Laser Periscope

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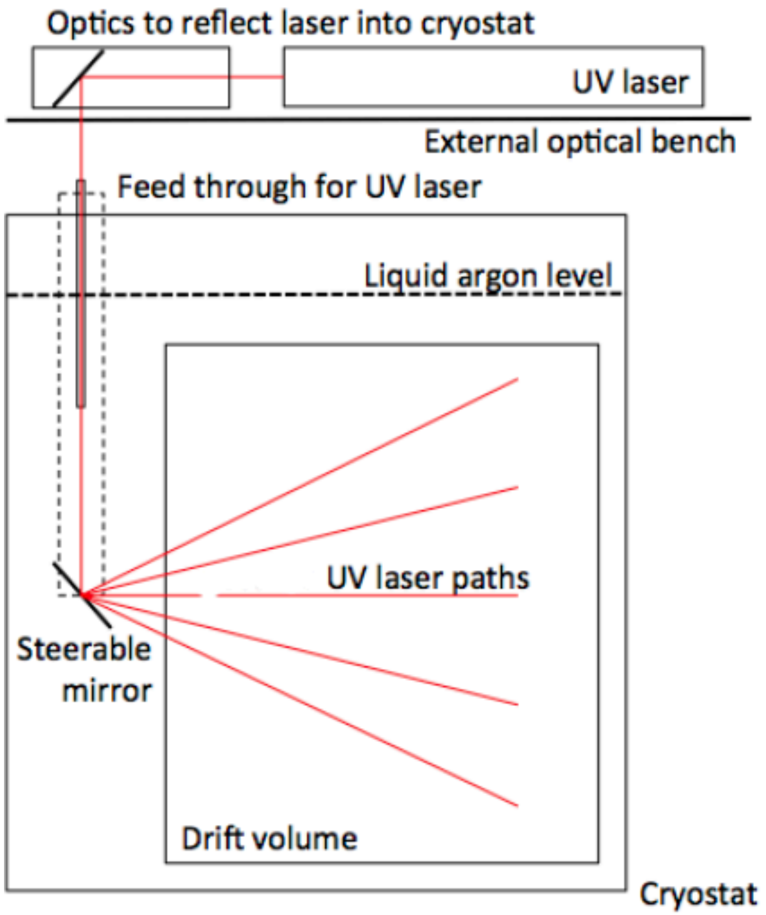
Ionization Laser Initial Design Review

September 16, 2020

Outline

- Overview of laser periscope system
- Optical design
  - Feedthrough and periscope, alignment target and camera
- Mechanical design
  - Polar and azimuthal movement (both designs)
  - Electrical break (both designs)
  - Vertical retraction and port aligner (Top Field Cage design)
  - Eccentric axis movement (End-Wall design)
- Laser beam coverage
  - Calculations of shadowing in various scenarios
- Revisit requirements

Design principles



- Based on design developed over many years by **Bern group**
- LAr ionization requires collimated intense UV beam — **laser** passage to cryostat **through quartz window**
- Wide coverage of the detector requires **mirror steering**
- Longevity and high field regions imply no motors inside — **rotational and linear couplings** for movement transmission

Main elements

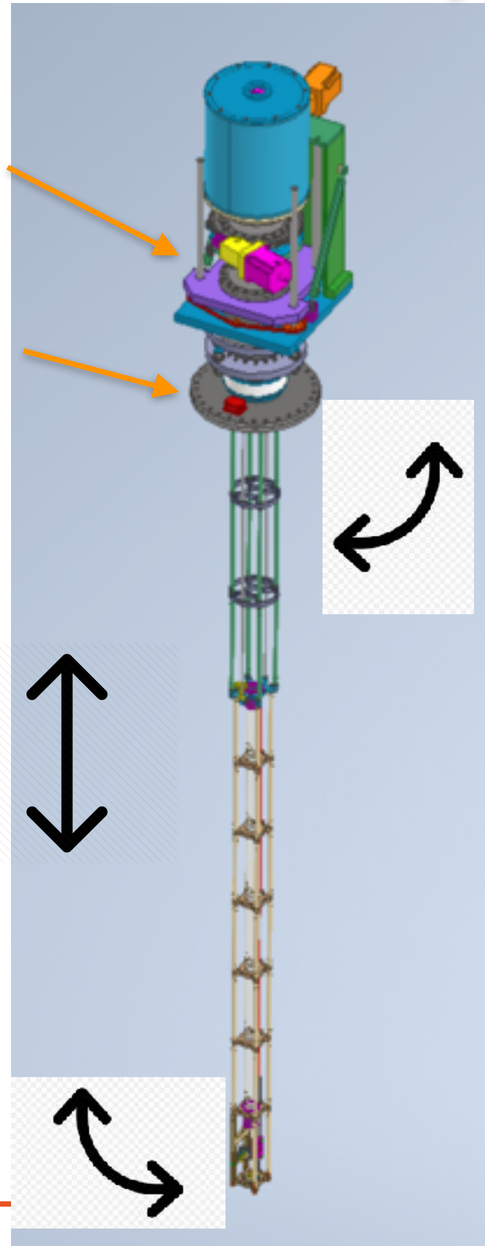
Beam from Laser Box enters here

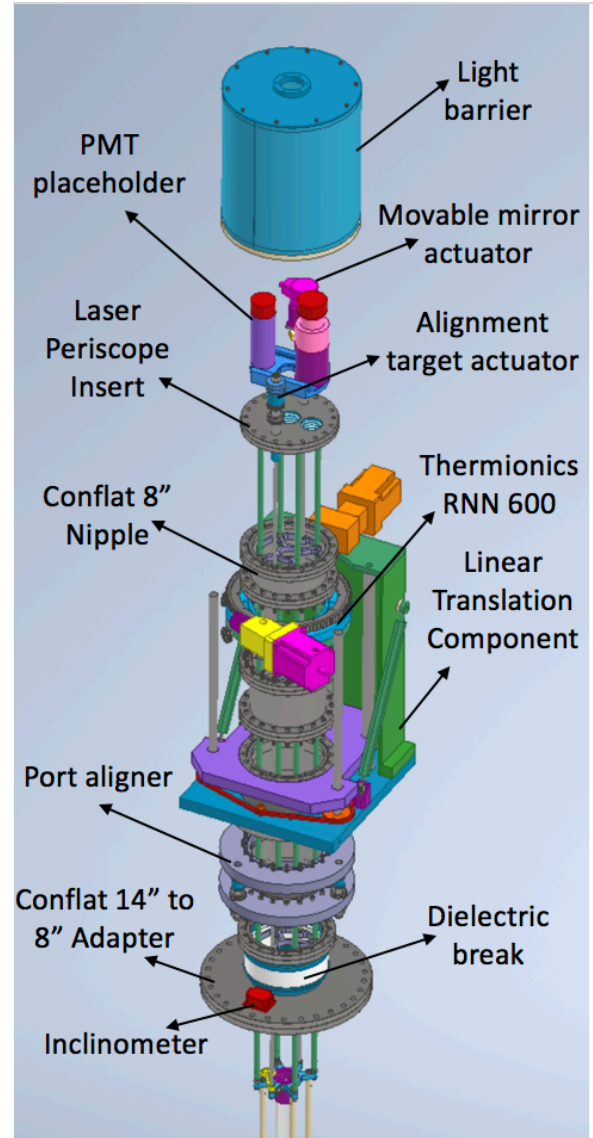
Rotary Stage: everything below this rotates azimuthally

Flange coupling to cryostat port

Structure mounted on rotary stage, with rod coupled to a linear stage

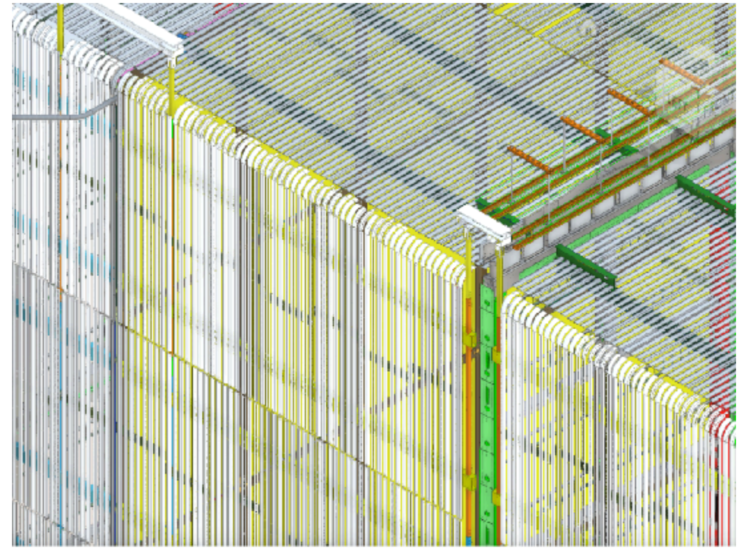
Steerable mirror with polar rotation

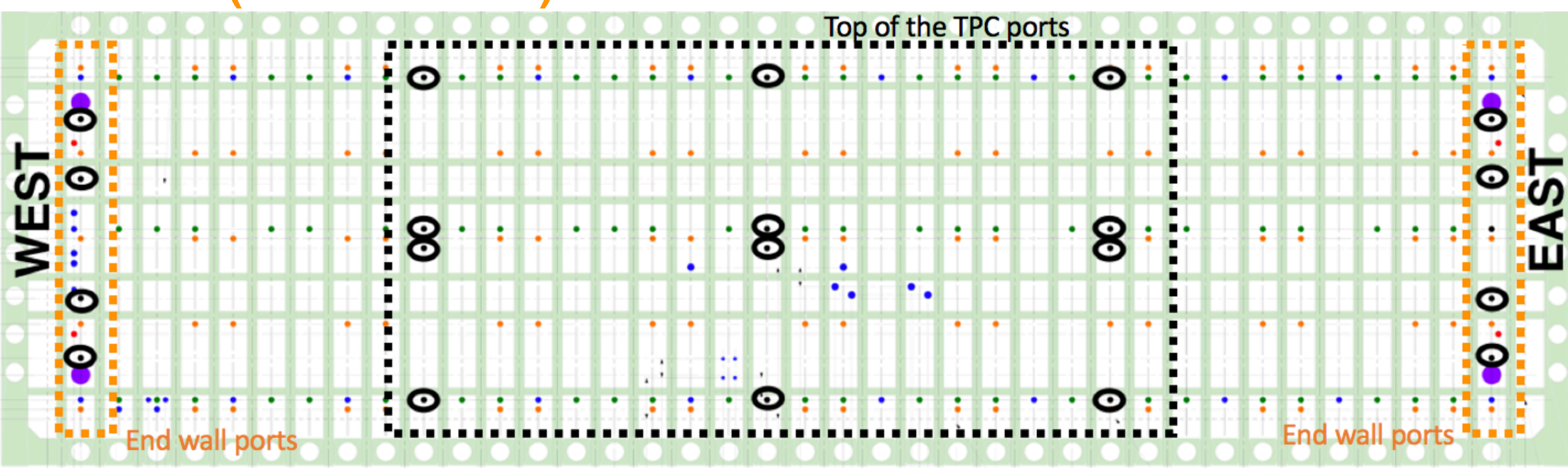




Design variants

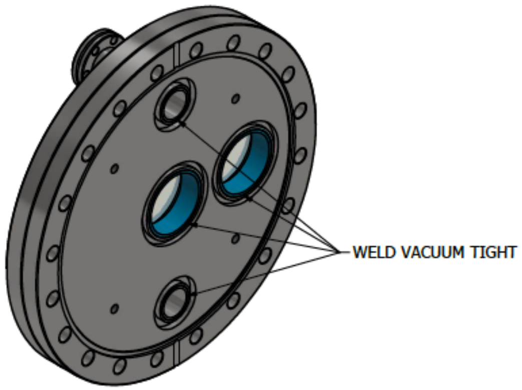
- MicroBooNE design — main limitation is FC shadowing
- We address this in two ways, according to location:
  - **Top FC penetration (also in SBND)**
  - **Dual rotation next to end-wall (new to DUNE)**

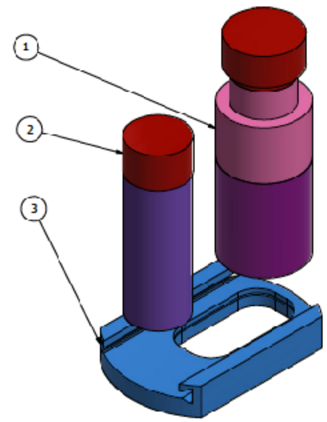




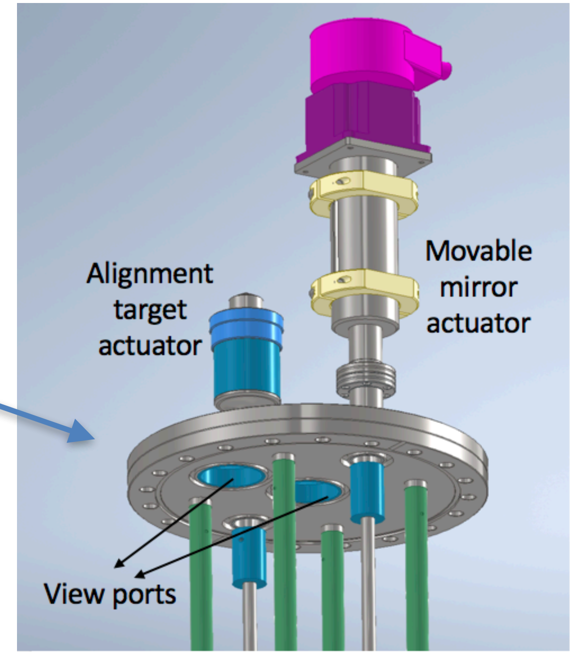
Optical Design

Optical feedthrough, top flange

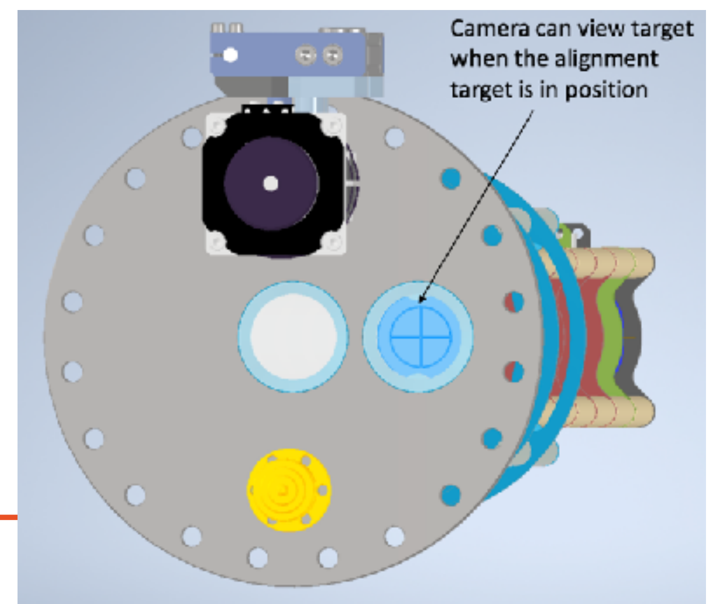




Camera & PMT mounted here too

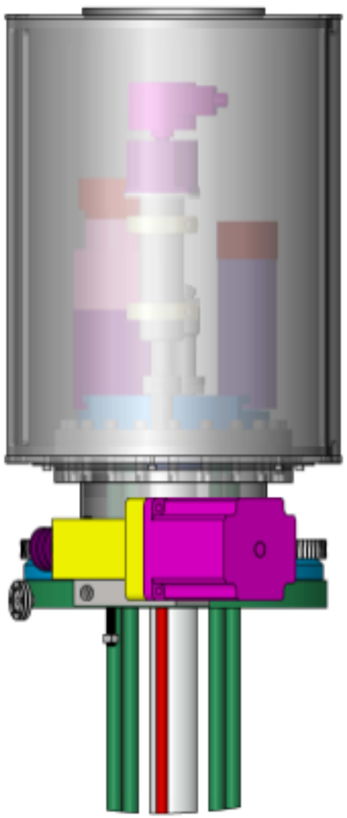


- Welded quartz viewports
  - no o-ring seals, no stress on glass tube
  - central viewport: laser beam
  - off-center port: camera/PMT
- Mechanical actuators
  - linear actuator for mirror polar movement
  - alignment target actuator

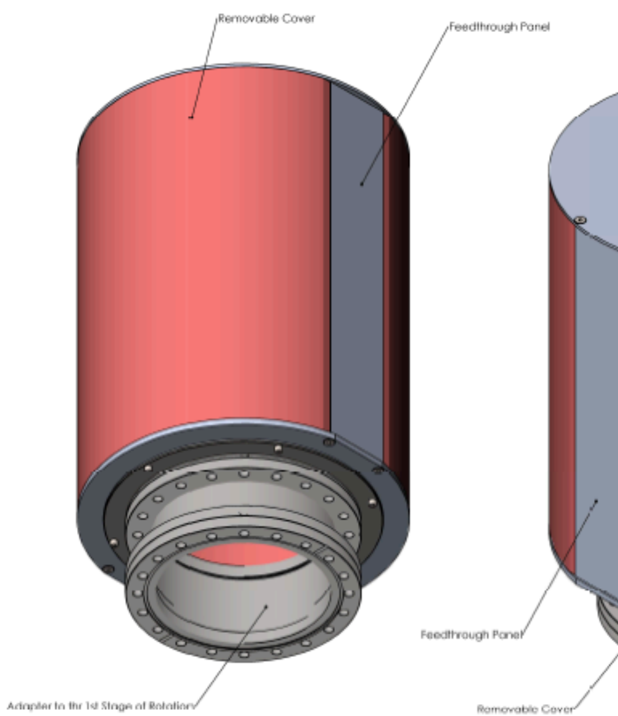


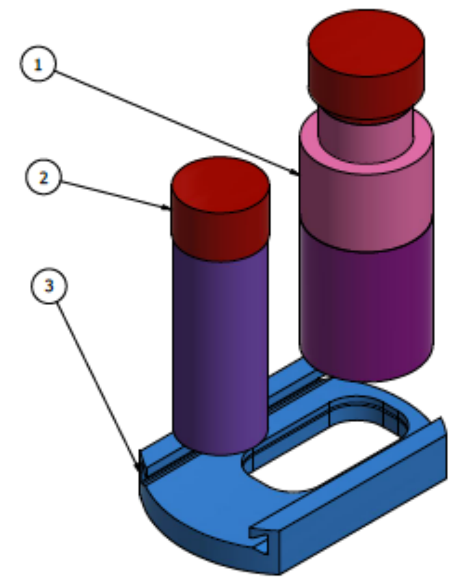
Optical feedthrough, light barrier

- Since laser is Class-IV, always need metal enclosure
- Cover *bucket* on top flange, including instrumentation feedthrough panel
- Quartz windows have sliding cover, can be closed when bucket open for maintenance

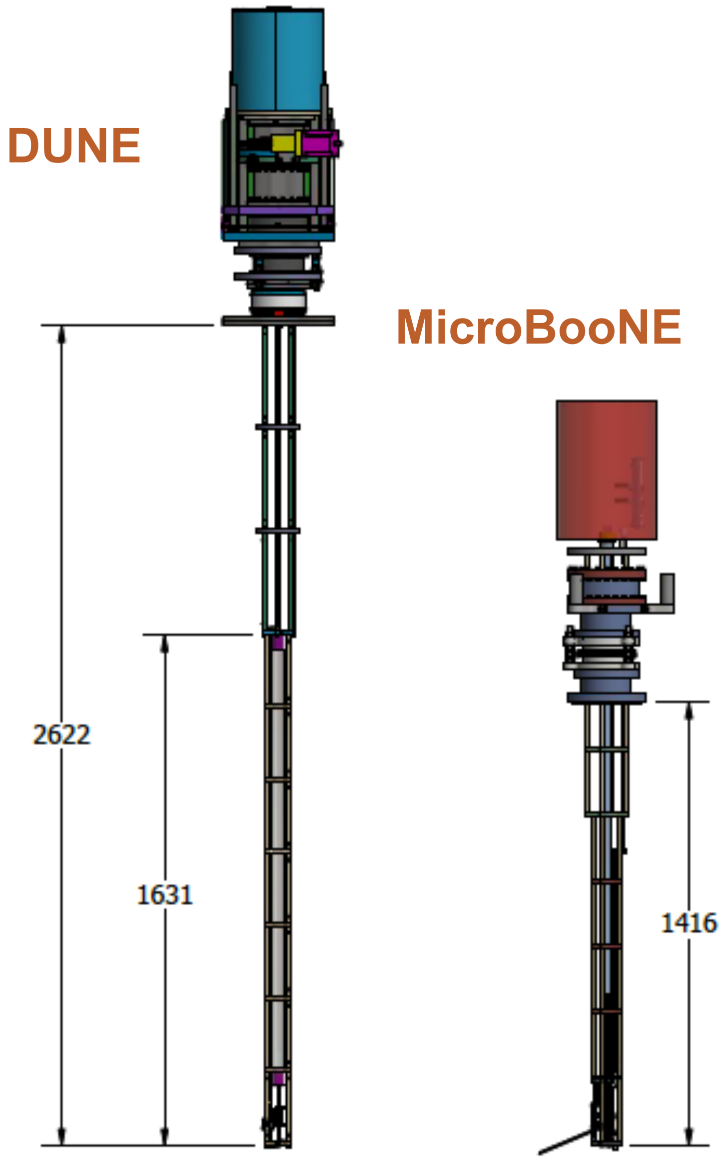


Showing end-wall design, similar for TFC



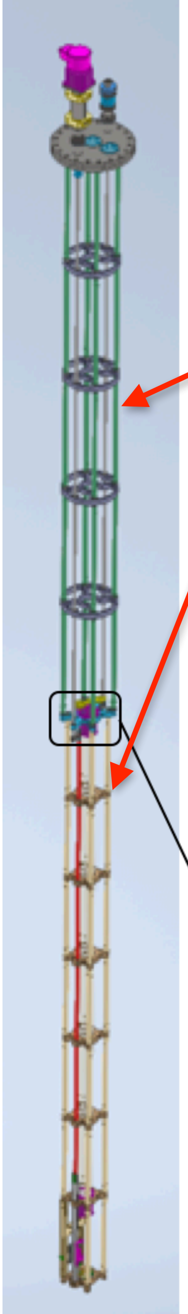


Inner periscope challenges

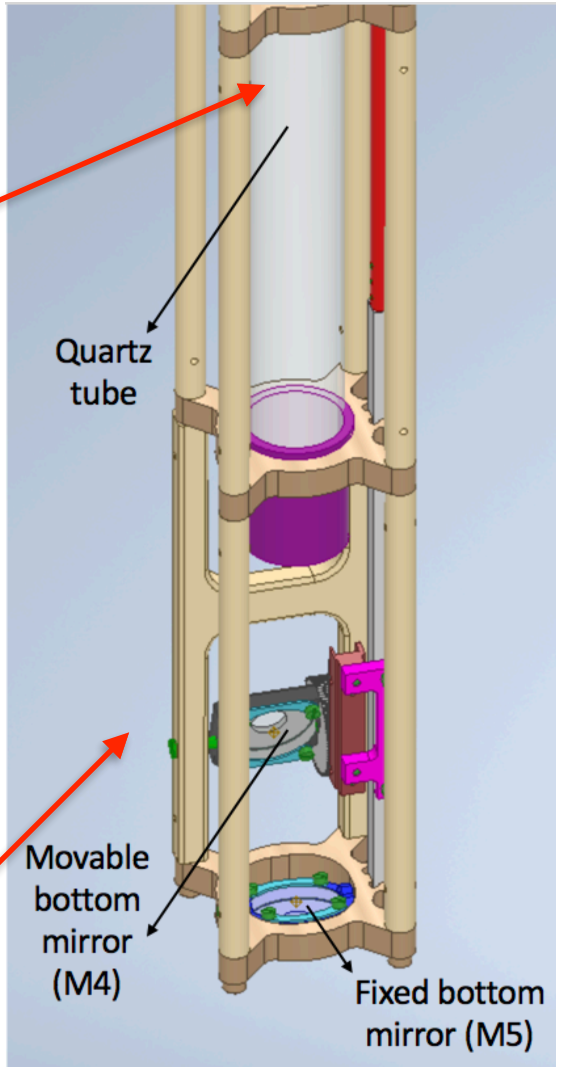


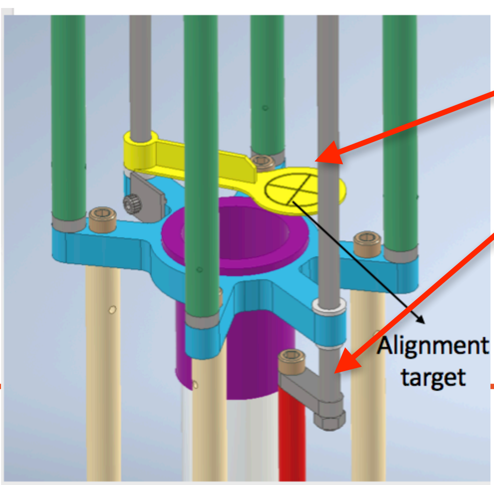
- DUNE has a larger cryostat and ullage than MicroBooNE
  - Much longer periscope
  - Harder to align accurately
- FC penetration -> straightness is critical
- Underground lab
  - less clearance above (~ 2 m to mezzanine)

Inner periscope design



- Periscope split in two parts to facilitate installation with low overhead clearance
  - Upper half in steel for stiffness and cost
  - Lower half in PEEK (to be tested), for cost
- Long (1.5 m) glass tube with quartz windows
  - same manufacturer as MicroBooNE
- Beam never hits GAr/LAr surface (ripples)
- On lower half only, but with option to have second glass tube also in upper half

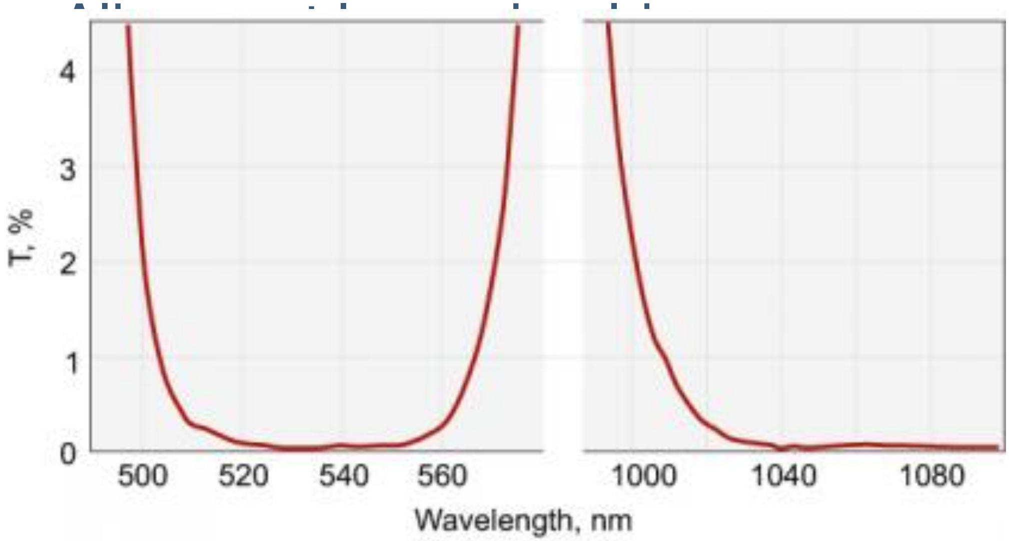




- Alignment target in between both parts
- Long rod that actuates mirror mechanism

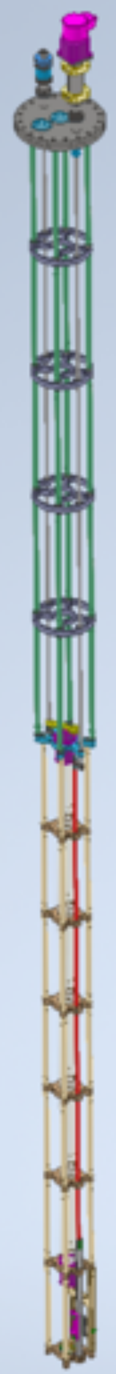
Choice of mirrors

- Mirrors must reflect 266 nm and also a visible wavelength, for the alignment laser and cameras
- There are dual-band dielectric mirrors, with 99.5% reflectivity at two wavelengths
- Showing 532+1064 nm plot. There is a 266+532 nm version.

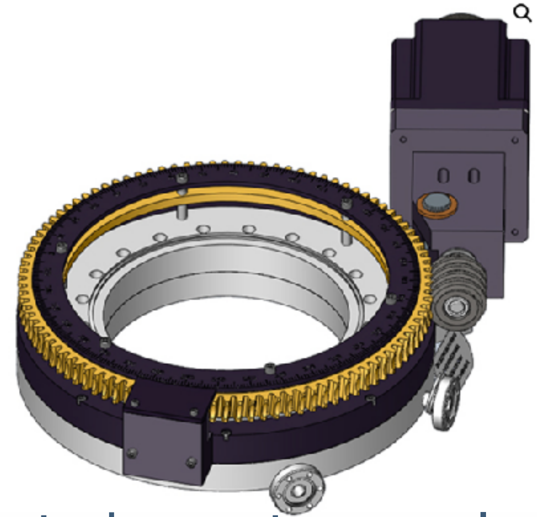


HR 532+1064 nm, AOI=45 deg

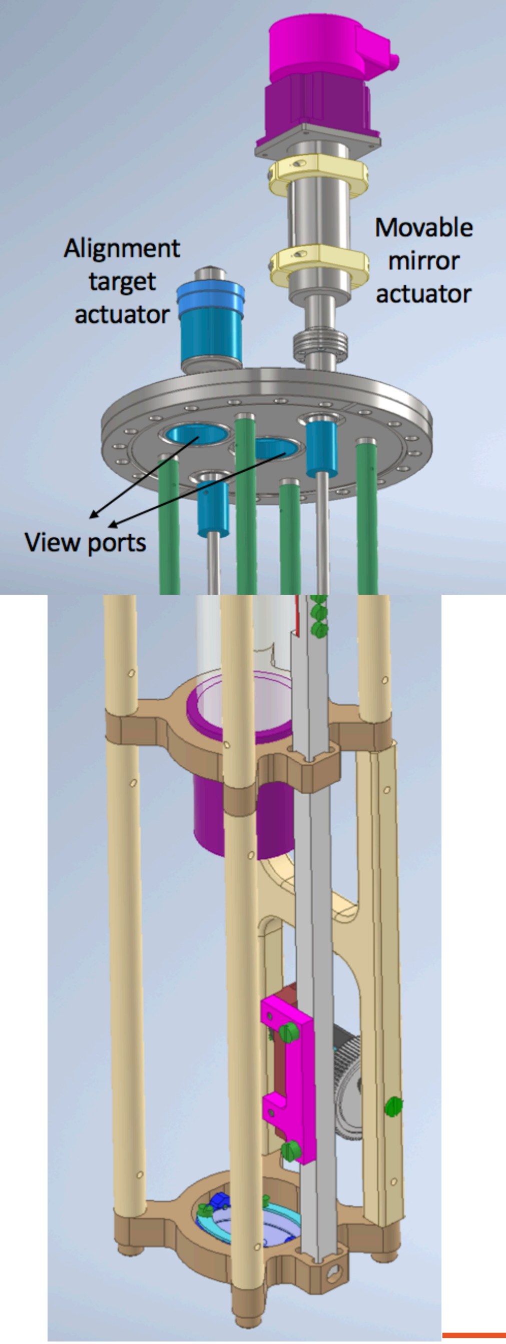
Mechanical Design



Azimuthal Movement



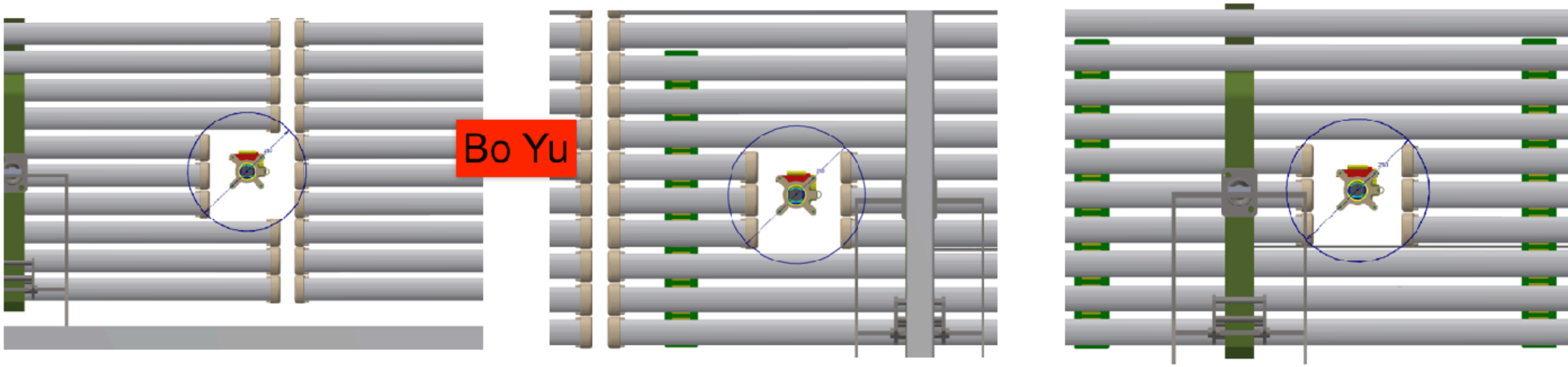
- Top flange and periscope mounted on rotary seal
  - transmits azimuthal rotation to mirror
- Choice of seal: Thermionics RNN600. Used in MicroBooNE. UHV specs (10^{-11} Torr)
  - Possible to flush gap between seals with GAr
- Motor drive specs
  - 0.018° (0.3 mrad) per full step
  - resolution < 0.004° ; repeatability < 0.008° (0.14 mrad)
  - meets 0.2 mrad requirement on positioning



Polar Movement

- Linear stage moves long rod with a rack at the end, acting on pinion where mirror is mounted
  - Linear stage ranges 2 in with 40 turns rotation
  - Pinion has R= 20mm
  - with this gear ratio, required resolution is 1 deg on linear stage, easily achieved.
- In any case, movement will be tracked by encoders in each motor shaft
  - more precise than counting motor steps
- Considering encoder EPC A58HB
  - 16 bit, absolute, multi-turn

Top FC design: FC penetration



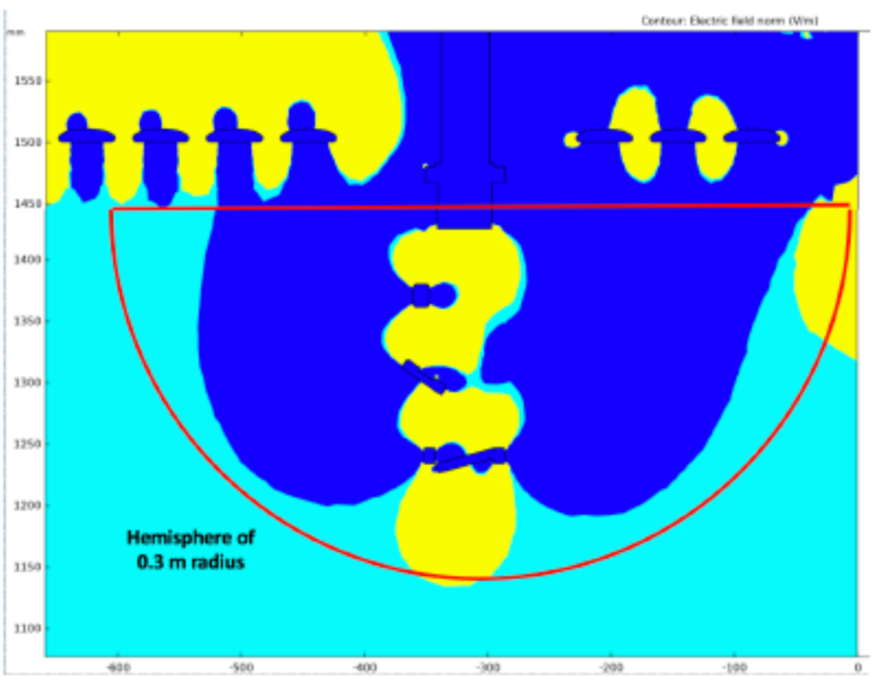
- FC penetration in DUNE will require the removal of 3 profile segments: 18 x 18 cm, to account for tilts and cool-down effects
- Periscope goes down by ~25 cm, so that the mirror clears the FC I-beam by ~10 cm
- See Interface drawings by Kyle, https://edms.cern.ch/2145142/3
- Impact on E-field calculated by Bo Yu (next)

link to May Review talk, see p 22 to 26

Q5 Continued

Case 4: FC opening with laser inserted at ~25 cm below the top FC

- Why ~25 cm? This is motivated by the requirement to have the periscope mirror below the FC I-beam by ~10 cm to prevent shadowing.
- Affected region of >1% distortions is further increased w.r.t. the "FC opening only" case. It extends to ~50 cm in X and ~30 cm in Y into the AV.
- **The impacted volume due to each FC opening is about 0.056 m^3. And for 12 FC openings, this results in a total of about 0.7 m^3.**
- **This is a 7% effect compared to the nominal loss due to the APA gaps (case 1) and is a 7x10^{-5} fraction of the total AV.**



"FC opening + Periscope" case.

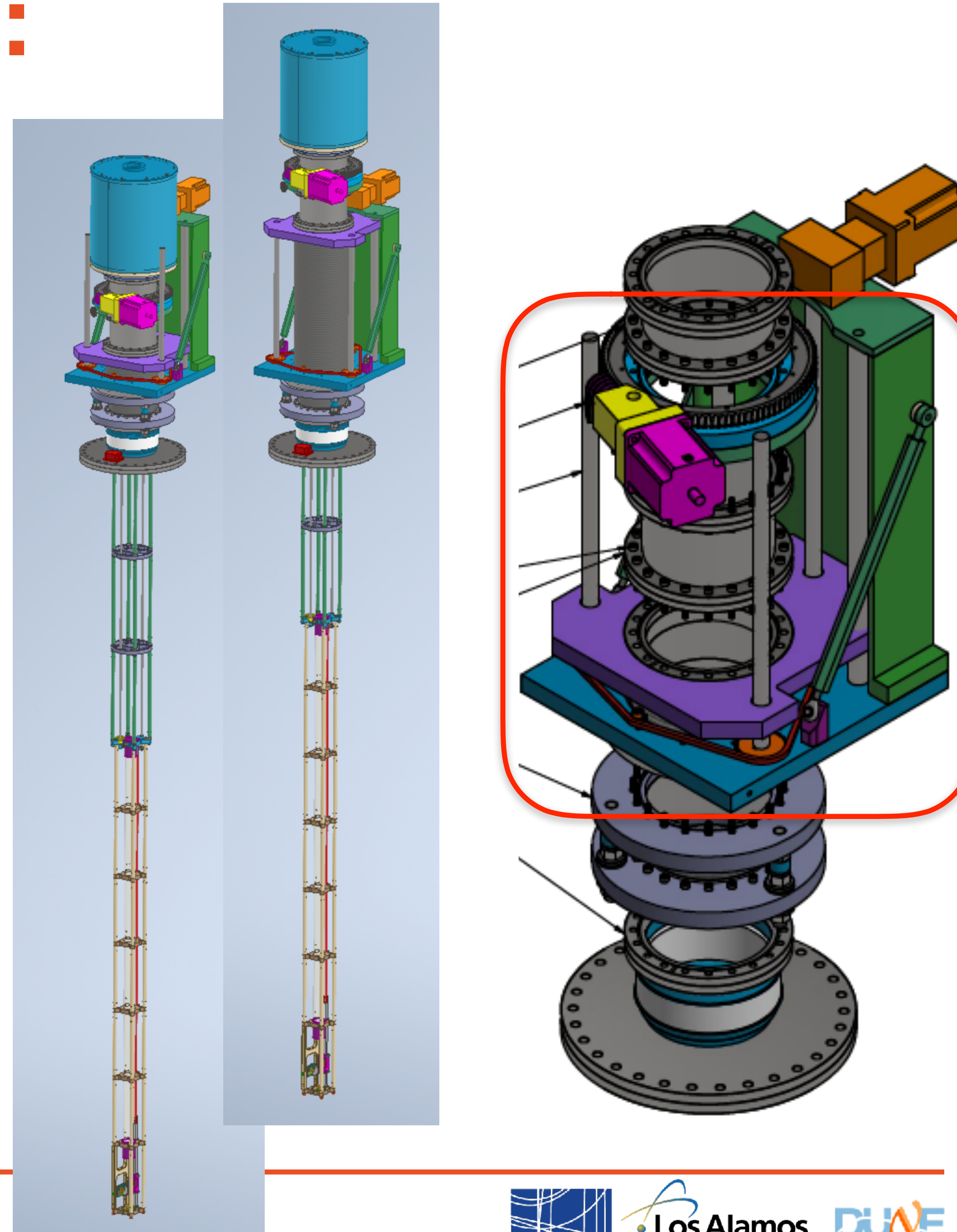
Affected active volume is increased compared to "FC opening only" case.

Active volume starts at 1450 mm.

A hemisphere of 0.3 m radius is drawn to estimate the impact on the active volume; as clearly seen this overestimates the impacted volume.

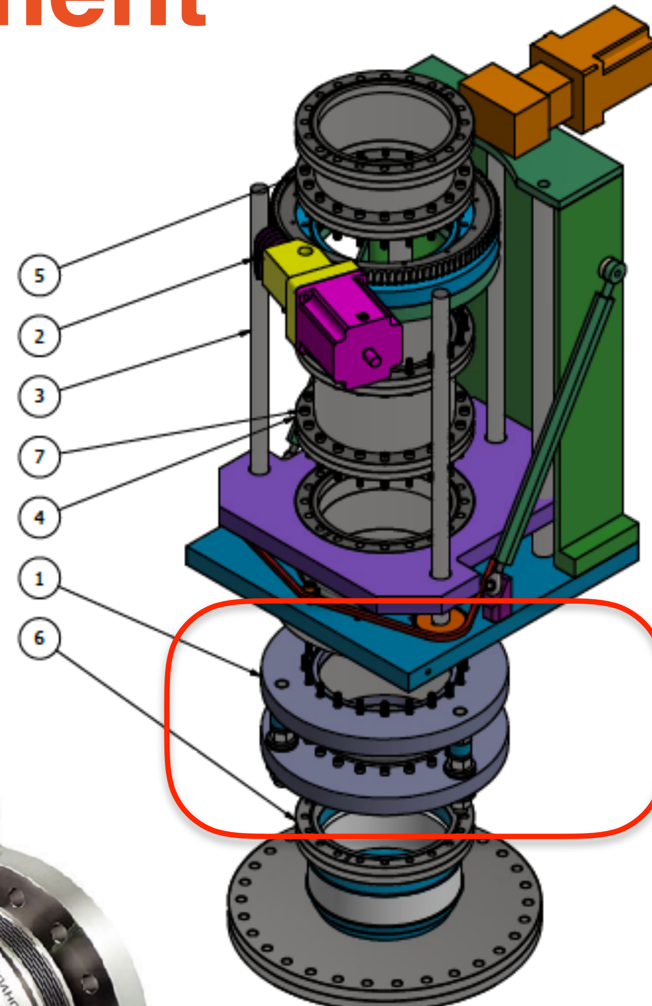
Top FC design: retraction

- Implemented vertical retraction via commercial system bellows
- Current design with 16 in (40 cm) travel
  - retracts 15 cm above FC



Top FC design: alignment

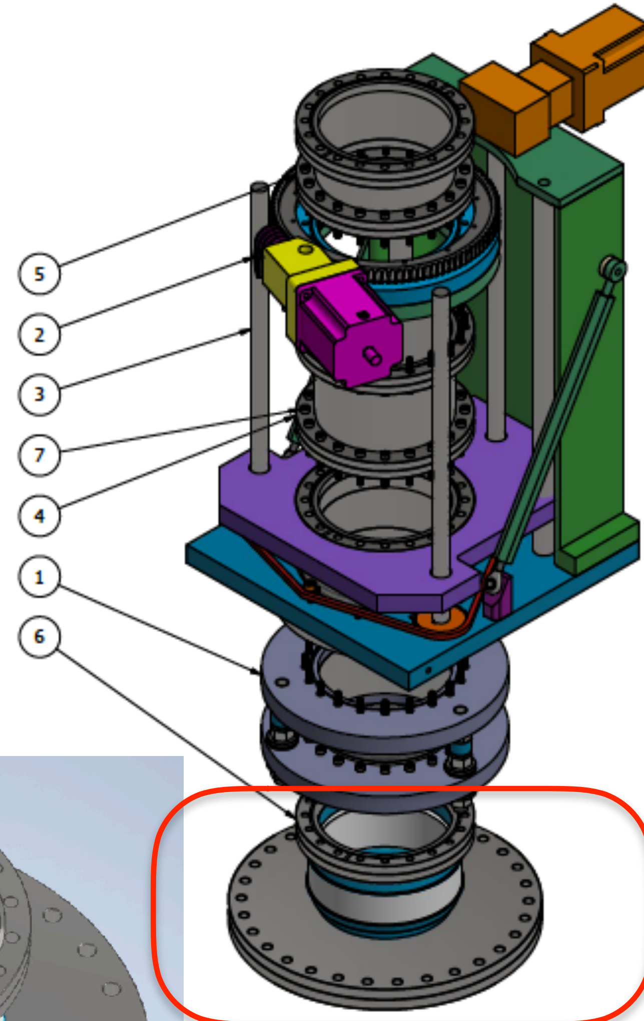
- Calibration ports may have deviations from horizontality up to 1 deg (from J. Fowler)
- This can cause a tilt of up to 6 cm at end of periscope
- Needs to be compensated before extending the periscope
- Include a port aligner just below the extension bellows, to carry out a one-off compensation
- Commercial port aligners: range of a few degrees

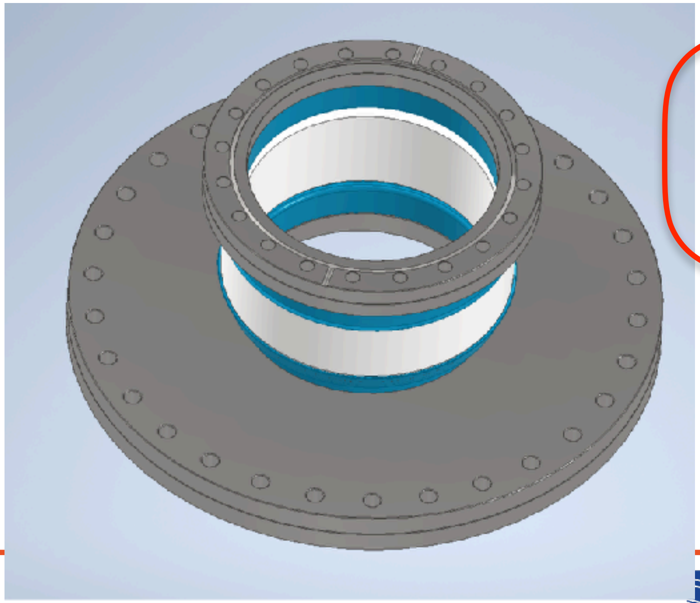


- Transient cryostat “breathing" expected to be very low and not requiring compensation. We still want to track it so we’ll have inclinometers close to each port

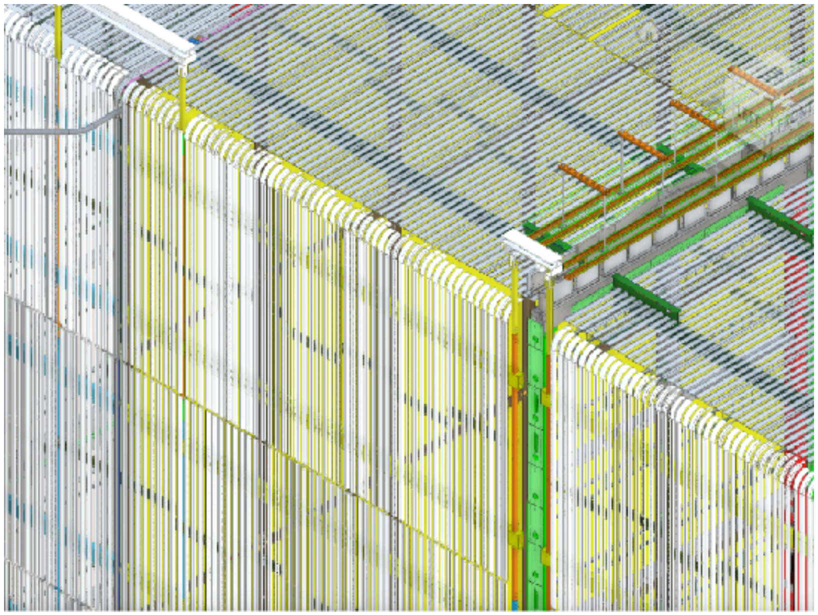
Electrical break

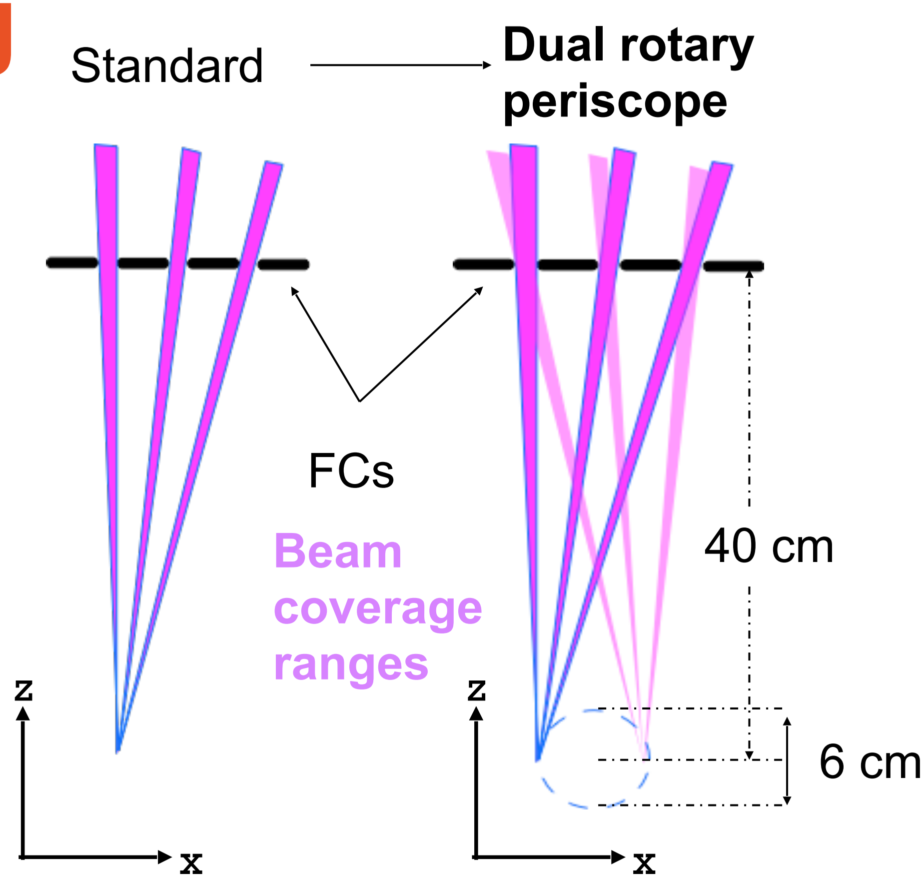
- Ongoing discussion on system grounding and need for electrical break between laser periscope and calibration port (see V. Sandberg's talk)
- Including it for now (can be bypassed)
- Commercial (from MDC)





End-wall design: Offset mirror to reduce shadowing

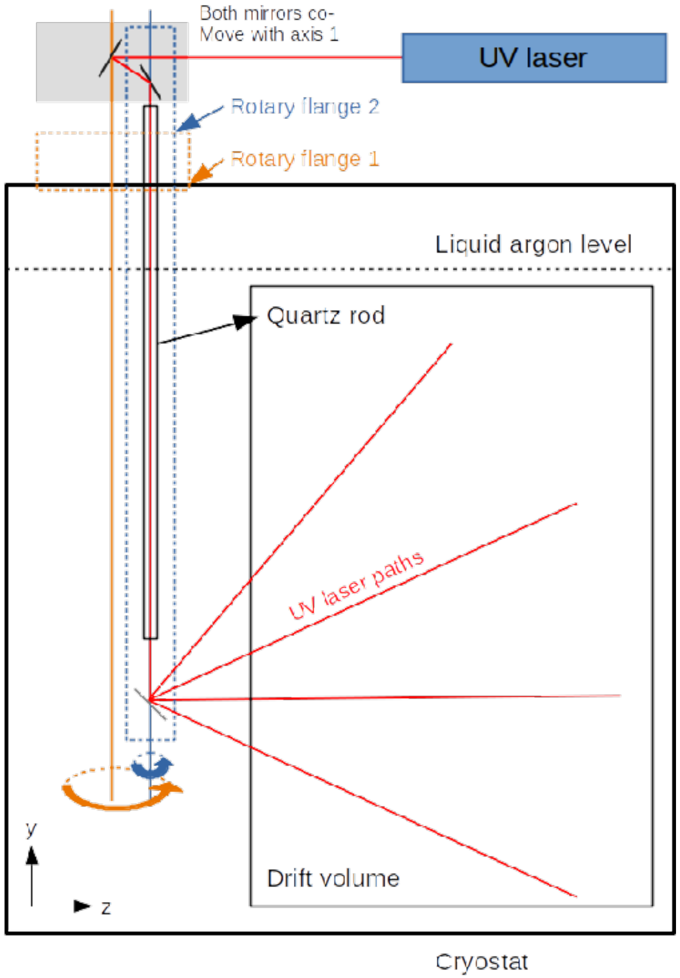




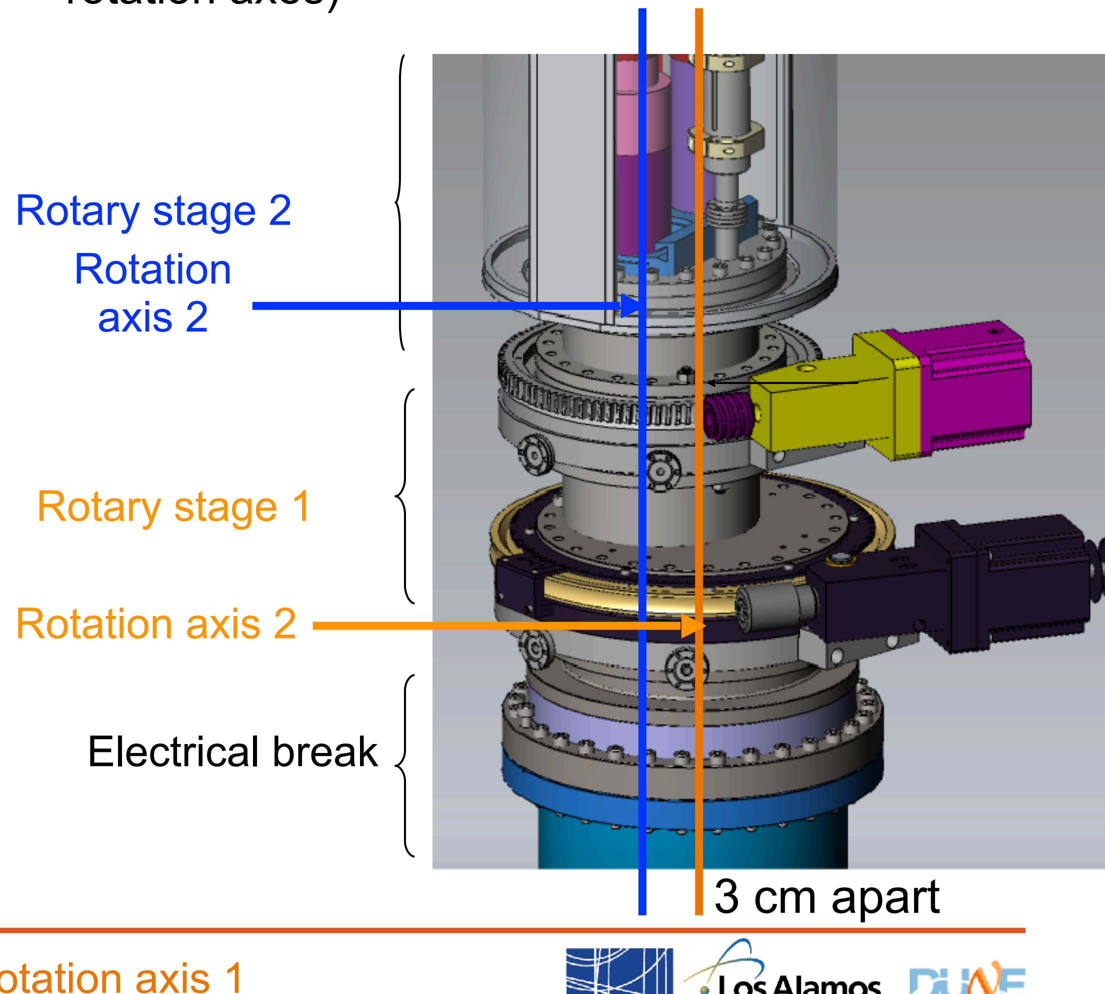
- Eight locations with periscopes 40 cm beyond FC end-wall
- Not practical to insert periscope into FC from side and move it
- Shadows are significant, since the gap is only 1.4 cm close to a 4.6 cm profile

- The workaround is to have a system that offsets the mirror position
- Even with just 6 cm off, parallax makes the shifted beams cover the regions previously shadowed

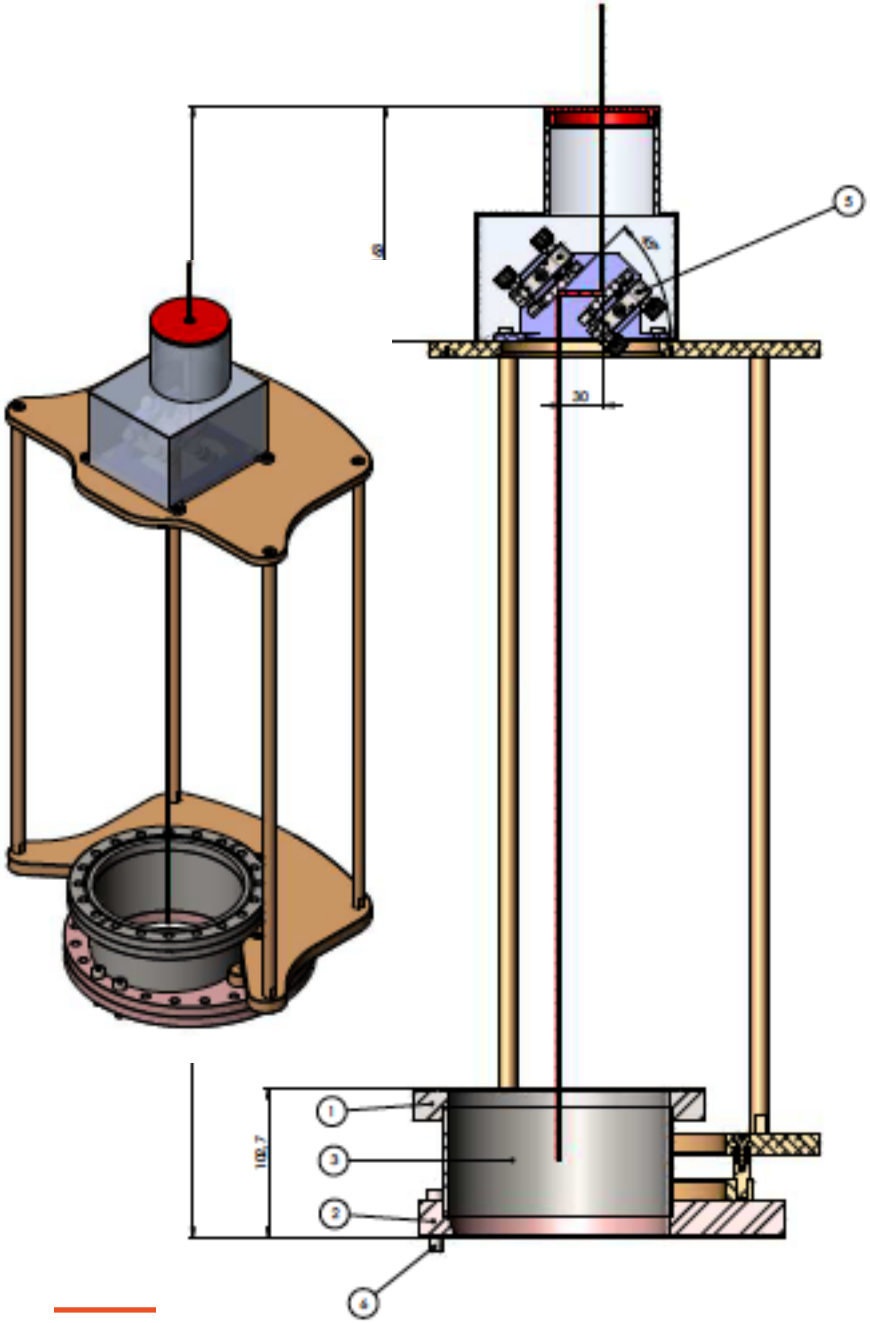
End-wall design: dual rotary axes



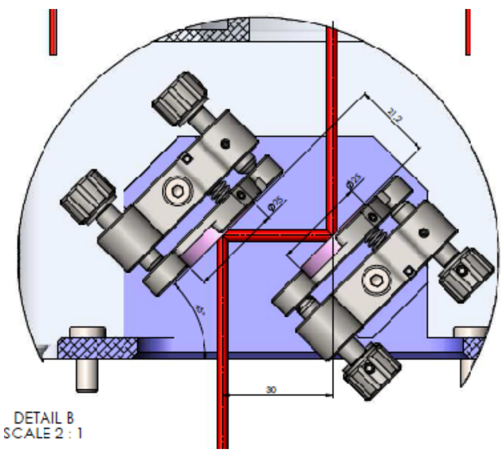
Avoid mechanical complexity inside the cryostat by using 2 eccentric rotary stages (with parallel rotation axes)



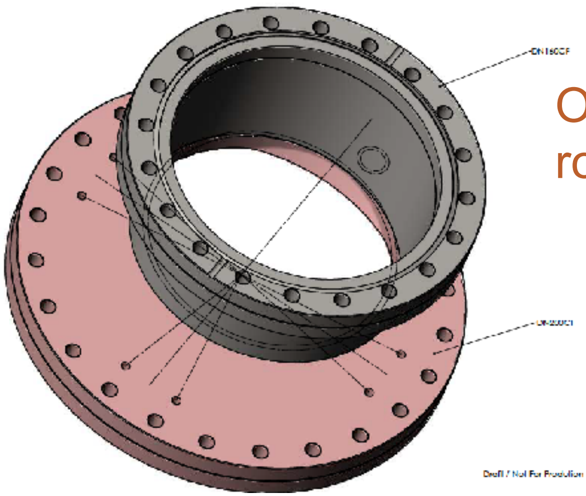
End-wall design: beam alignment



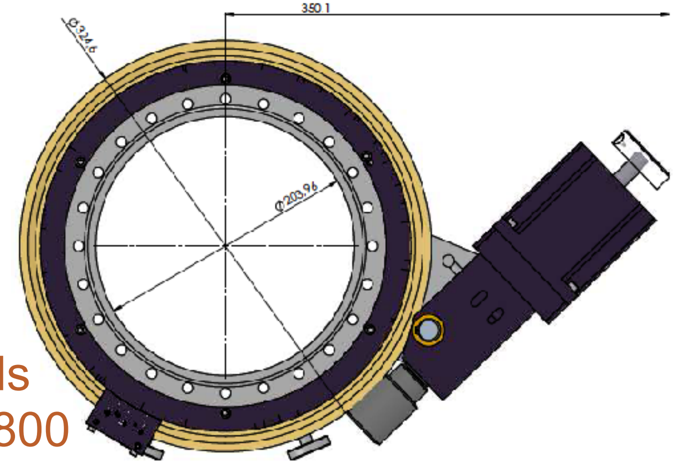
- Parallel 45 deg mirrors on top bracket offset incoming beam
- Bracket rotates with stage 1 (lower), so it keeps beam aligned with rotation axis 2
- Mirror mounts adjustable, will require careful alignment



End-wall design, further details

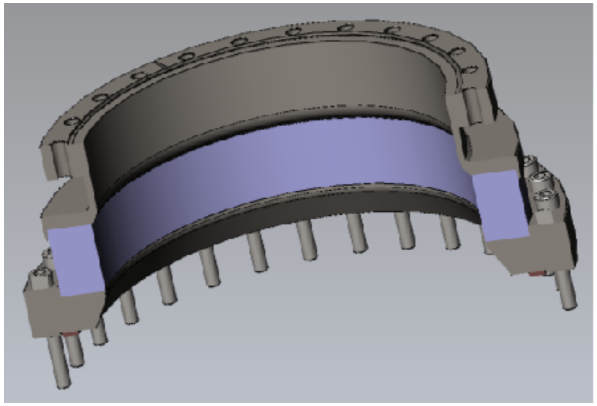


Offset adapter between rotation stages 1 and 2



Lower stage needs to be wider: RNN800

Ceramic break from MDC, main option. Not shown with required flanges, waiting for updated quote (we have one for RNN1000)



LIP design for electrical break with POM on steel flanges. Cost savings alternative. Will carry out POM/steel seal test at LIP.

Laser beam coverage

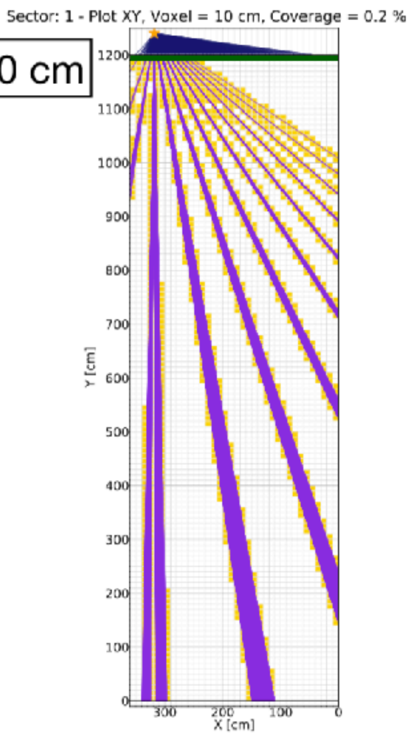
Calculations of shadowing from HV system elements

- Approximate geometrical model of FC elements (profiles, supports), and laser periscope position
- Sending “beams” from mirror position, checking their shadowing and counting the voxels that are hit
  - 2 assumptions: including, or not, beams toward APA
- Calculating coverage as the fraction of hit voxels
- Next: 2D plots
  - sideview for top FC design
  - topview for end-wall design

M. Fani, J.Maneira

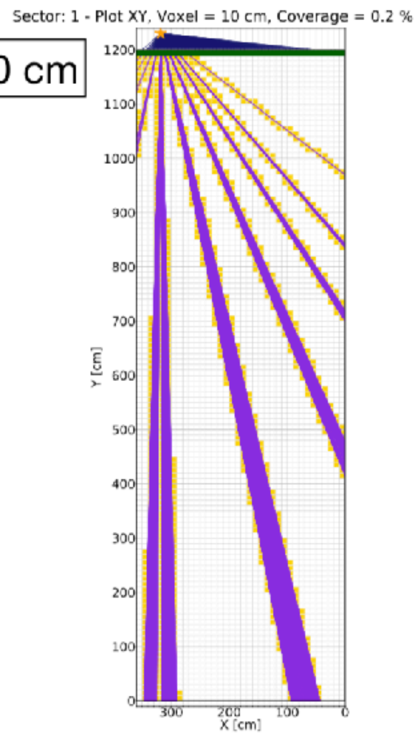
Top FC, no penetration

40 cm



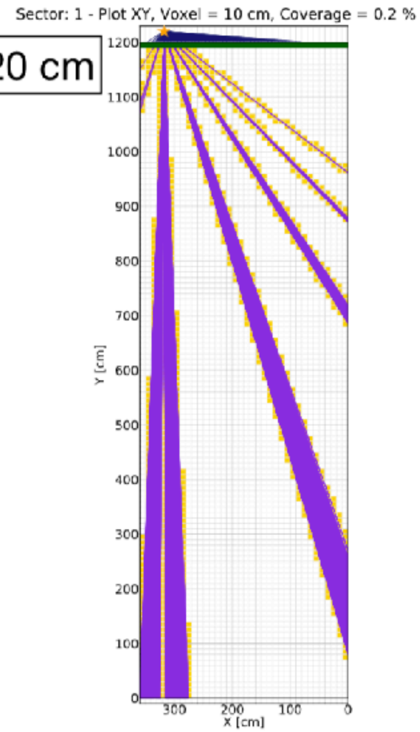
Coverage (2D) =
= 37%

30 cm



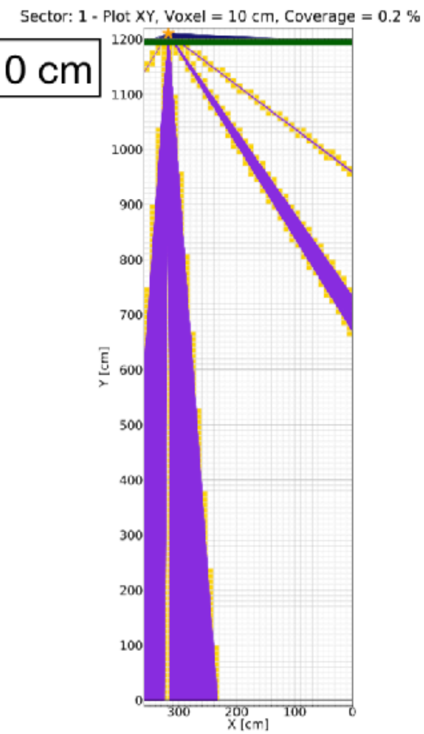
Coverage (2D) =
= 32%

20 cm



Coverage (2D) =
= 31%

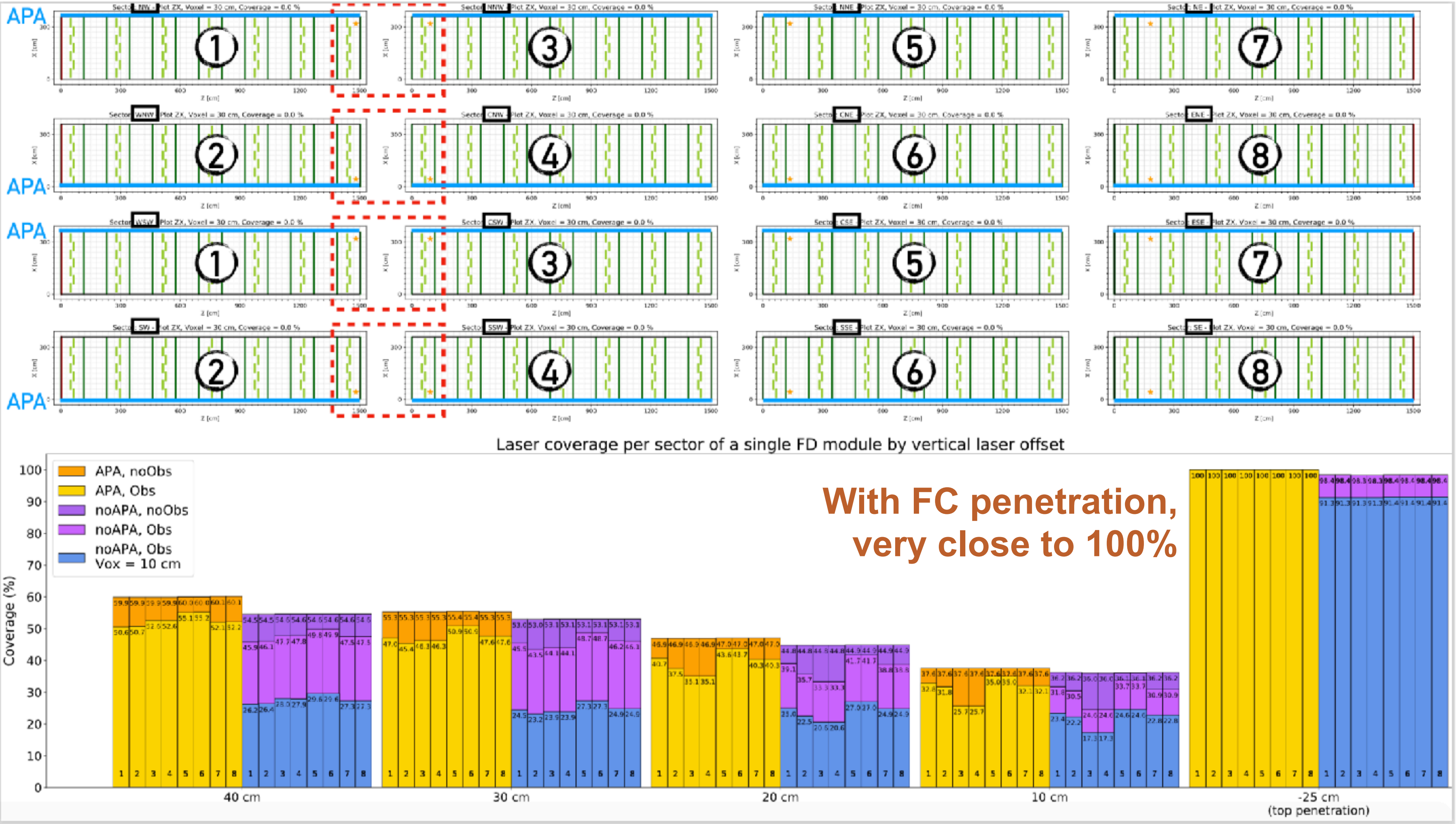
10 cm



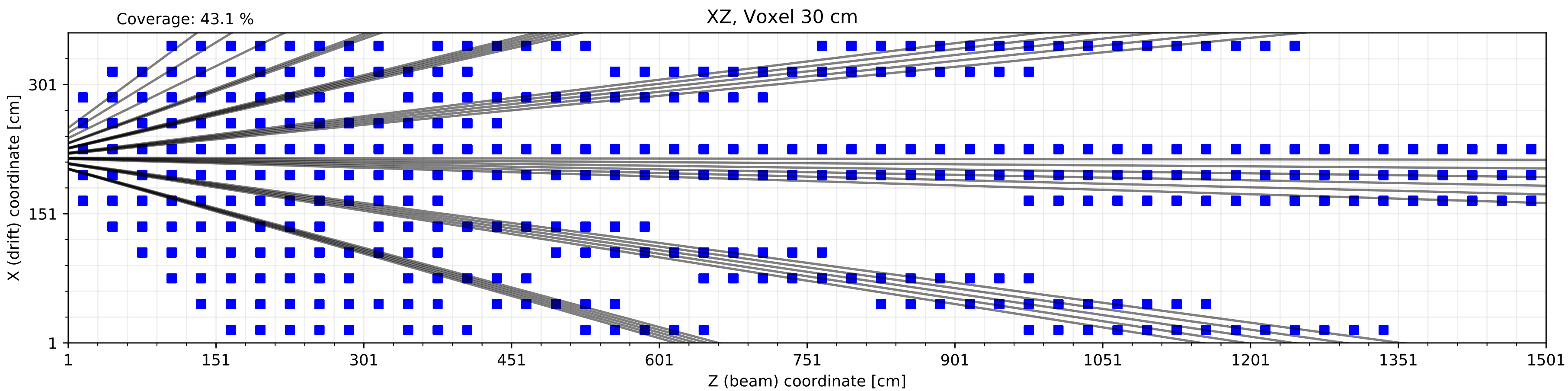
Coverage (2D) =
= 29%

Top FC, with/out penetration

M. Fani, J.Maneira



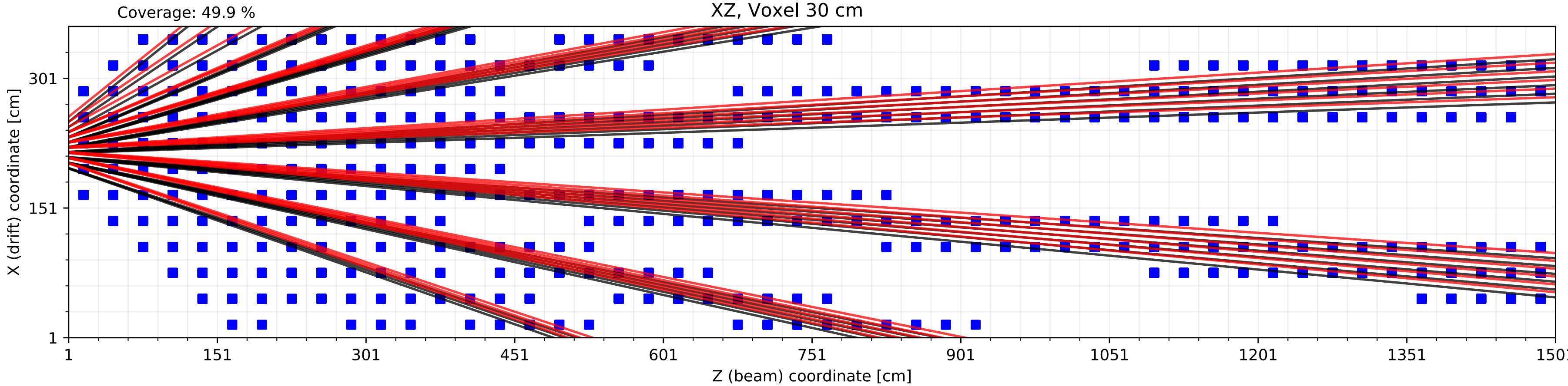
End-wall, no dual rotation



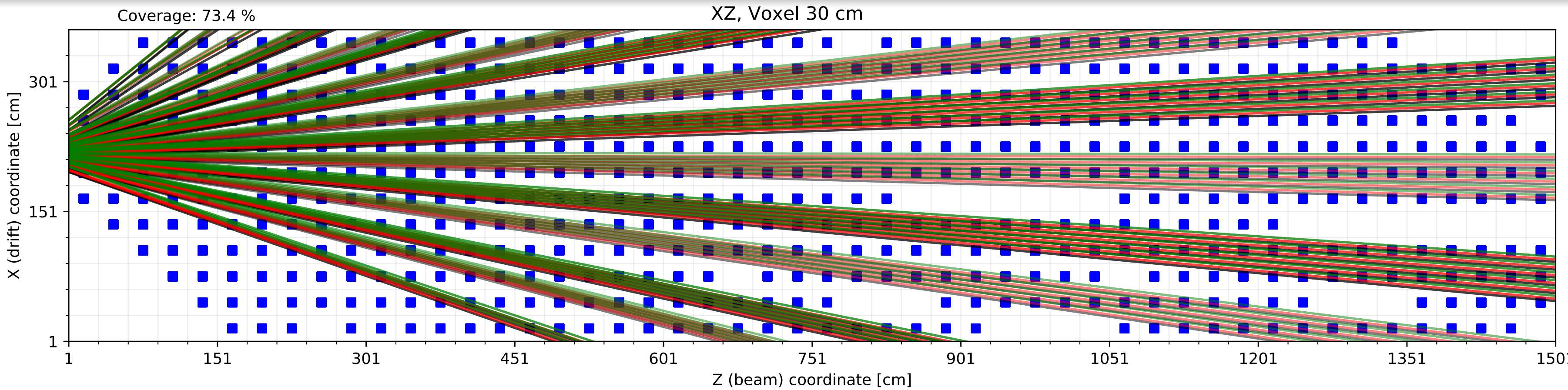
- Mirror at 40 cm from FC, considering only FC profiles
- Maximum of 43% 2D coverage on XZ plane (30 cm, no APA)
  - in 3D somewhat smaller due to I-beams and supports

End-wall, dual rotation

30 cm voxels, noAPA



- With **two** origin points within 6 cm mirror range



- With **three** origin points within 6 cm mirror range
  - no optimization done on positions, may be possible to do better

Revisit Requirements

EB-held requirements

Artifact Type	Name	Primary Text	Value
Specification	Laser calibration system single beam coverage	The number and coverage of the SP laser system periscopes shall be such that it covers, with at least one beam, 100% of the APA and CPA resistive panels (RP).	100%

✓ Coverage with FC penetration close to 100 %

Specification	Laser calibration system two beam coverage	The number and coverage of the SP laser system periscopes shall be such that it covers with two beams at least 1/8 of the SP detector.	> 1/8 of the SP detector

✓ There are available ports. End-wall design allows this in corner region.

TB-held requirements

Artifact Type	Name	Primary Text
Specification	SP CALCI/HV ionization laser FC penetration	There must be openings on the top FC modules allowing the laser periscopes to penetrate the active volume to achieve 100% APA and CPA RP single laser beam coverage. The periscopes must have a retraction system.

✓ Openings designed, interface docs exist. Retraction system feasible with bellows

Specification	SP CALCI laser beam not pointing at PDS	The laser system shall prevent the beams from being aimed at the PDS modules.

✓ Mirror control system being designed to not go within a given range in phi (rotation stage).

Consortium-held, integration

Artifact Type	Name	Primary Text
Specification	SP CALCI laser periscope openings closeable	All light openings have to be closeable, in order to maintain PDS data quality while servicing the laser system for maintenance.

✓ Light cover on top flange openings

Specification	SP CALCI Max. E field near calibration/instrumentation devices	EB-held req. 2264 applies here.

✓ Rounded edges, simulations by HV consortium

Consortium-held, installation

Specification	IoLaser periscope length	The IoLaser periscopes have to be segmentable in parts smaller than ~2 m in length.

✓ Full length about 3 m, then it's split in two

Consortium-held, design 1

Name	Primary Text	Value
UV reflectivity of harmonic separator	The reflectivity at 266 nm of the harmonic separator located immediately at the exit of the laser should be at least 95%.	> 95%
Combined trasmission of laser optical path	The combined transmission of the optical elements in the laser optical path shall be higher than 50%.	> 50%
UV reflectivity of mirrors	The reflectivity at 266 nm of each mirror in the path of the laser should be at least 96%.	> 96%
Flatness of mirrors	Any optical mirror in the laser path should have laser quality flatness, i.e. lambda/10 or better.	lambda/10

✓ Met or exceeded by all chosen and identified components

Laser port installation flatness compensation	The laser system periscopes installed above the top FC shall include devices capable of compensating deviations from flatness of the as-installed ports, with a range up to 1 degree.	1 deg

✓ Commercial port aligners have ranges of a few degrees

Consortium-held, design 2

Name	Primary Text	Value
FC opening tolerance for laser port dynamical flatness	The top FC openings for the laser periscopes, and the periscope positioning inside them, must be wide enough to accommodate deviations of horizontality of the ports, due to changing operational pressure conditions, of up to 0.1 deg.	0.1 deg
FC opening tolerance for cool-down effects	The top FC openings for the laser periscopes, and the periscope positioning inside them, must be wide enough to accommodate the shrinking of the FC by up to 0.1%.	0.10%
Quartz discs surfaces parallelism	The two flat sufaces of the quartz discs along the path of the laser must be parallel to about 0.02 mm over a 30 mm diameter	0.02 mm over 30 mm diameter
Angular resolution of last mirror positioning	The relative angular position of the last mirror in the laser periscope must be known to better than 0.2 mrad	< 0.2 mrad
Angular resolution of the position encoders	The angular resolution of the motion encoders should be better than 1 degree.	< 1 deg

✓ Opening of 18 cm wide enough for maximum shifts of 6 mm and 15 mm

✓ Same spec and manufacturer as MicroBooNE

✓ Motor drive precision repeatability 0.14 mrad

✓ 16-bit encoder vastly exceeds this

Conclusions

- Present designs address the requirements
  - Coverage: FC penetration with safety retraction, end-wall dual rotation
  - Precision and alignment: using MicroBooNE design, precision components and machining, new targets and cameras, location systems
  - Optical transmission: quartz windows, high reflectivity mirrors
  - Protection against leaks: using commercial flanges, components and welding as much as possible, leak-check all else
  - Ease of installation: Split periscope in two to fit under mezzanine
- Essential to move forward with PD2 integration