BigBOSS Focal Plane Assembly

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[DOE Review of BigBOSS, Berkeley, Dec. 6-7, 2011]

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- BigBOSS Spanish Participation Group (BSPG)
- WBS & Tasks assigned
- Focal plate requirements, status, interfaces and R&D scope
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BigBOSS in Spain

Spanish Participation Group:

- Instituto de Astrofísica de Andalucía, IAA-CSIC
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  Contact: C. Allende-Prieto
- Institut de Ciencies del Cosmos, ICC-UB
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  Conctact: A. González-Arroyo
- Observatori Astronomic de la Universitat de Valencia, OA-UV
  Contact: V. Martínez

Contributors to the Focal Plane activities

- IAA-CSIC BigBOSS Team:

  F. Prada, P.I. & Instrument Scientist
  M. Azzaro, Project Manager
  S. Becerril, System & Mechanical Engineer
  J. Sánchez, Electronics Engineer
  A.D. Montero-Dorta, Postdoc

  In collaboration with the Spanish Company AVS.

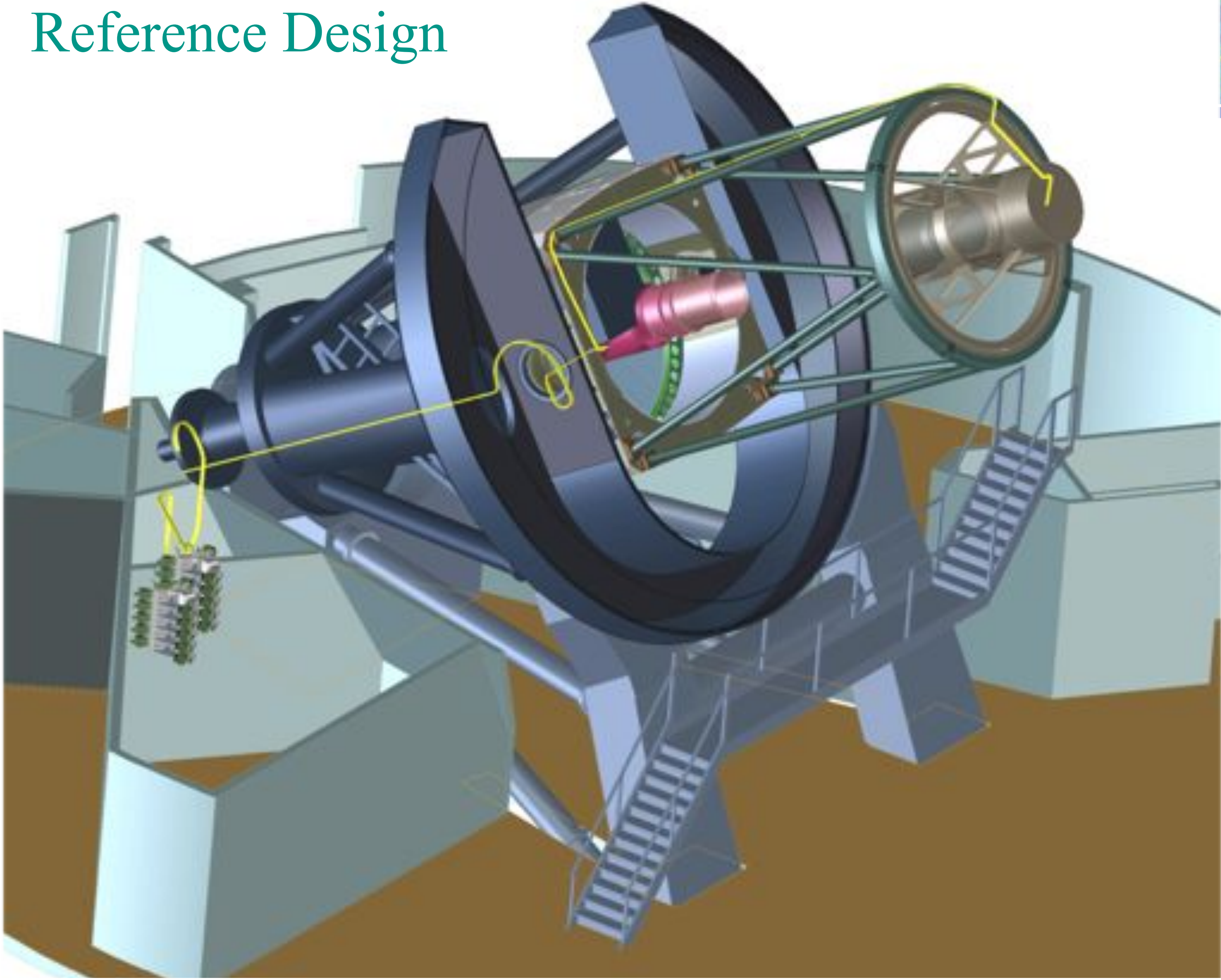
  Other collaborations:

  CEI UAM+CSIC, EPS Madrid (electronics)
  MultiDark Consolider Project

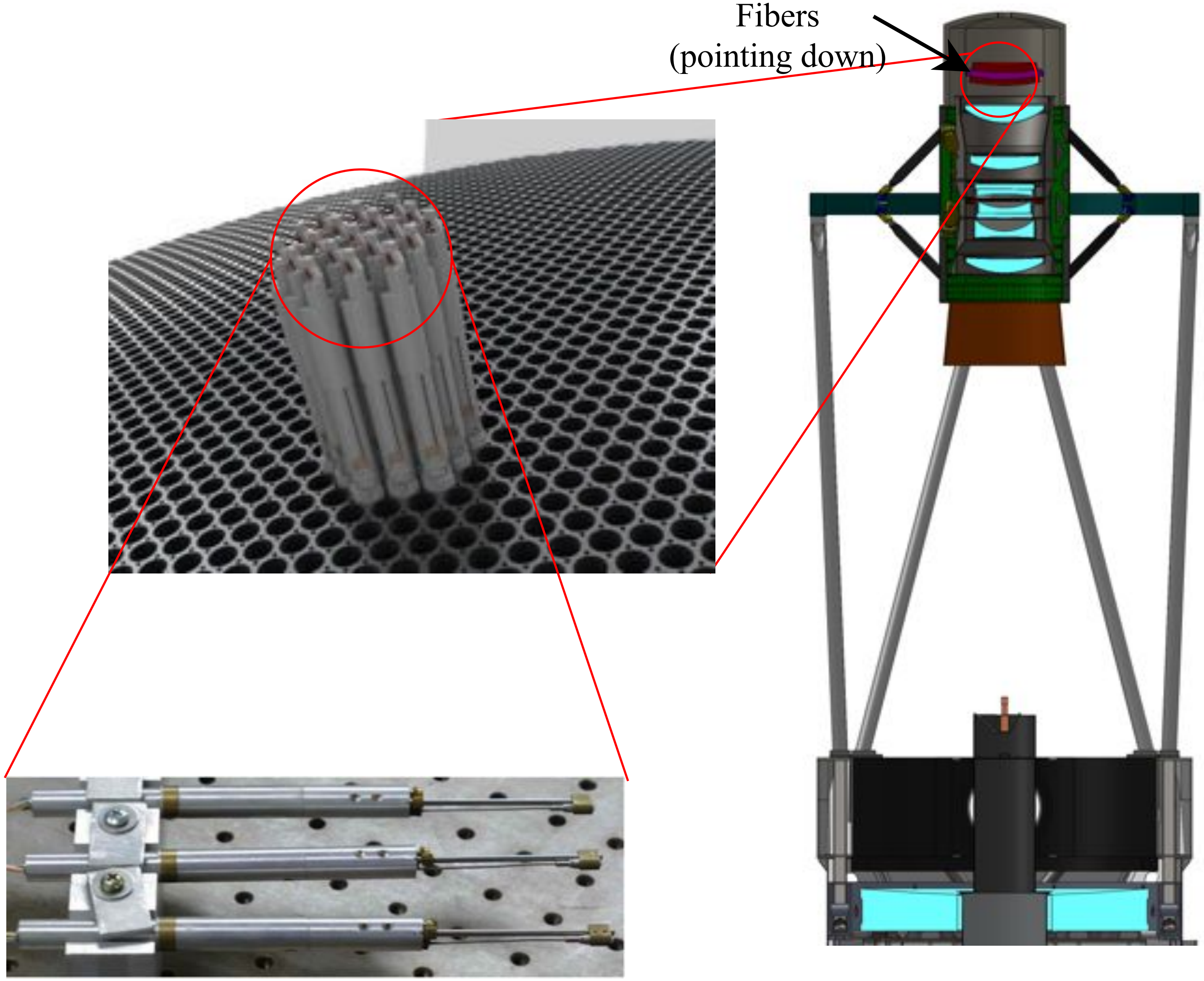
- UCB/LBNL Team:
  R. Besuner, J. Edelstein, P. Jelinsky, P. Perry, M. Sholl, J. Silber, C. Schenk, Z. Zhou.

- USTC Team:
  C. Zhai, H. Hu

Reference Design



Focal Plane System

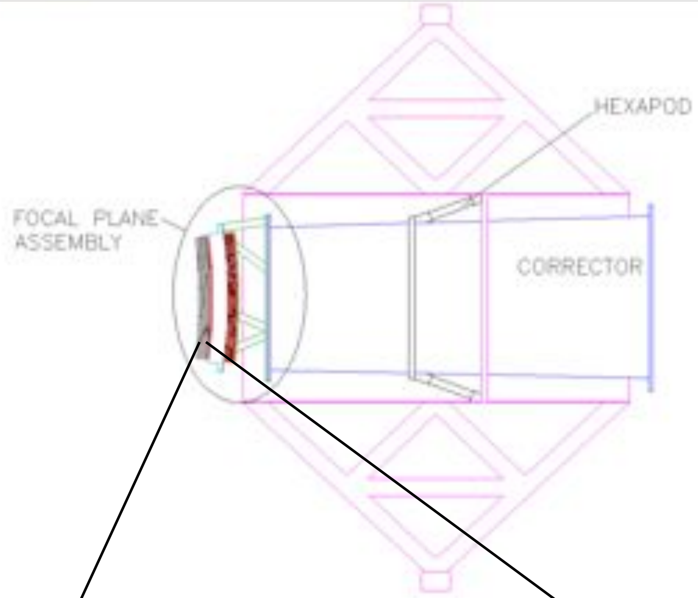


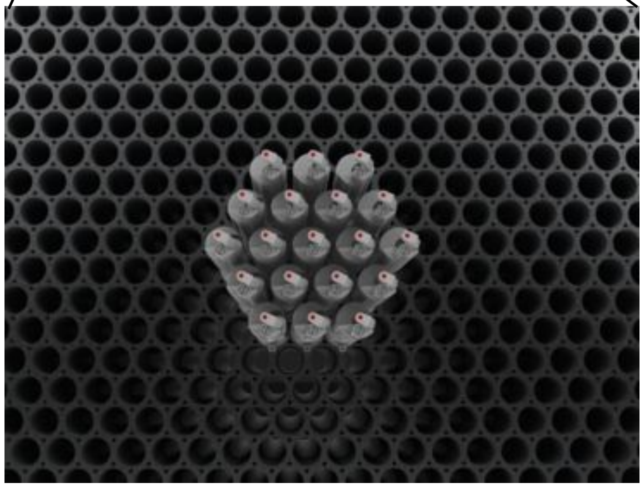
Focal Plane WBS & Tasks

- Focal plate.
    - Requirements and error budget
    - Topology
    - CAD modeling
    - FEM analysis (with LBNL)
        - Structural
        - Thermal Transient
    - Search for proper materials AlSi machineability tests
    - Thermal study (with LBNL)
    - Focal Plate tolerancing (with LBNL)

- Theta-theta fiber positioner.
    - Requirements and error budget
    - Concept design
    - Motor tests
    - Electronics concept
    - Positioning software

- Develop Interfaces
    - Focal Plate/Actuator interfaces
    - Interfaces for fiducial fibers
    - Interfaces for guiders
    - Repeatable, semi-kinematic mounts
    - Adapter interfaces

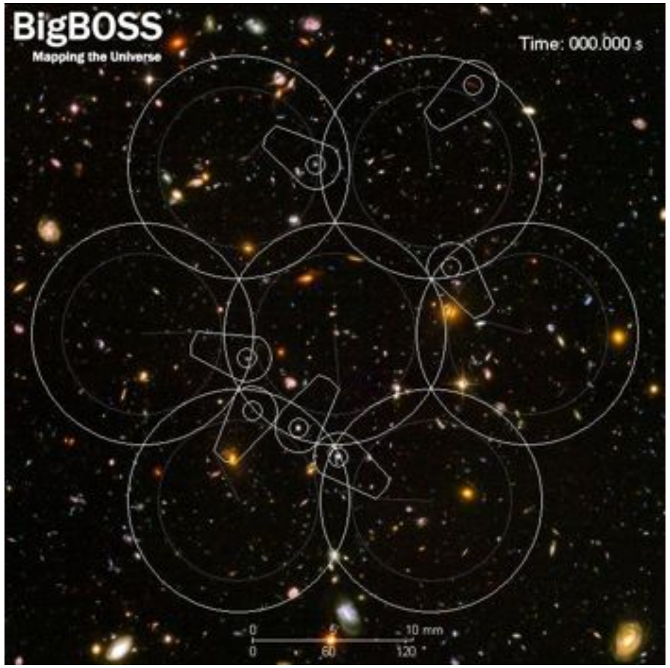


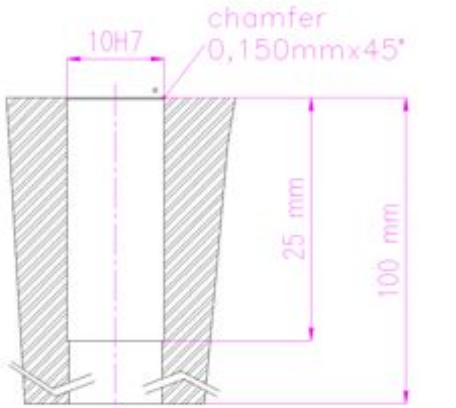


Focal Plate Requirements

General requirements for the Focal Plate	
Number of actuators	5000
Hole pattern	Hexagonal
Diameter	0.95m
Plate thickness	100mm
Positioner pitch	12mm on the Focal Surface
Radius of curvature of focal surface	>2.5m
Maximal Errors on Z direction	
Figure error of focal plate	≤±30µm (goal: 20µm)
Thermal and gravitational sag of focal plate	≤±20µm
Maximal Errors on lateral direction (XY)	
Lateral positioning accuracy of holes	≤±40µm
Maximal Tilt Errors	
Hole angular tolerance	≤±0.02°
Temperature Requirements	
Survival temperature range	-20°C to +60°C
Operating temperature range	-10°C to 30°C
Hole chamfer	0.1 to 0.3mm
Mount flange edge radius	Undercut
Interface Requirements	
Guiders, fiducial fibers, kinetic mountings, etc	

Focal Plane Patrol discs layout

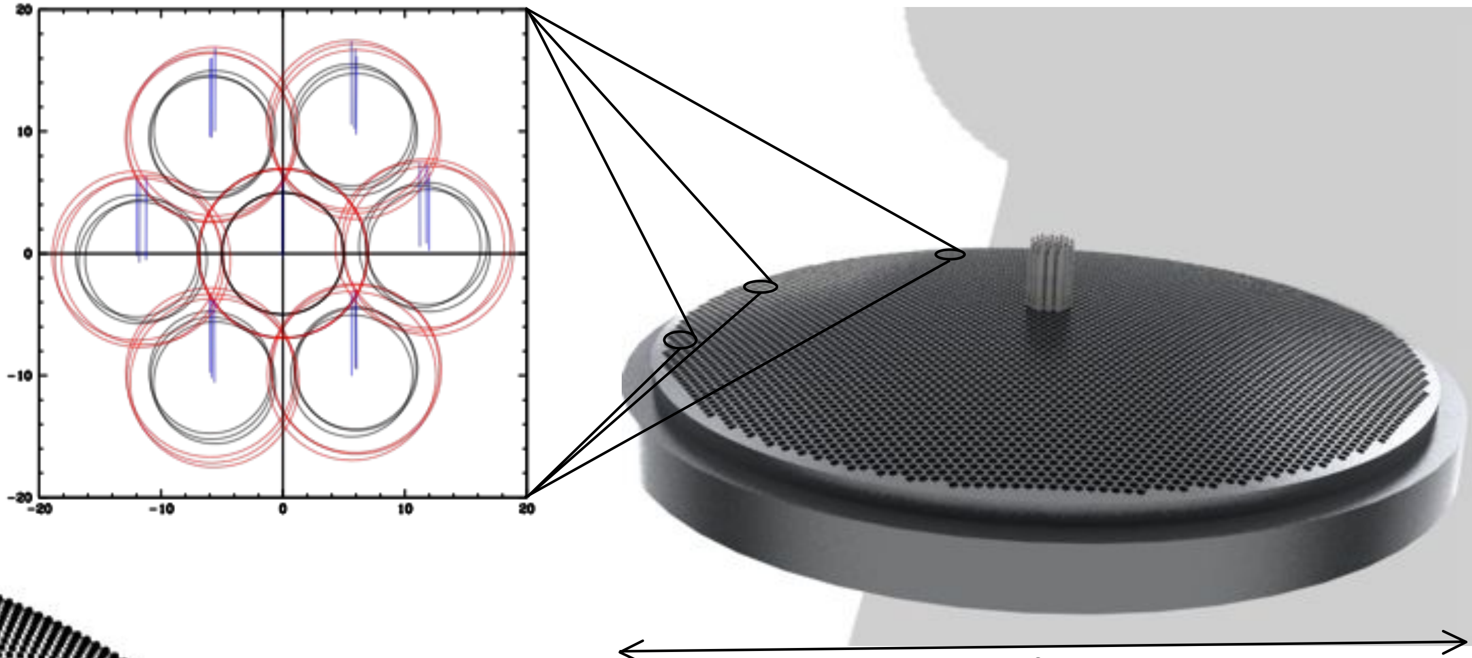


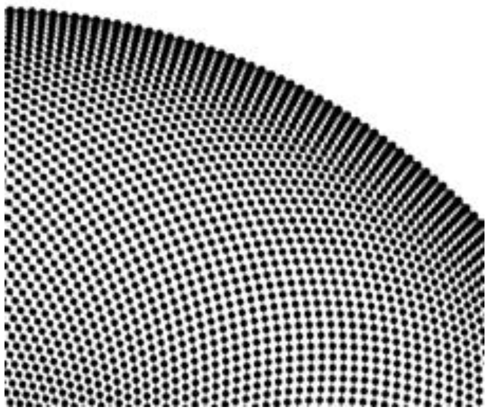


Focal Plate/Actuator Interface
for IAA/AVS, USTC & LBNL

Focal Plate topology

The deformation of different parts of the border of the focal plate. The curvature radius is much smaller than the real one (750 mm) in order to make the effect more visible.

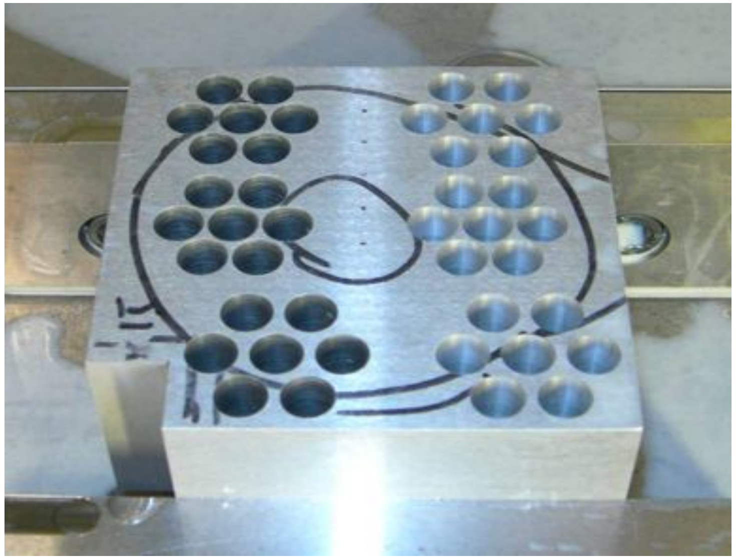




The theta-theta concept, combined with stepper motors, gives a discrete set of positions available to the fiber on the patrol disc. The worst-case resolution available is about 4 μ (requirement is < 5 μ).

Because of the curvature of the plate, the pitch of the positioners cannot be uniform and the maximum difference will be of the order of 72 μ. Also, because of the step motors, the fiber can move on a grid of nearly 210 million positions within the patrol disc of each positioner.

Focal Plate material tests



Drilled (left) versus milled (right) holes

Milled holes finish detail

Aluminum, steel and Al/Si alloy are considered. Tests are ongoing in order to ascertain the best-structurally and thermally behaving material. Al/Si was tested also for machining, because it is a less known alloy, with the advantage that its expansion coefficient is very close to that of steel and is stiffer than normal Aluminum.

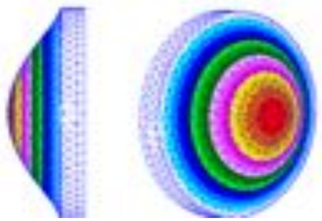
A bulk of Al/Si was set under test in order to find the best machining method. Milling of the metal is found to give the best results both for flat surfaces and forming holes (drilling and wire cutting were also tested). No problems are found with small wall thickness. Tapping the alloy with small threads does not present special difficulties. No overheating is observed.

Al/Si Focal Plate Gravitational Deflection

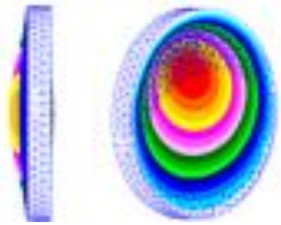
				MAXIMUM DISPLACEMENT								
				90° ELEVATION (OUT OF PLANE)			0° ELEVATION (IN PLANE)			5° ELEVATION		
caso	h[mm]	Pitch[mm]	Ø hole[mm]	R [μ]	θ [μrad]	φ [μrad]	R [μ]	θ [μrad]	φ [μrad]	R [μ]	θ [μrad]	φ [μrad]
1	2,000	10,000	8,000	**3,400**	**0,577**	**0,582**	0,104	0,019	0,351	0,105	0,008	0,350
2	2,000	11,000	9,000	**3,580**	**0,608**	**0,612**	0,112	0,020	0,374	0,112	0,009	0,372
3	2,000	12,000	10,000	**3,730**	**0,632**	**0,636**	0,120	0,021	0,392	0,120	0,010	0,391
4	2,000	13,000	11,000	**3,880**	**0,653**	**0,656**	0,128	0,023	0,408	0,128	0,011	0,406
5	1,750	9,750	8,000	**3,670**	**0,626**	**0,631**	0,115	0,021	0,387	0,115	0,009	0,386
6	1,750	10,750	9,000	**3,840**	**0,656**	**0,660**	0,123	0,022	0,410	0,123	0,010	0,408
7	1,750	11,750	10,000	**3,970**	**0,678**	**0,682**	0,130	0,023	0,428	0,130	0,011	0,426
8	1,750	12,750	11,000	**4,100**	**0,695**	**0,698**	0,138	0,025	0,442	0,138	0,012	0,440
9	1,500	9,500	8,000	**3,970**	**0,684**	**0,689**	0,127	0,023	0,430	0,127	0,011	0,429
10	1,500	10,500	9,000	**4,120**	**0,710**	**0,715**	0,135	0,025	0,452	0,135	0,011	0,451
11	1,500	11,500	10,000	**4,230**	**0,728**	**0,731**	0,142	0,026	0,468	0,142	0,012	0,466
12	1,500	12,500	11,000	**4,320**	**0,739**	**0,740**	0,149	0,027	0,478	0,149	0,014	0,476
13	1,250	9,250	8,000	**4,310**	**0,748**	**0,753**	0,142	0,026	0,482	0,142	0,012	0,480
14	1,250	10,250	9,000	**4,420**	**0,768**	**0,772**	0,149	0,027	0,500	0,149	0,013	0,498
15	1,250	11,250	10,000	**4,480**	**0,777**	**0,779**	0,155	0,028	0,511	0,155	0,014	0,509
16	1,250	12,250	11,000	**4,500**	**0,778**	**0,777**	0,160	0,029	0,514	0,160	0,015	0,512

FIELD OR RADIAL DISPLACEMENTS FOR THREE LOAD CASES:

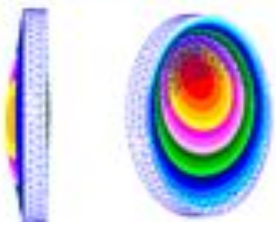
OUT OF PLANE (90° elevation)



IN PLANE (0° elevation)



5° elevation



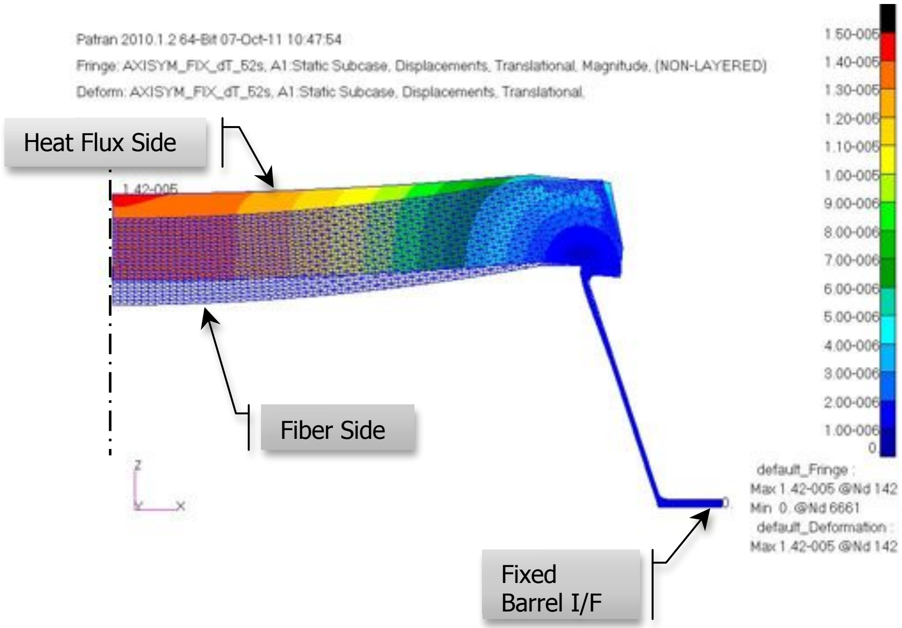
The most critical gravity deformation is in the Z direction. Analyses performed in collaboration with LBNL show that, with an Al/Si plate 100 mm thick and clamped boundaries, the maximum Z displacement can be kept to less than 4μm (requirement is <~15μm).

Thermal Distortion

- Thermal gradient deflection through focal plate:
  Constant heat flux (q=1155 w/m^2) at z=0 for 52sec
- Axi-symmetric finite element model of focal plate and adapter

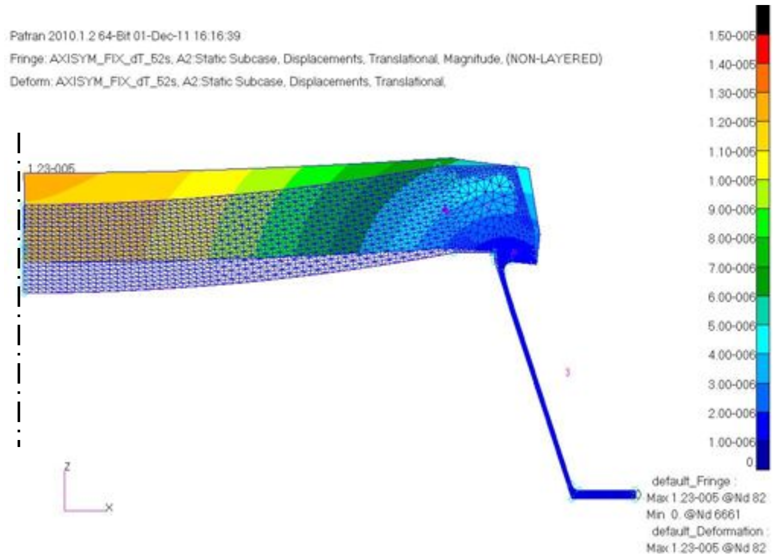
STEEL

14 um peak deflection



ALUMINUM

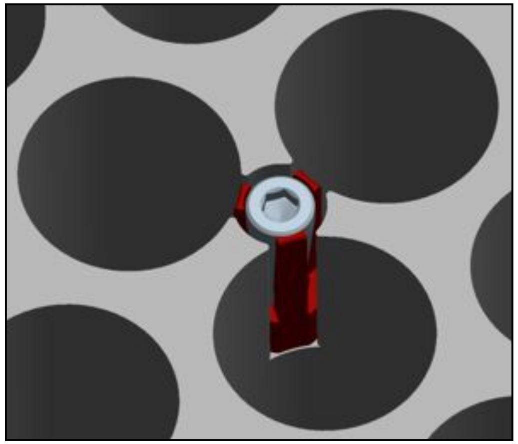
12 um peak deflection

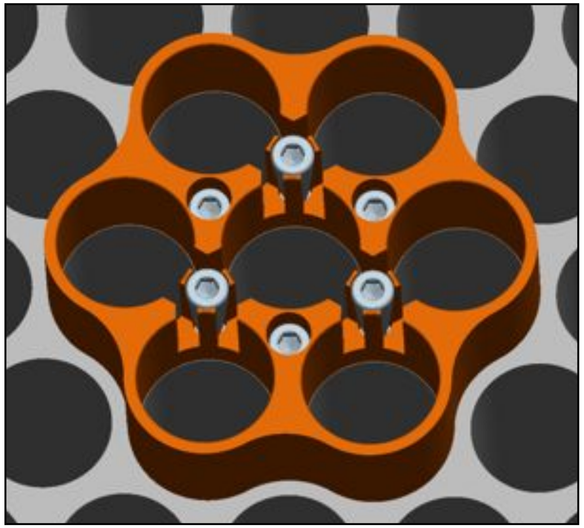


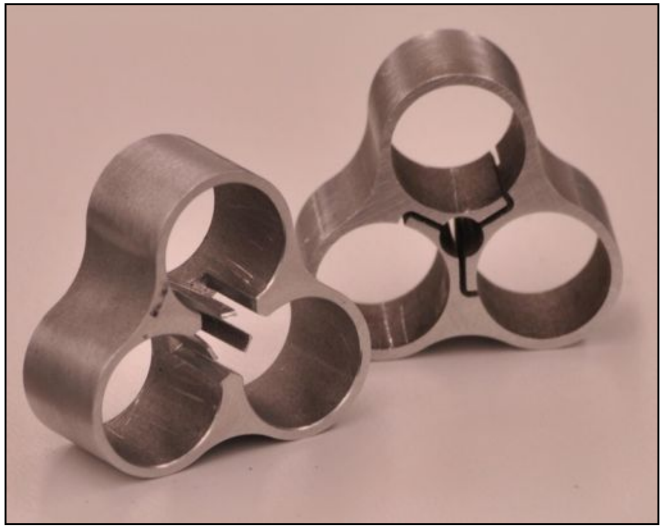
Preliminary results suggest that aluminum may be acceptable, despite its relatively high CTE due to its high thermal diffusivity and rapid equilibration of through-the-thickness temperature gradients.

Fiber Positioner Retention

- Development and testing of interface hardware for clamping fiber positioners into focal plate
- Must retain positioner with long-term stability in arbitrary orientations with varying environmental conditions
- Principle is to use a tapered screw in a retained insert or flexural ring to clamp multiple adjacent positioners
- Other possibilities will be explored (e.g. actuator screwed directly onto the front of the plate)







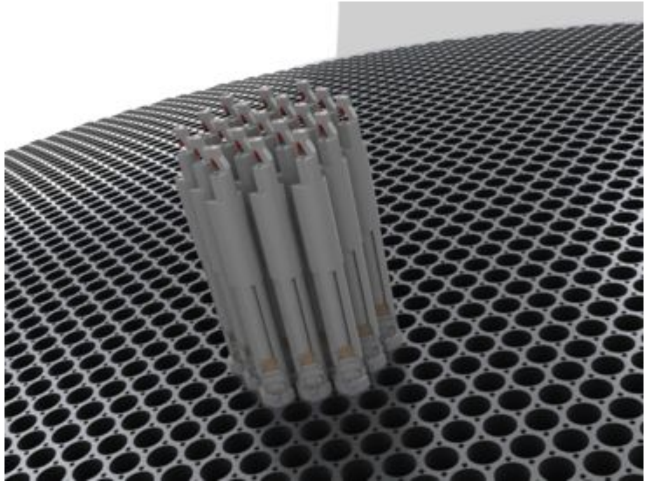
Focal Plate R&D Scope

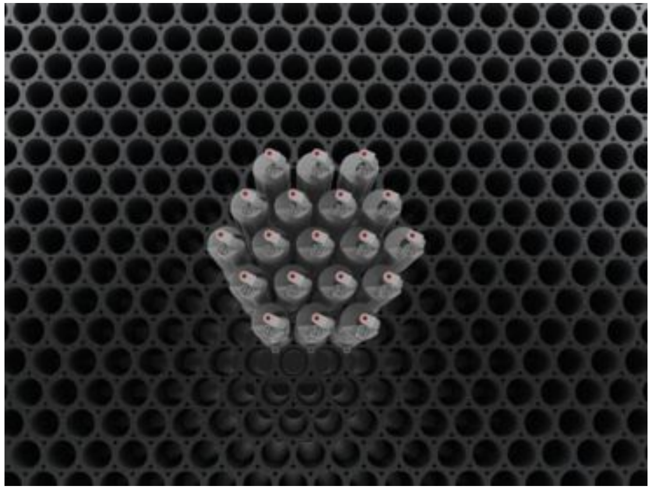
During the R&D phase the most critical issues of the design shall be faced up in order to produce a safe and consistent preliminary design.

Most of them will be mitigated by the production and testing of a sub-scale plate. Indeed, this will give us important information about the long-term dimensional stability of the material and the errors produced during the manufacturing. The thermal/structural FEM models will also be checked through the sub-scale plate.

Thus, both the interface with the fiber positioner and the error budget tolerances of the Focal Plate will be revised/confirmed. Efficient metrology and manufacturing procedures for the further production of the Focal Plate will also be established.

All these inputs will result in a realistic cost estimate of the Focal Plate component.





Actuator Requirements

General requirements	
Fiber core diameter	120µm
Repositioning time	45s
Full coverage of Focal Surface	13.86mm diametre Patrol Disc
Mounting and fiber routing requirements	
Mounting trajectory of Fiber Ferrule into the Actuator	From back side to front side (or viceversa)
Maximal bending radius of the fiber	50mm
Routing of fiber through the actuator	≈1.5mm clear diametre routing from end to end
Interface with the Focal Plate	10g6 over 25mm length
Maximal Errors on Z direction	
Fiber positioner error (over range of motion)	≤±20µm
Precision over range of motion	≤±5µm
Spherical Departure	≤±5µm
Mounting precision Fiber Ferrule w.r.t. Actuator	≤±5µm
Mounting precision Actuator w.r.t Focal Plate	≤±5µm

Maximal Errors on lateral direction (XY)	
Lateral positioning precision of actuator	≤5µm
Later positioning accuracy of actuator	≤40µm
Positioner step inhomogeneity	≤2µm
2nd cycle absolute error	≤5µm
Patrol Disc Granularity	≤2µm
Error produced between successive tracking corrections	≤8µm
Tracking course error	≤5µm
Maximal Tilt Errors	
Positioner and ferrule holder tolerance	≤±0.15°
Temperature Requirements	
Survival temperature range	-20°C to +60°C
Operating temperature range	-10°C to 30°C
Others	
Lifetime	250,000 cycles

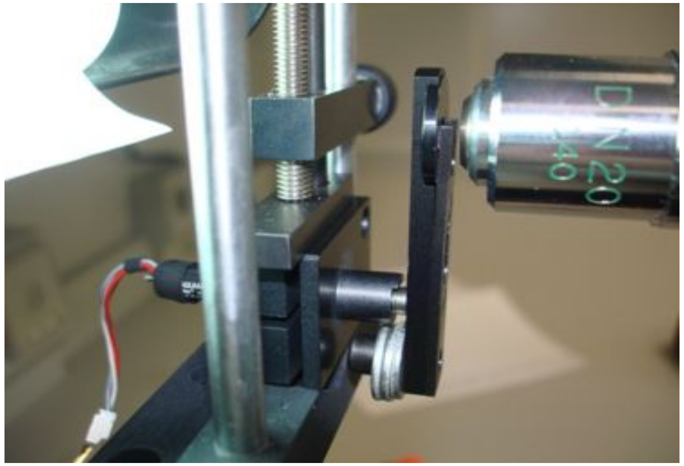
IAA/AVS Actuator Concept

- Two rotational DoFs (theta-theta concept)
- Backlash cancelled through standard torsion springs (successfully tested)
- Gearing ratios: 1/512 for ROT2 and 1/1024 for ROT1
- Two stops limit the range of movement for ROT1 (1 turn) and ROT2 (half turn)
- Both rotations are provided with a semi-closed loop device which sense the movement of the fiber in real time. This is crucial for avoiding incidental collisions.
- Overall features: 10mm diameter, ≈200mm length, 75g weight
- Final design of the prototype close to be completed.

Simulation of the Fiber Positioning Software

Positioner motor tests

The 6 mm Faulhaber motor with the 1024:1 gearbox.



The Faulhaber motor and gearbox, preloaded with a steel spring was tested with a 20X microscope.

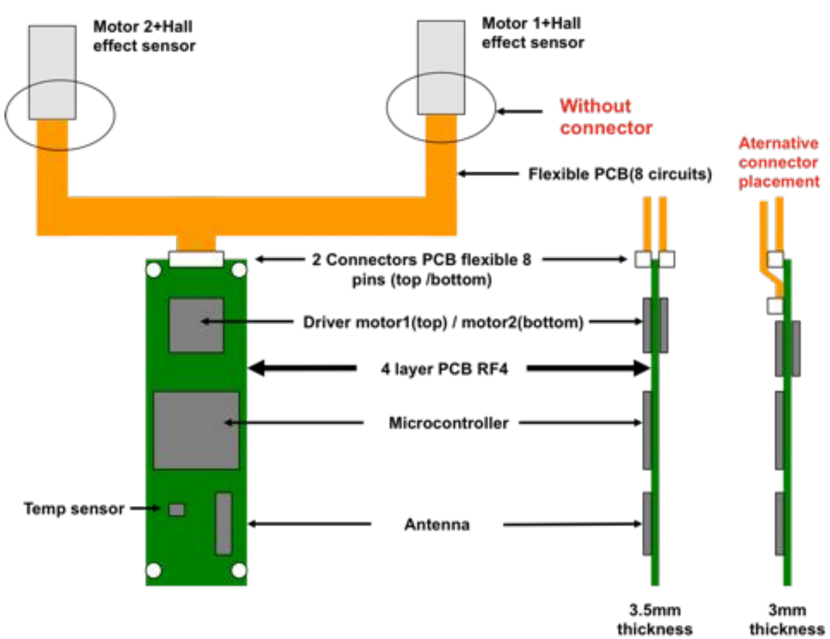
Results are scaled to the Patrol Disc radius (worst-case) of 7 mm.

- Steady position shift in disable mode ≤ 5 % of step (0.1 μ)
- Step homogeneity (gearbox output) = ± 47% of step (± 1 μ)
- Repeatability = ± 0.8 μ
- Residual backlash (with preload) = 0.9 μ
- Short run error ≤ 5 μ
- Longest run error (whole turn run = 20480 steps) = 15 steps or 32 μ
- Average absolute positioning error < 65 μ
- Power Consumption < 80 mW (not measurable in sleep mode)
- Life test passed (equivalent to 5 years operation)

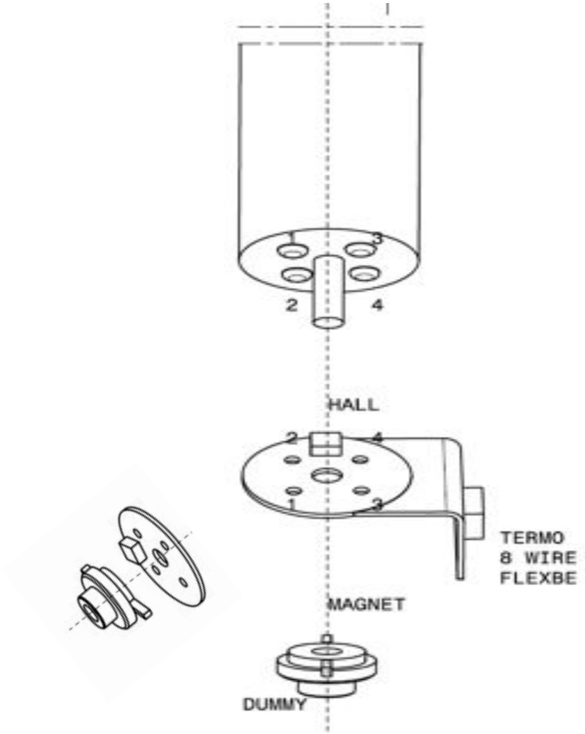
The Faulhaber motor+gearbox is totally suitable for the BigBOSS positioner.

Positioner electronics

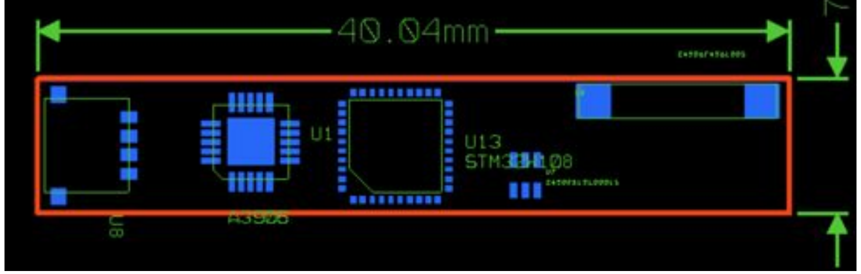
Electronics & Motor Assembly



Hall effect & Thermo sensor

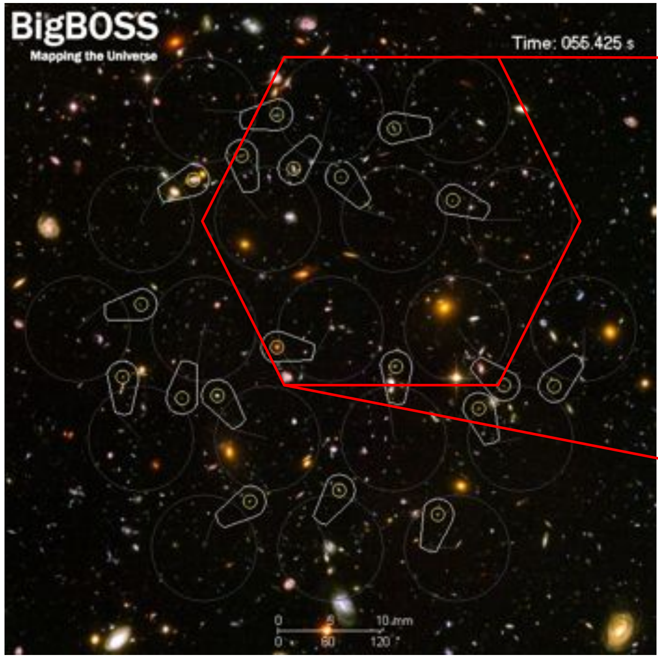


Electronics board can be kept within 40x8x3.5mm, Including Hall effect indexing for both motors and temperature sensors

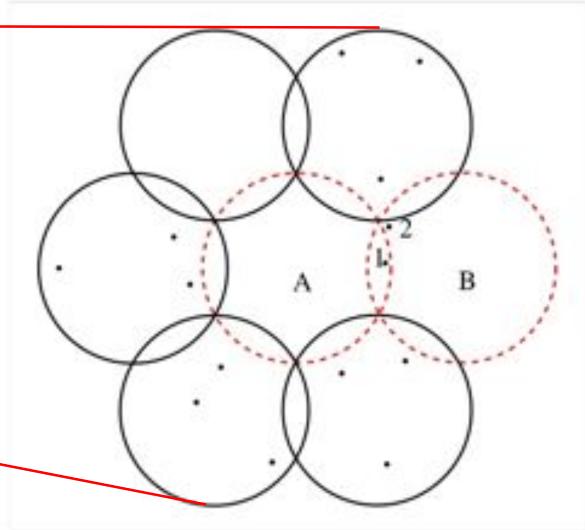


The electronics must be constrained within the actuator envelope (10 mm). The current concept is based on the SIDE electronics, but with a Zigbee modulus for wireless communications and a Hall effect indexing in semi-close loop for security of movement (very important in case of power loss or mechanical failure or **actuator collisions**).

Assignment & anti-collision software



Draining Algorithm



See Morales et al. 2011

In short, the software can properly deal with objects in common areas (shared by 2 or even 3 positioners). This is not possible with a random assignment. A summary of the advantages is:

- ~2% improvement as compared to a random assignment.
- ~4.5% for slight field rotations (+/- 2°, BigBOSS) and 5-6 % for unlimited rotations or small shifts (TBC).
- Fiber collisions are solved optimally.
- Dynamic collisions (during fiber positioning) are minimized and avoided.

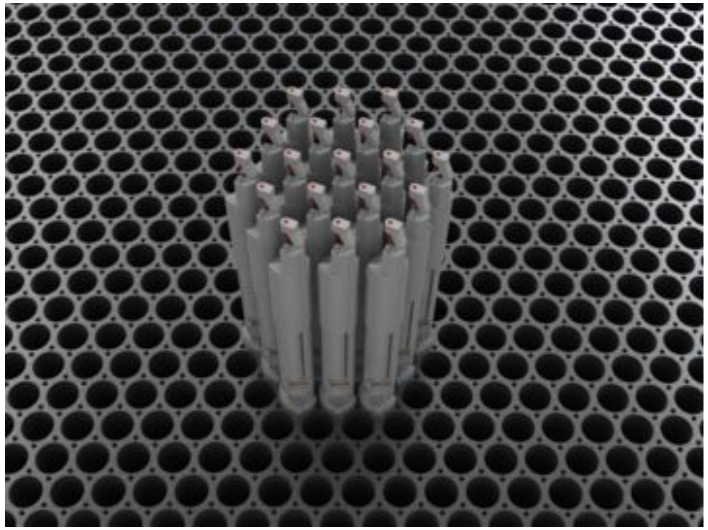
For BigBOSS, several hundreds of thousands targets are gained, or, equivalently, ~350 sq deg (~50 tiles).

Actuator R&D Scope

Some of the main actuator uncertainties will be mitigated by the production and testing of a 12mm-pitch demonstrator prototype. Thus, the actuator interface and locking mechanism will be tested. The fulfillment of the mechanical requirements and the error budget estimate will also be revised or confirmed.

Further issues (actuator collisions, integration of the Fiber Ferrule into the actuators, electronics, control software, etc) will be mitigated by a further stage with the production and testing of a sub-system of 19 units.

Finally, appropriate cost minimization and estimate for serial production of the Actuators will be done.



Simulation of the 19 actuator sub-system mounted on the Focal Plate

Summary:
Focal Plane R&D Work Plan 2012

- Sub-scale plate prototype production and testing by end of 2012.
- Actuator prototype produced by early Summer 2012.

Testing LCDM with BOSS/MultiDark

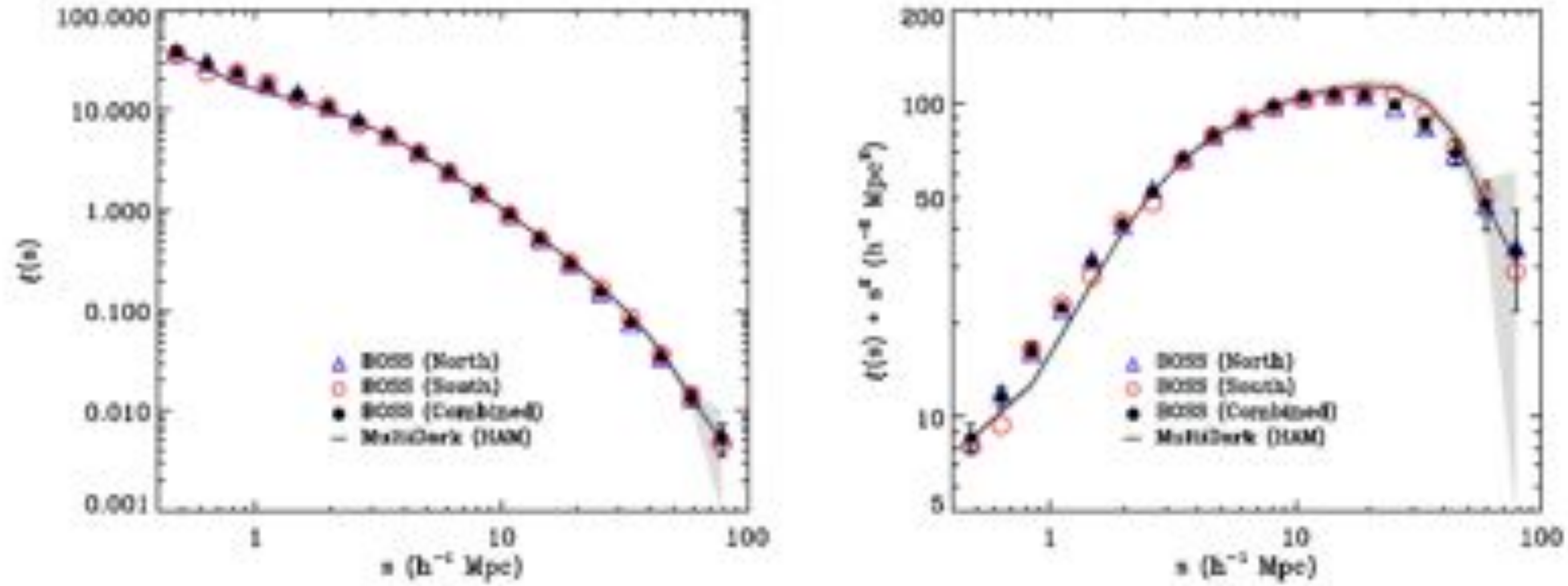
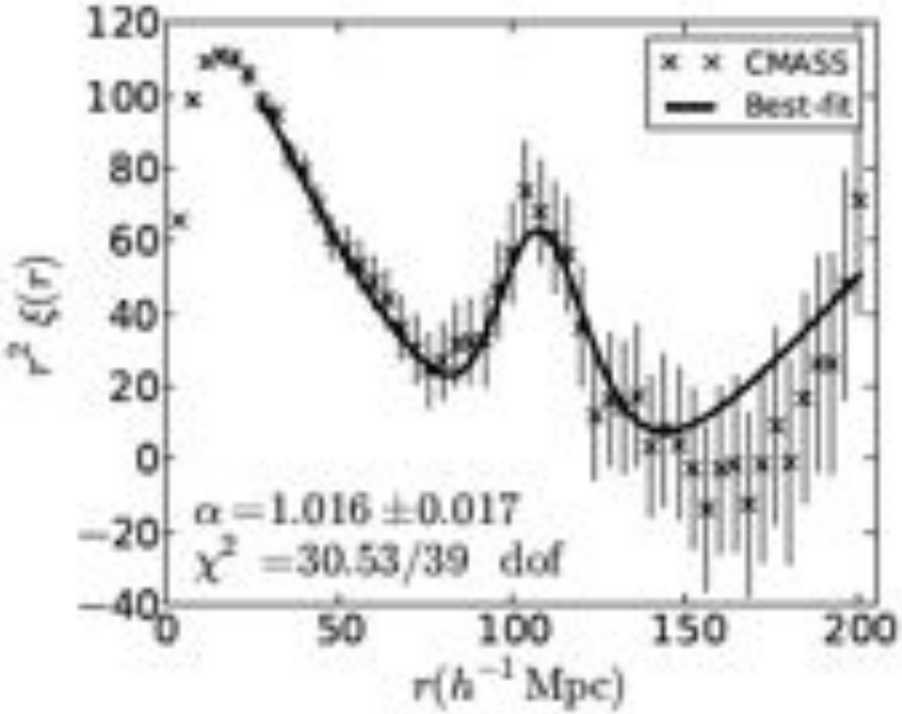
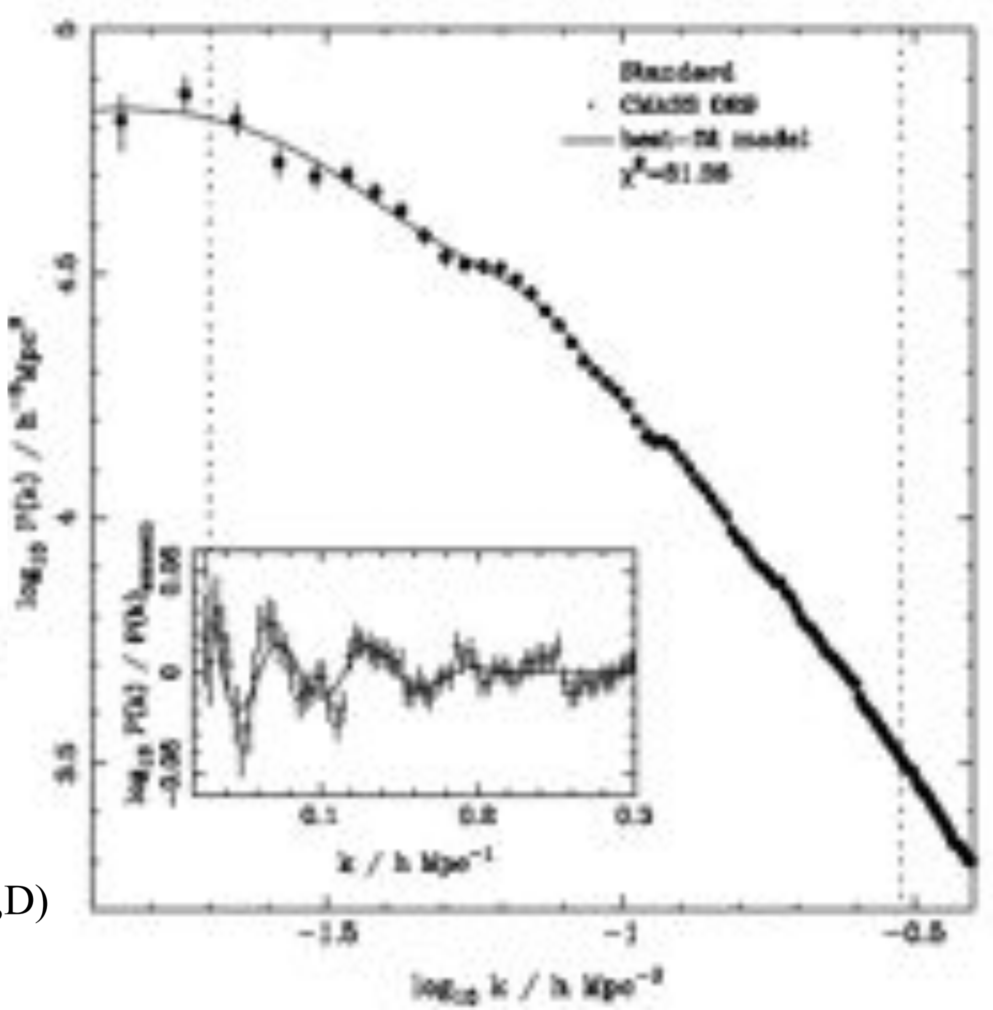


Figure 7. *Left panel:* Redshift-space correlation function for the $0.4 < z < 0.7$ DR9 BOSS-CMASS North, South and Full galaxy samples (open blue triangles, open red circles and filled black circles respectively) and the MultiDark catalog selected with the HAM procedure at $z = 0.53$ (solid line). Standard deviation for model and observations are shown in the same way as in Fig. 6. *Right panel:* Shown is the quantity $\xi(s)\,s^2$ which better reflects the differences between our ΛCDM model and BOSS clustering measures.

Nuza et al. 2012

First BAO results from BOSS!





arXiv:submit/0446072
From: David Schlegel <DJSchlegel@lbl.gov>
Date: Thu, 29 Mar 2012 13:11:54 EST (2799kb,D)

Title: The clustering of galaxies in the SDSS-III Baryon Oscillation Spectroscopic Survey: Baryon Acoustic Oscillations in the Data Release 9 Spectroscopic Galaxy Sample

First BAO results from BOSS!

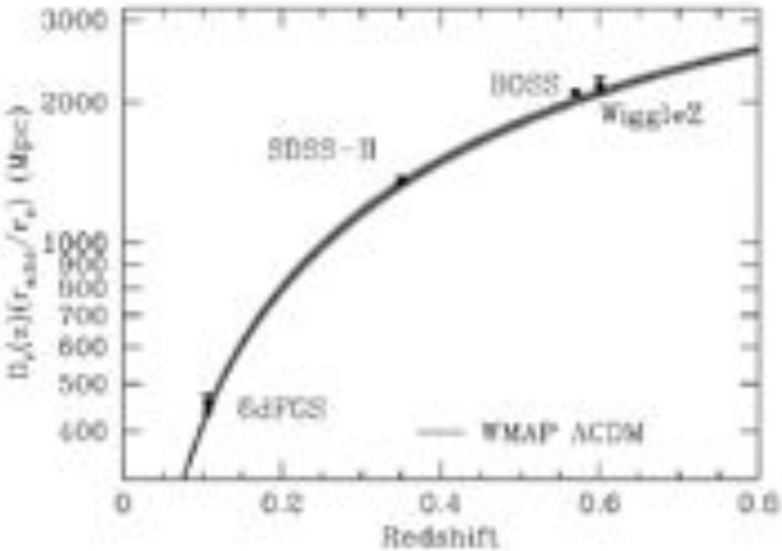


Figure 18. A plot of the distance-redshift relation from various BAO measurements from spectroscopic data sets. We plot $D_V(z)/r_s$ times the fiducial r_s to restore a distance. Included here are this CMASS measurement,

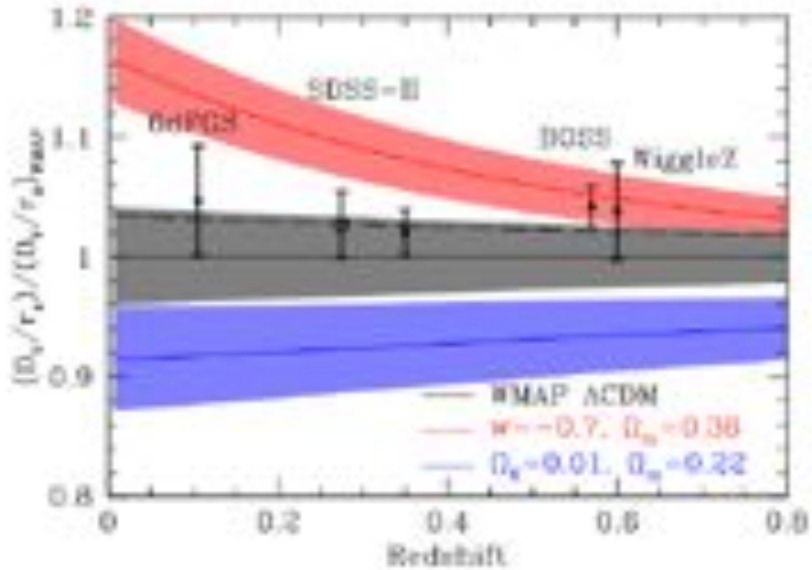


Figure 19. The BAO distance-redshift relation divided by the best-fit flat, ΛCDM prediction from WMAP ($\Omega_m = 0.266$, $H_0 = 0.708$; note that this is slightly different from the adopted fiducial cosmology of this paper). The grey band indicates the 1 σ prediction range from WMAP. In addition to the