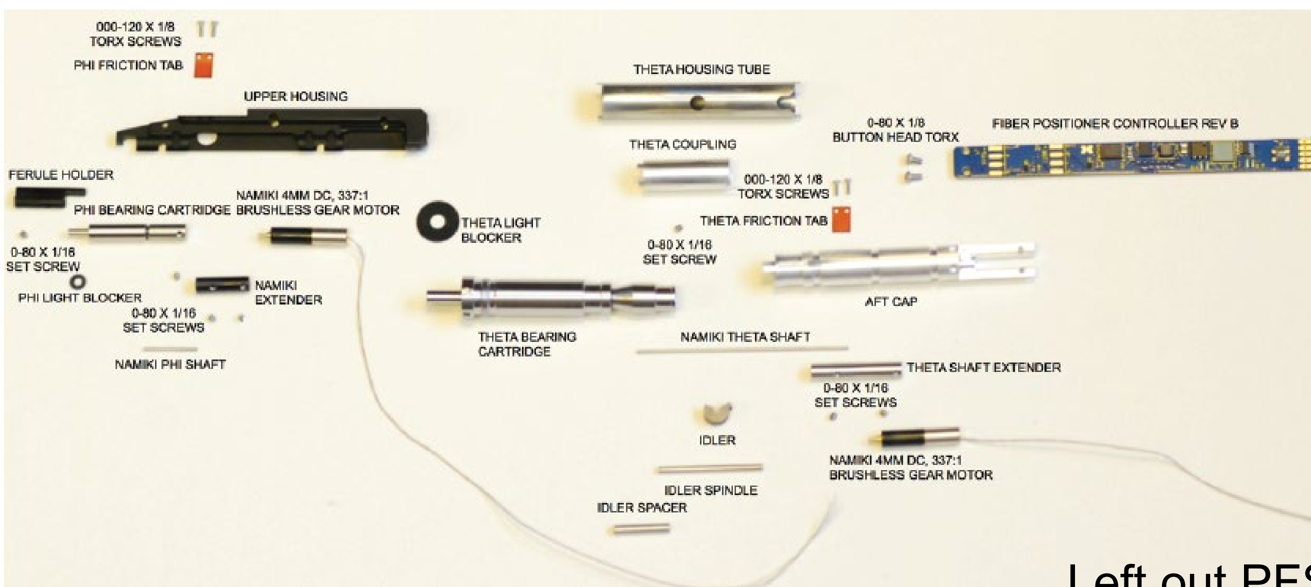
TAIPAN instrument at Siding Spring operating now with 150 fibers



DESI “Twirling Post”

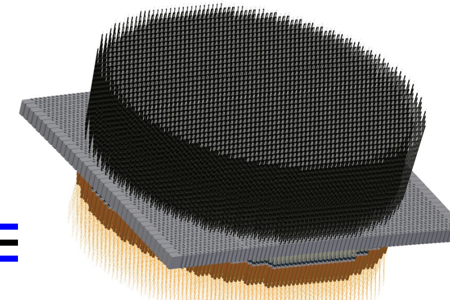
- Fiber is held on an rotating arm at the top of a rotating post (two rotators)
- DESI F.P. ~ 8 mm diameter, 10.4 mm pitch, Patrol Radius = 6 mm
- Big (0.812m) Focal Plane has 5000 F.P.s
- Lots of wee moving parts including two DC Brushless Gear Motors

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

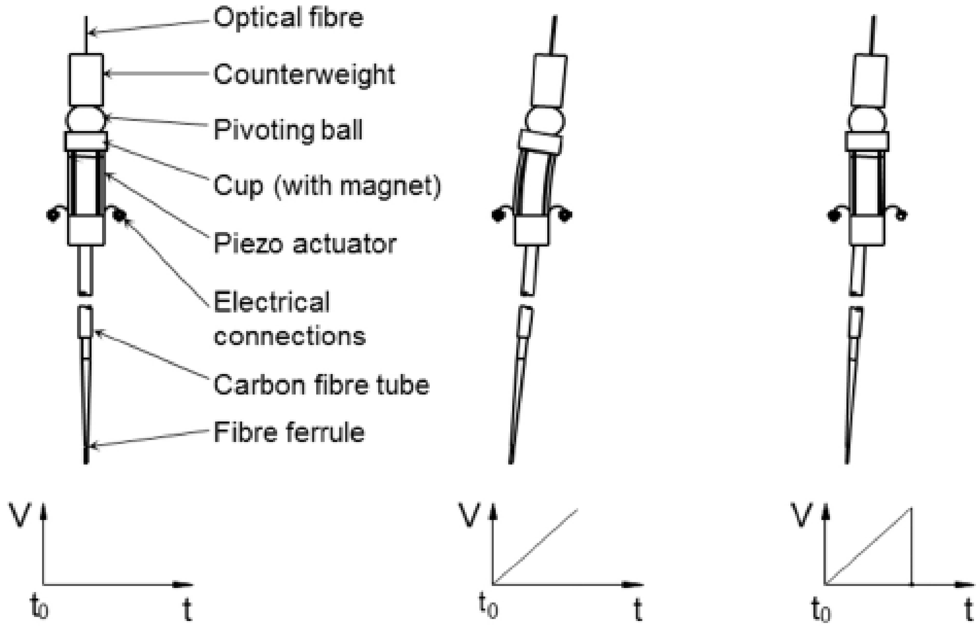


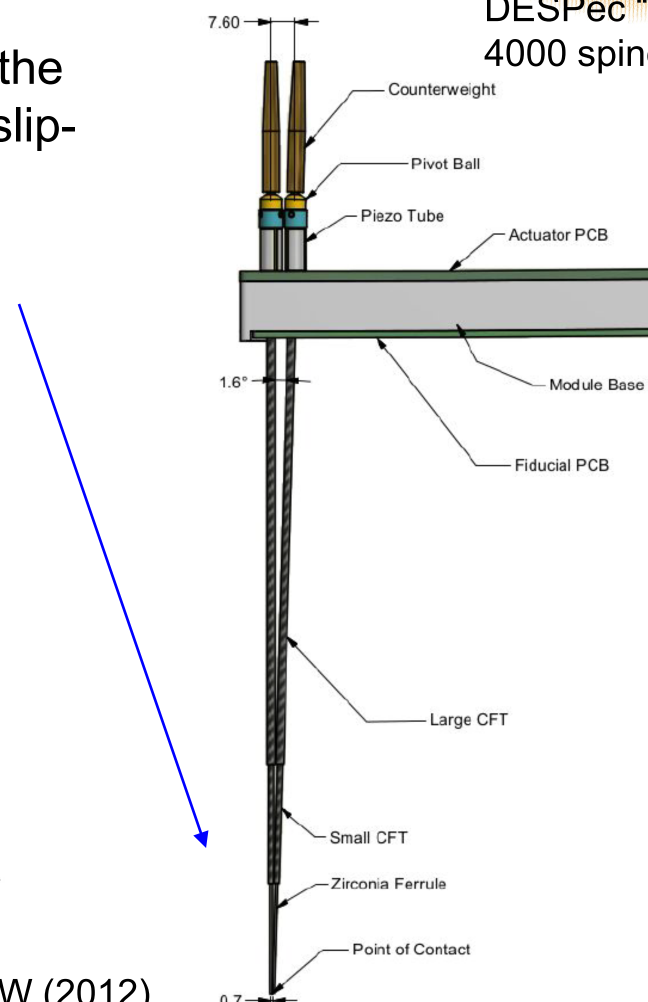
Left out PFS “Cobra”

Tilting Spines



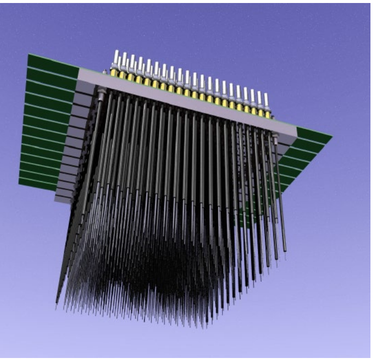
- Fiber is held in the center of the spine.
- Spine is magnetically held to a cup glued to the piezo-tube. Electric (sawtooth) pulse cause slip-stick motion at the ball-cup contact point.
- Accumulate tiny motions to locate the tip.

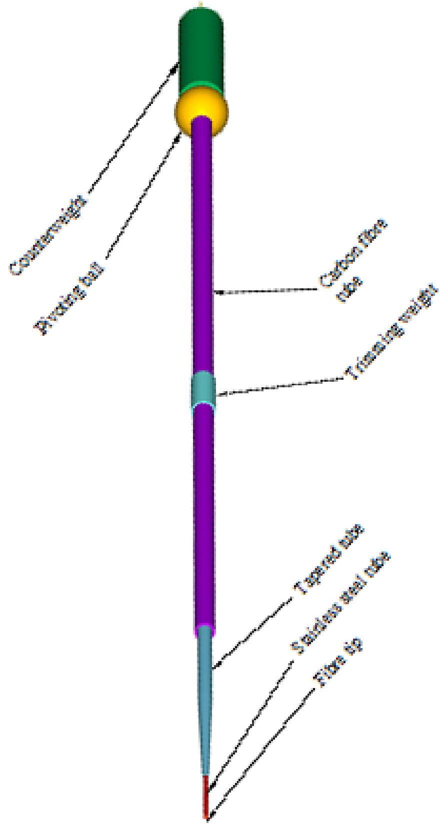


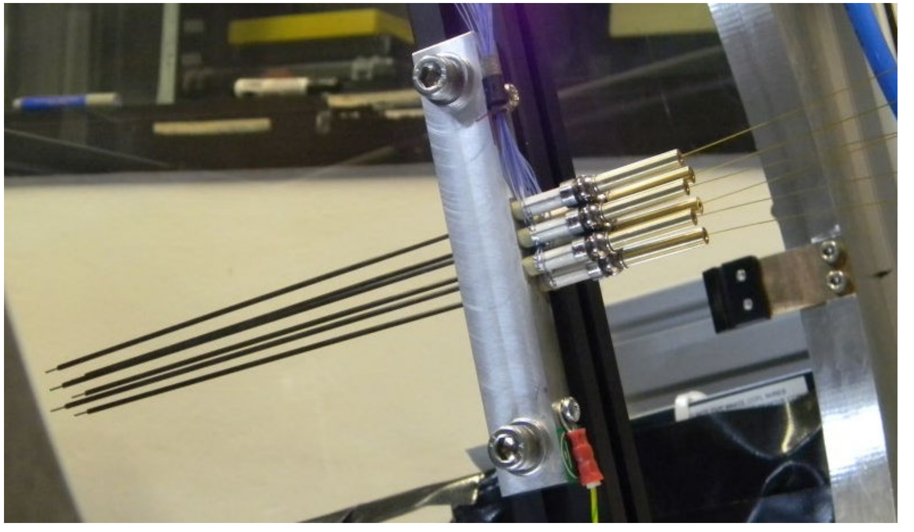


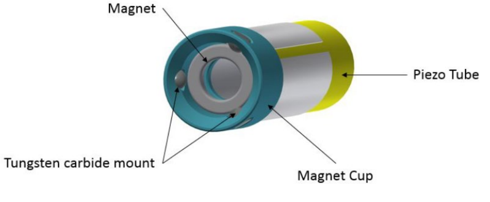
Will Saunders et al., "MOHAWK …" Proc. SPIE 8446, 84464W (2012).
A. Sheinis et al., Proc. SPIE 9151, 91511X (2014).

“Tilting Spines”





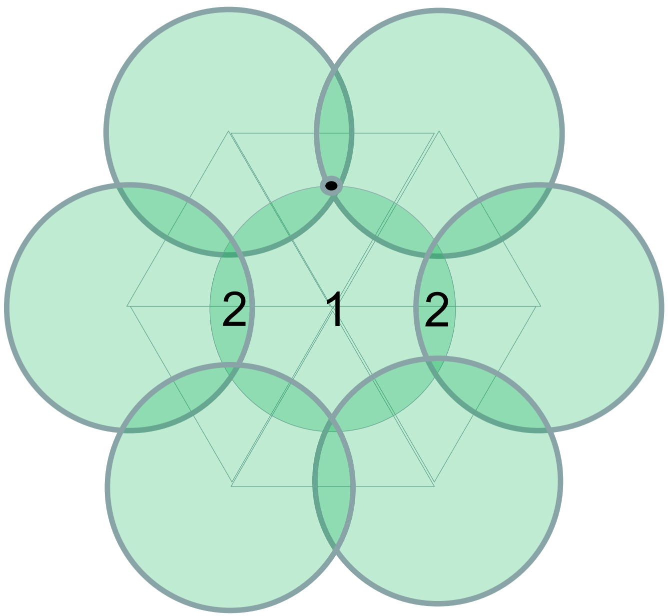


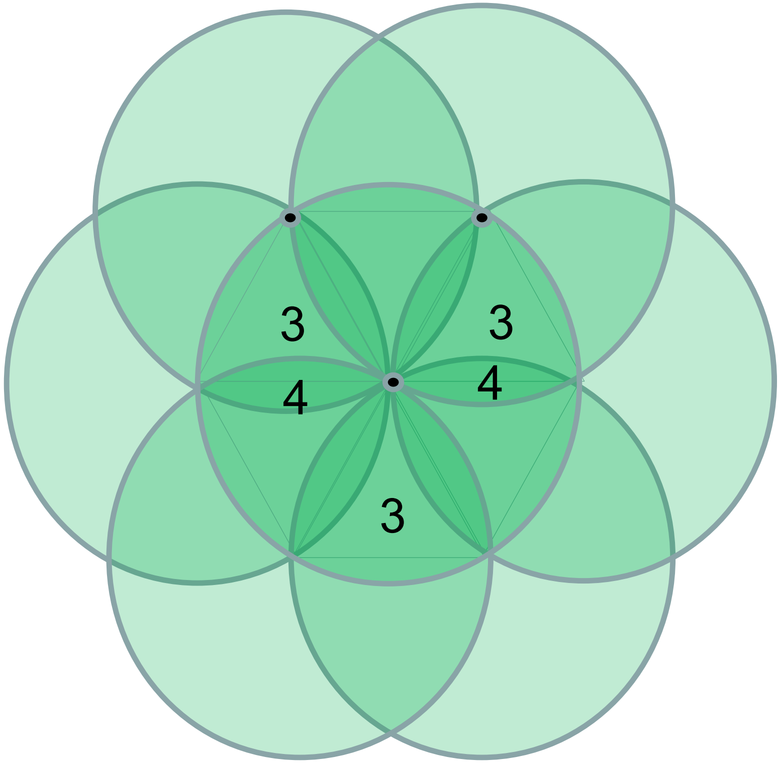


400 fiber FMOS Echidna used on the Subaru Telescope

- Optical fiber centered in spine. One moving part.
- FMOS (400), *DESpec (4000),* 4MOST (2436), *MSE (4332)*
  - 4MOST: 9.5 mm pitch, 11.8 mm patrol radius
- *DESpec/MSE* even smaller pitch: 6.7/7.6 mm
- Prototypes are already smaller than T.P.s
- Could put more than one fiber in a spine

Value of Patrol Radius: Target Eff'y & Flexibility & Close Sources like Galaxies in Clusters



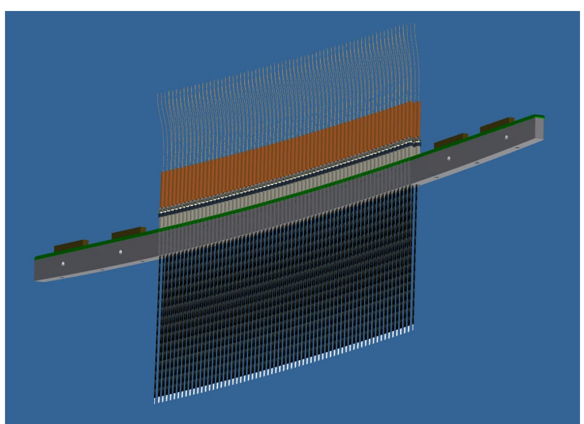


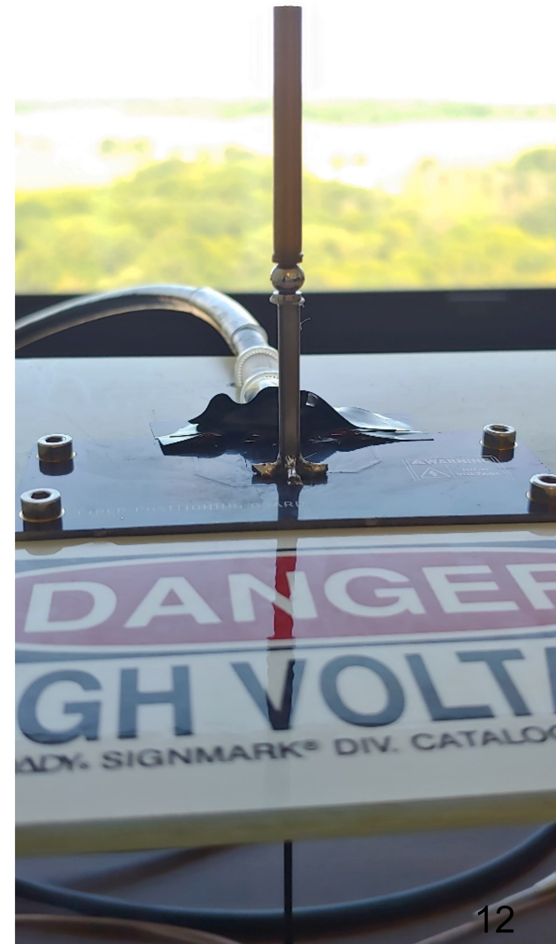
- Patrol Radius 60% of pitch
- Most area covered by only one fiber, some by two.

- Same pitch as LHS
- Patrol Radius 100% of pitch
- ~3.5 spines avg.

"Low Hanging Fruit"
5 mm pitch FP

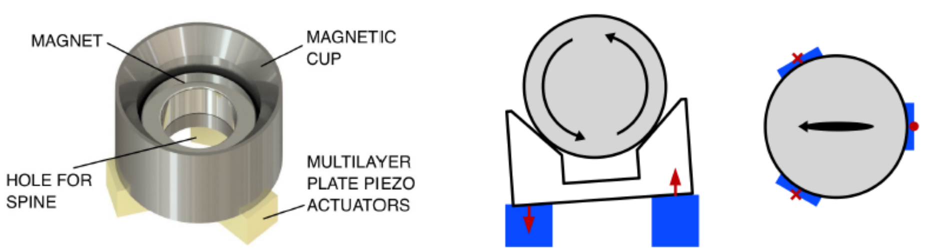
- With collaborators at FNAL, Brandeis, Texas A&M, Michigan, AAO/Lowell Observatory
- Understand the engineering and design limits of the prototypes that we have and develop and test an engineering model.
- Build 5m pitch prototypes and a demonstration system of a small array.





“Game Changing” Minimize the FP Size

- Ambitions* of 25,000+ FP on a focal plane ~2/3 m diameter focal plane will require even smaller FP’s
- In the process of eating the low-hanging fruit we’ll be learning what we need to think about for a 2 to 3 mm pitch FP design.
- Engineer and demonstrate the smallest possible design based on currently available technology.



(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).

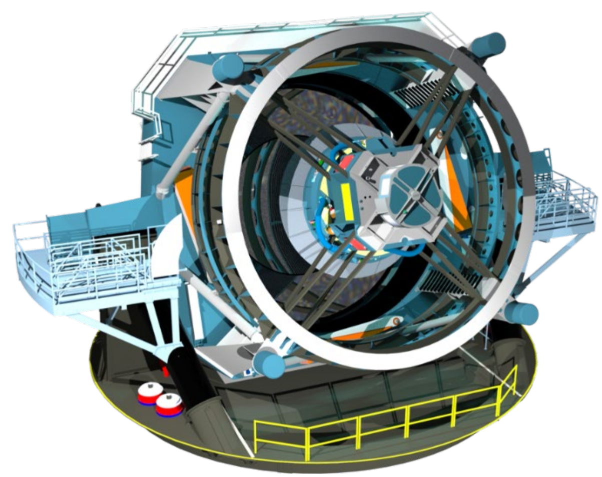
* 2020 Astro Decadal Survey White Papers: https://ui.adsabs.harvard.edu/public-libraries/uZ71y9jERUiiOpuDvrXNSg

Summary

- A fiber positioner system allows one to economically accumulate many objects spectra in parallel using a telescope.
- There are many types of fiber positioners. Tilting Spines & Twirling Posts are practical robotic options.
- At 5 mm pitch there are advantages/disadvantages of the FP designs (comparing equal pitch) depending on the telescope optics and survey design.
- Twirling Posts size limitations is availability of robust, tiny brushless motors and gears
- Tilting Spines size limitations is less explored and could be significantly smaller.
- On course to engineer, design and build a 5 mm pitch Tilting Spine FP.
- While doing that we will be learning what we need to do to build a minimum-sized design

Acknowledgements

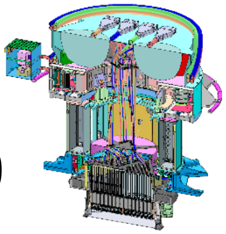
- Steve Kent, Kyler Kuehn, Joe Silber, Will Saunders, Michael Schubnell, Greg Tarle, Matthew Colless, Darren DePoy, Jennifer Marshall, Ting Li, Klaus Honscheid, Marcelle Soares-Santos
- I presented some of this talk at “LSST NEXT-GENERATION INSTRUMENTATION WORKSHOP”, APRIL 11-12, 2019 @ ANL. Workshop Summary: arXiv:1905.04669
- DESPEC concept paper
- CVDE Process & Participants



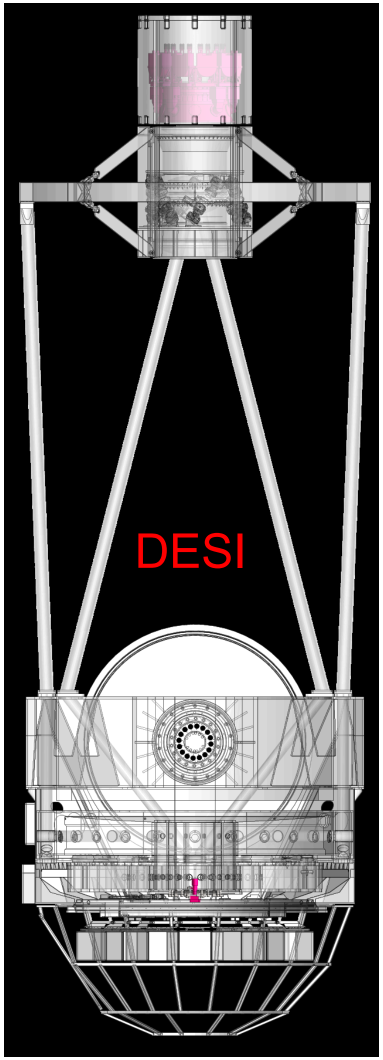
Old Instrument Ideas

- 2009: Gemini 8m telescopes (WFMOS) proposals for a Cassegrain Instrument with O(2500) fibers. Optical design had a 1 sq-deg focal plane (I recall).
- 2012: Blanco 4m telescope at Cerro Tololo (DESPEC) arXiv:1209.2451 & J. L. Marshall et al, Proc. SPIE 8446, 844656 (2012) at Prime Focus. O(<100M) spectra due to mirror size. Also "DESI in the South" ideas.
- 2013: LSSTSpec https://www.noao.edu/meetings/lsst-spec/ & the conference in 2018 at ANL. Called for 3 mm pitch. Also see Christopher W. Stubbs and Katrin Heitmann, "Report on LSST Next-generation Instrumentation Workshop April 11-12, 2019", https://arxiv.org/abs/1905.04669.

Current Instruments



- 2020?: Subaru Telescope Prime Focus Spectrograph will have 2400 piezo-driven Twirling Posts with 8mm radius and ~ 1 cm pitch
- 2019: DESI at Kitt Peak has 5000 TP FPs with 1 cm pitch. Tiny motors and gears.
- 2022: 4Most on the VISTA telescope at La Silla will have 2400 Tilting Spines ~ 1 cm pitch



New instrument Ideas

- 2016: “Billion Object Apparatus” https://kicp-workshops.uchicago.edu/FutureSurveys/
- 2018: Mauna Kea Spectroscopic Explorer w/ 4000 fibers on a new 11.25 m telescope https://mse.cfht.hawaii.edu/ & arXiv:1810.08695
- 2019: MegaMapper w/ 20,000 fibers on a new, Magellan-like telescope at Las Campanas arXiv:1907.1117
- SpecTel and others. See:

2020 Astro Decadal Survey White Papers:
https://ui.adsabs.harvard.edu/public-libraries/uZ71y9jERUiiOpuDvrXNSg

How many spectra, say following Up LSST Imaging?

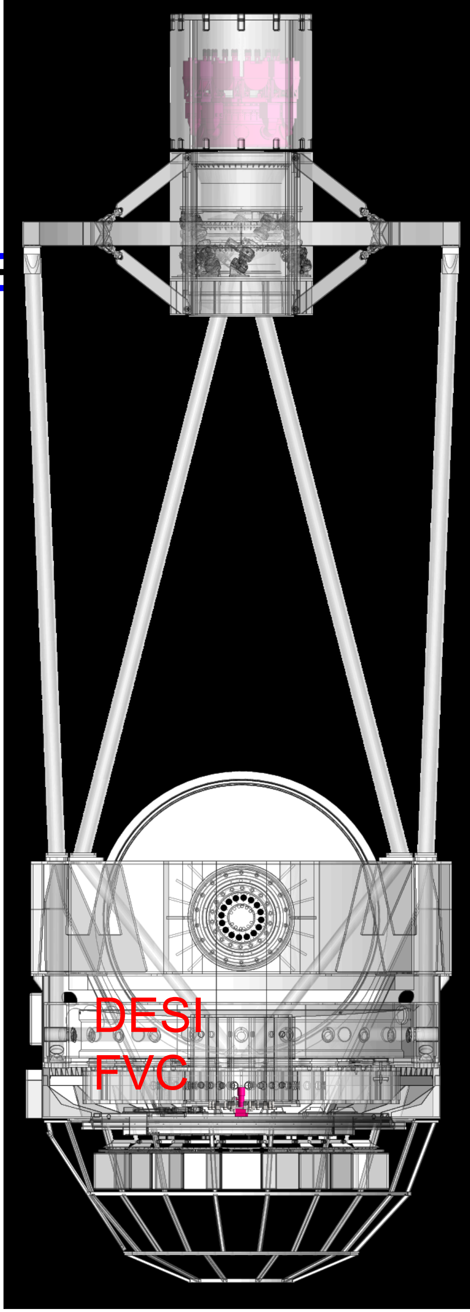
$$N_{Objects} = N_{Fibers} N_{Nights} N_{Exp/Night} W_{eather}$$

- Some LSST Survey Characteristics:
  - 18,000 square degrees.
  - ~ 20 Billion galaxy detections
  - Magnitude $20 < i_{AB} < 23.5$ yields 50,000 objects per sq-deg. Conceivable to acquire spectra of billion galaxies.
- Acquiring 500M to 1B spectra demands high multiplexing.
- The workshop suggests 30,000 FPs 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 …
- LSST Optics (current) not well-suited to FP’s of any kind

“Report on LSST Next-generation Instrumentation Workshop April 11-12, 2019”, https://arxiv.org/abs/1905.04669.

More Fiber Positioner Components & Technical Design Considerations

- 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?



How FP R&D fits into DOE's Cosmic Plans

- The Cosmic Visions Small Projects Report outlined the need for R&D into Fiber Positioners.
- A "Small projects Portfolio follow Up" (Kyle Dawson et al.) outlined the scope of effort we are looking at. There were 4 milestones applying to R&D on twirling posts as well as tilting spines. This is aiming for a 5-6 mm pitch.
  - *Milestone 1 (by August 2020):* Prototype the critical components. Complete preliminary designs for fully-functional positioners based upon these components.
  - *Milestone 2 (by December 2021):* Complete first generation fiber positioner prototypes and performance testing for positioning accuracy. Complete preliminary designs for ferrules.
  - *Milestone 3 (Prior to Snowmass):* Construct second generation fiber positioner prototypes, based upon both performance results and assembly lessons from the first generation prototypes. Conduct testing …
  - *Milestone 4:* Build and test assemblies of 50 positioners with fibers …