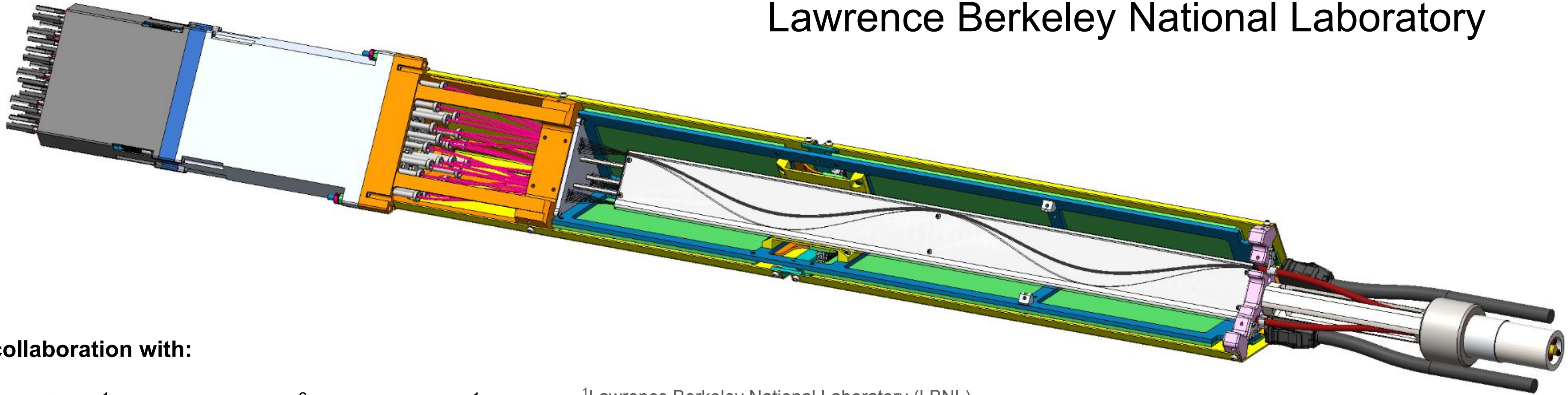
Design of High-Density Fiber Positioning Raft Modules:
Integration with Fibers and Positioners

Nicholas Wenner
Lawrence Berkeley National Laboratory



In collaboration with:

Joseph Silber[1], Travis Mandeville[2], David Schlegel[1], William Van Shourt[3], Ricardo Araujo[4], Charles Baltay[5], Robert Besuner[1], Emily Farr[6], Julien Guy[1], Jean-Paul Kneib[4], Maxime Rombach[4], Claire Poppett[3], Michael Schubnell[7],, Markus Thurneysen[4], Sarah Tuttle[2], Greg Tarlè[7], and others

[1]Lawrence Berkeley National Laboratory (LBNL)
[2]University of Washington
[3]Space Sciences Laboratory (SSL)
[4]École Polytechnique Fédérale de Lausanne (EPFL)
[5]Yale University
[6]University of Colorado
[7]University of Michigan

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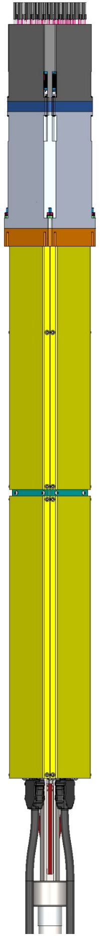
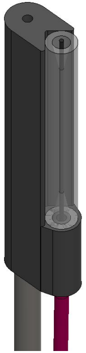
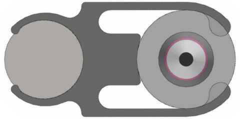
University of Chicago
February 27, 2024

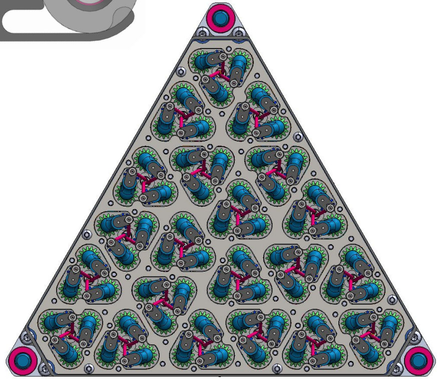
Outline

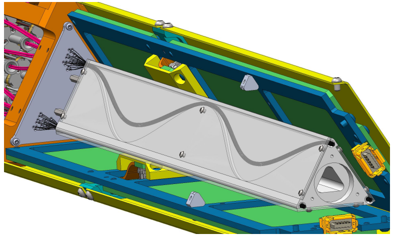
- Raft Design
  - Fiber Routing
  - Fiber Arms
- Fiber Installation Process
  - “Push-to-Focus”
- Repair / Rework Process

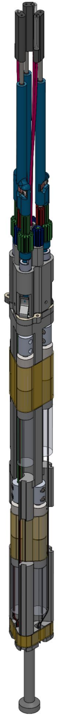


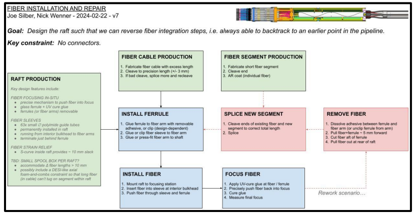




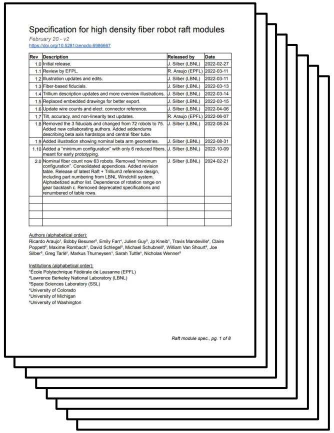








Key Specifications:
Raft


Specification for high density fiber robot raft modules

February 20 - v2

https://doi.org/10.5281/zenodo.6986667

Rev	Description	Released by	Date
1.0	Initial release.	J. Silber (LBNL)	2022-02-27
1.1	Review by EFPL.	R. Araujo (EPFL)	2022-03-11
1.2	Illustration updates and edits.	J. Silber (LBNL)	2022-03-11
1.3	Fiber-based fiducials.	J. Silber (LBNL)	2022-03-13
1.4	Trillium description updates and more overview illustrations.	J. Silber (LBNL)	2022-03-14
1.5	Replaced embedded drawings for better export.	J. Silber (LBNL)	2022-03-15
1.6	Update wire counts and elect. connector reference.	J. Silber (LBNL)	2022-04-06
1.7	Tilt, accuracy, and non-linearity text updates.	R. Araujo (EPFL)	2022-06-07
1.8	Removed the 3 fiducials and changed from 72 robots to 75. Added new collaborating authors. Added addendums describing beta axis hardstops and central fiber tube.	J. Silber (LBNL)	2022-08-24
1.9	Added illustration showing nominal beta arm geometries.	J. Silber (LBNL)	2022-08-31
1.10	Added a "minimum configuration" with only 6 reduced fibers, meant for early prototyping.	J. Silber (LBNL)	2022-10-09
2.0	Nominal fiber count now 63 robots. Removed "minimum configuration". Consolidated appendices. Added revision table. Release of latest Raft + Trillium3 reference design, including part numbering from LBNL Windchill system. Alphabetized author list. Dependence of rotation range on gear backlash ε. Removed deprecated specifications and renumbered of table rows.	J. Silber (LBNL)	2024-02-21

Authors (alphabetical order):
Ricardo Araujo[1], Bobby Besuner[2], Emily Farr[4], Julien Guy[2], Jp Kneib[1], Travis Mandeville[6], Claire Poppett[3], Maxime Rombach[1], David Schlegel[2], Michael Schubnell[5], William Van Shourt[3], Joe Silber[2], Greg Tarlé[5], Markus Thurneysen[1], Sarah Tuttle[6], Nicholas Wenner[2]

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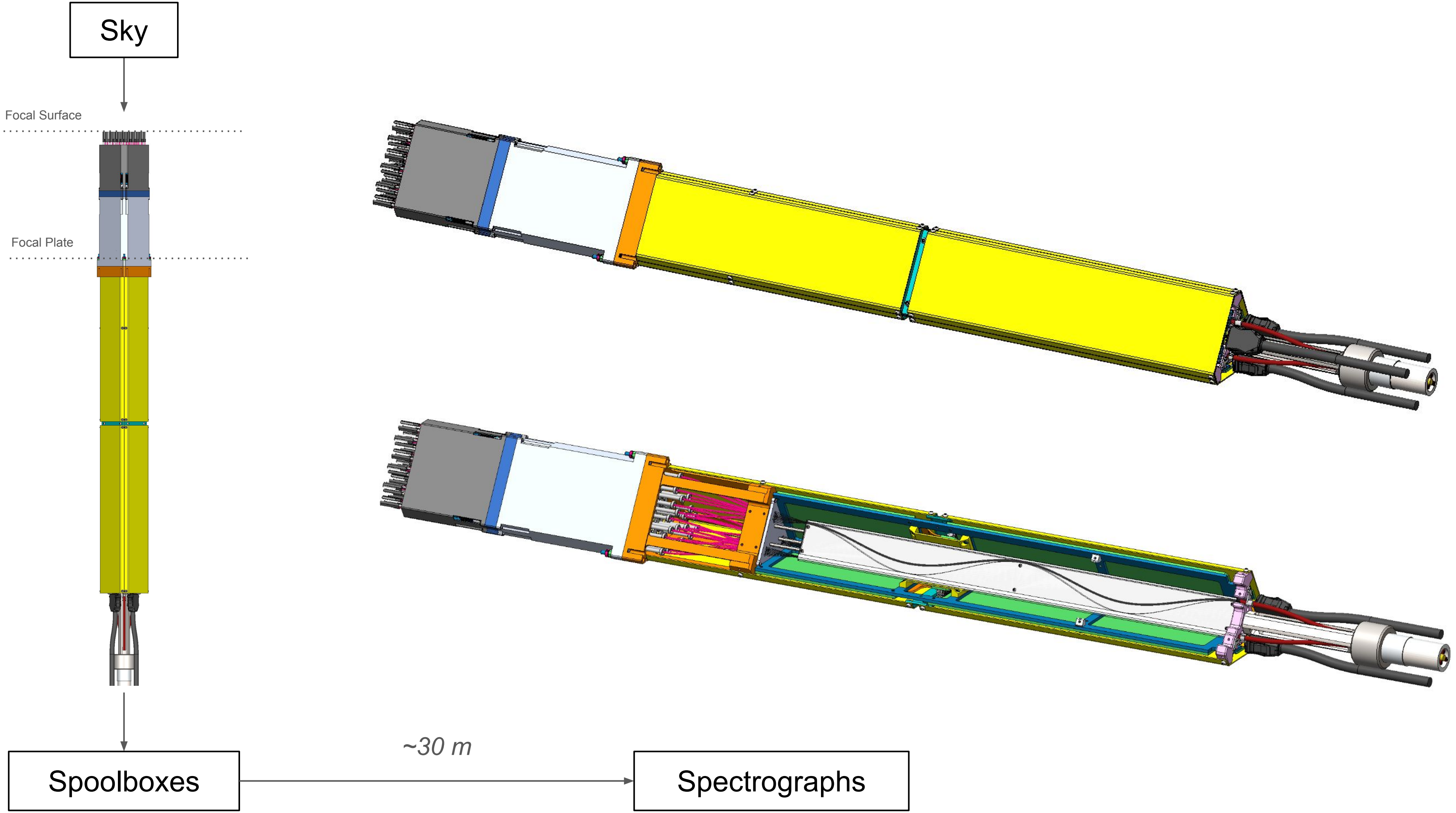
Raft module spec., pg. 1 of 8

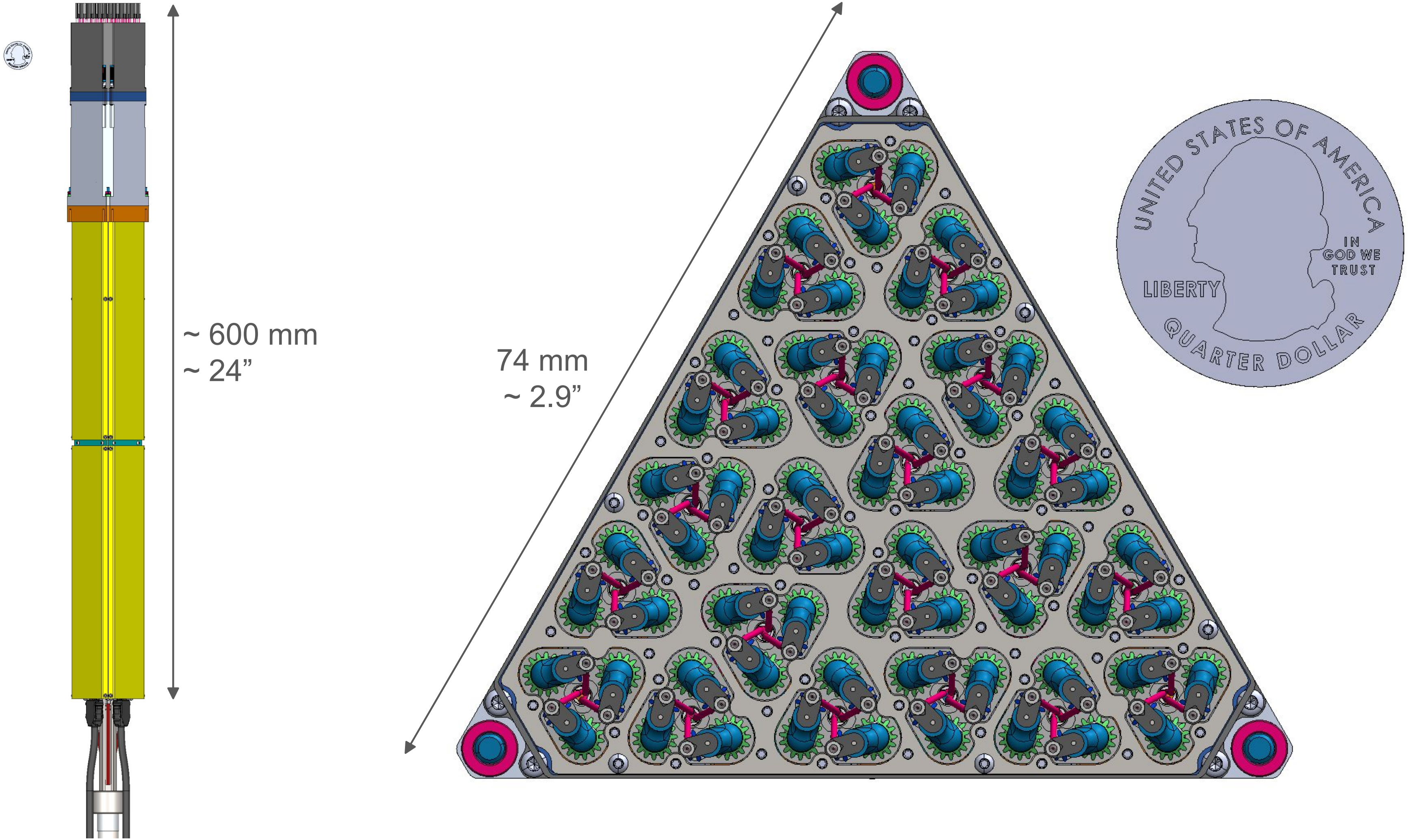
39 total specs

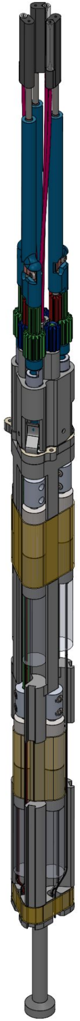
Title	Requirement or Feature
Envelope	Equilateral triangle with 74 mm sides, chamfered by 2.5 mm at corners
Length & mass	≤ 650 mm, ≤ 1.5 kg
Robot spacing	6.2 mm center-to-center
Number of fiber robots	63
Kinematic arm lengths	Ra = 1.8 mm (from central axis to eccentric axis) Rb = 1.8 mm (from eccentric axis to fiber center)
Arm length variation	|Ra - Rb| ≤ 0.1 mm
Ranges of motion	(-2° - ε) ≤ α ≤ (362° + ε) Example: If backlash = 5°, then -7° ≤ α ≤ 367° (-2° - ε) ≤ β ≤ (182° + ε) Example: If backlash = 5°, then -7° ≤ β ≤ 187°
Gear backlash	ε ≤ 5°
Hard stops	both axes
Fiber guide tubes	OD ≤ 0.7 mm ID ≥ 0.19 mm (TBC)
Min fiber bend radius	50 mm
Power consumption	≤ 1.2 W per motor, moving at full speed
XY positioning precision	≤ 5 um rms
XY positioning accuracy	≤ 50 um rms
Fiber defocus	≤ 50 um, for all (α, β)
Fiber tilt	≤ 0.5°, for all (α, β)
Speed at output shaft	180°/sec (goal), 30°/sec (minimum)
Lifetime	≥ 100,000 move cycles
Operating conditions	Temperature: -20°C to +40°C Humidity: ~0 to 80% RH

Additional Goals/Constraints

- **Repairability** ⇒ Make as many steps as possible **reversible**
- **“Push-to-focus”** fiber alignment process
  - Employ disposable glass ferrules with in-raft UV cure to mount, protect, focus, and align fiber tips
- **Continuous fiber run**
  - Avoid losses from splicing and connectors
  - Connectors could be easily integrated, if sufficiently performant ones were designed
- **63 fibers per raft**, based on studies of packing density in the focal plane
  - Currently based on **Trillium fiber positioners**, but others could be used

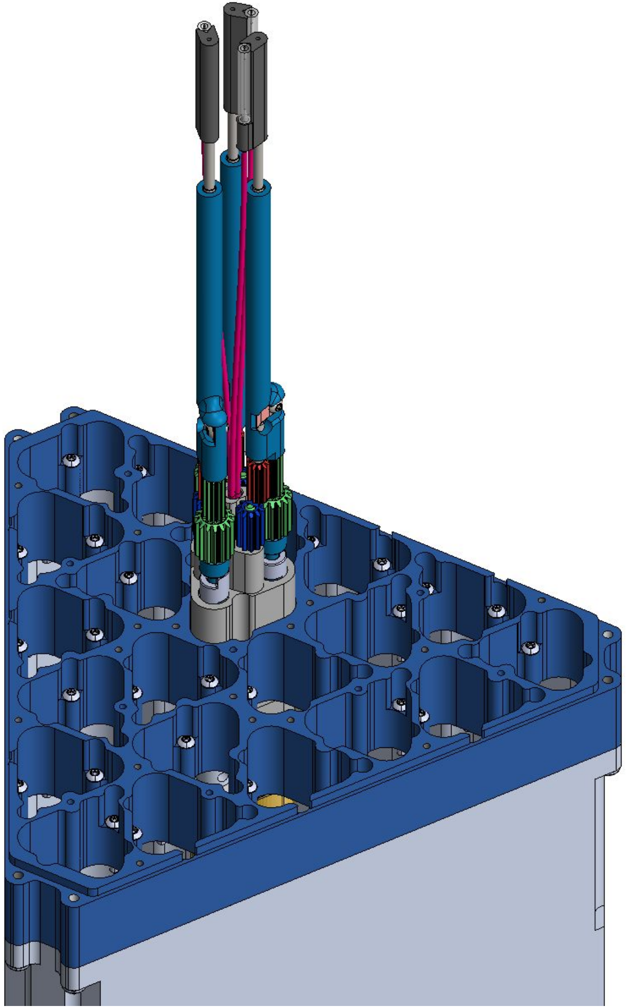

Sky
Focal Surface
Focal Plate
~30 m
Spoolboxes
Spectrographs

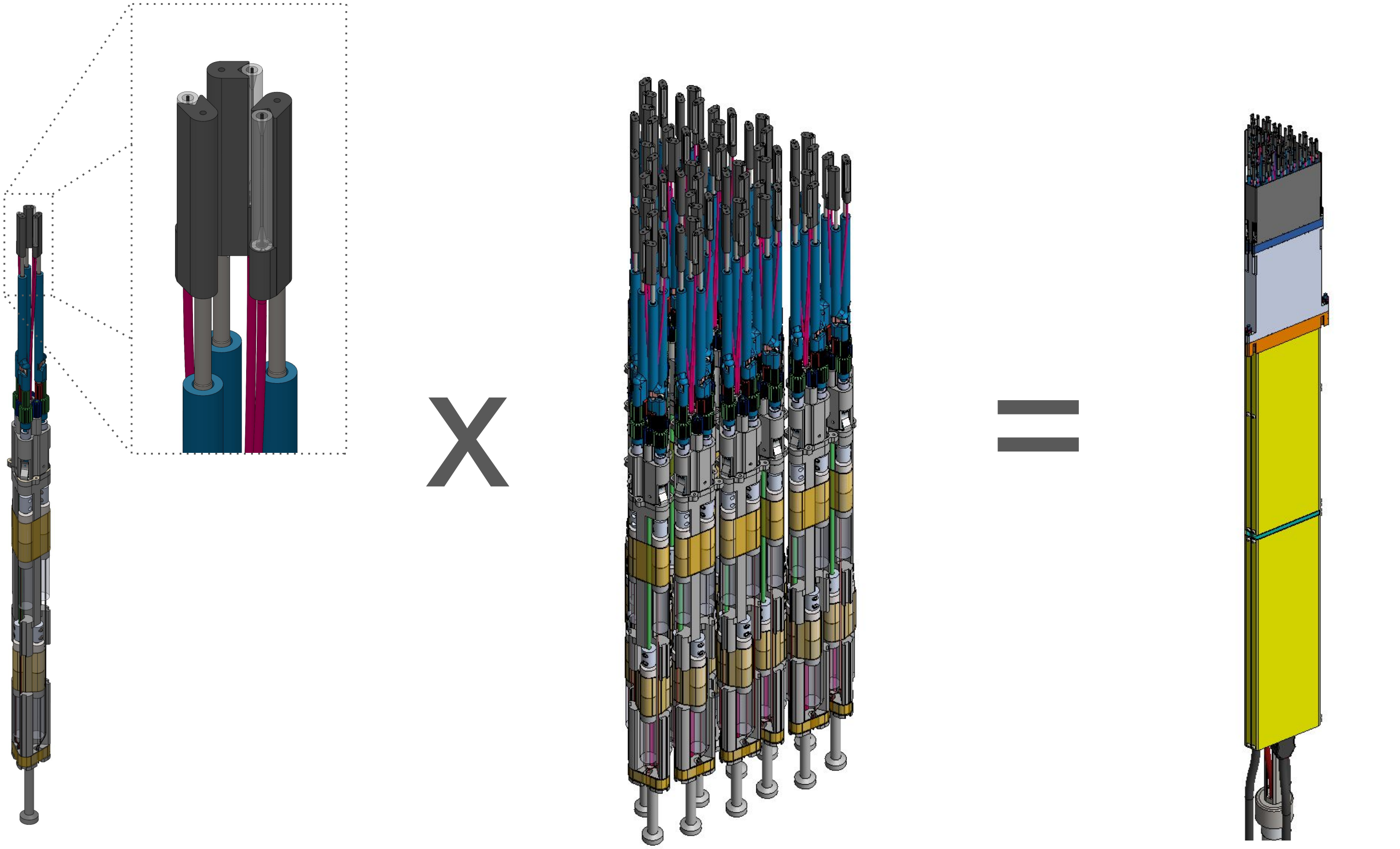

~ 600 mm
~ 24”
74 mm
~ 2.9”
UNITED STATES OF AMERICA
IN GOD WE TRUST
LIBERTY
QUARTER DOLLAR



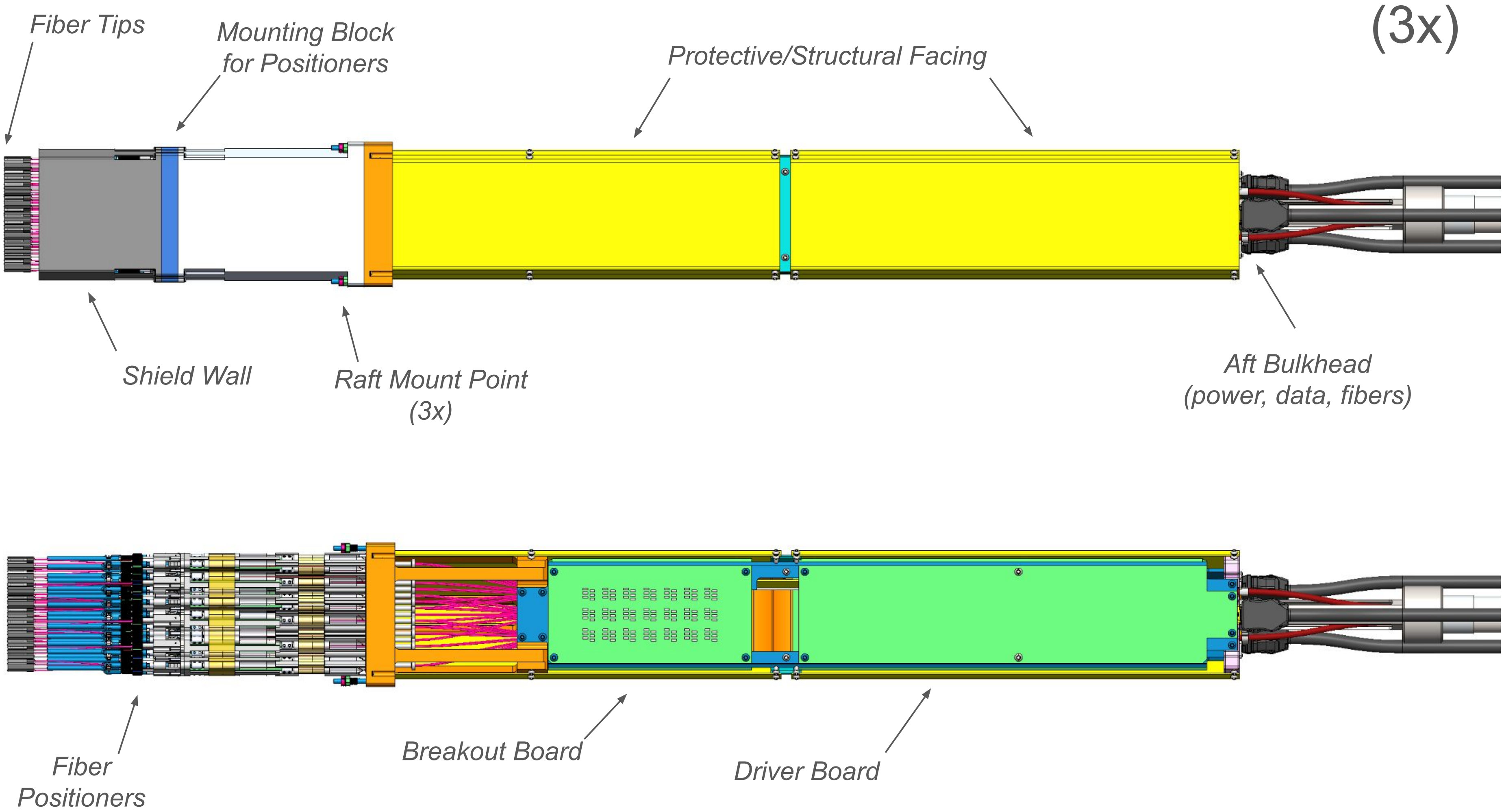
Raft currently designed for Trillium3

Other types of positioners could be used

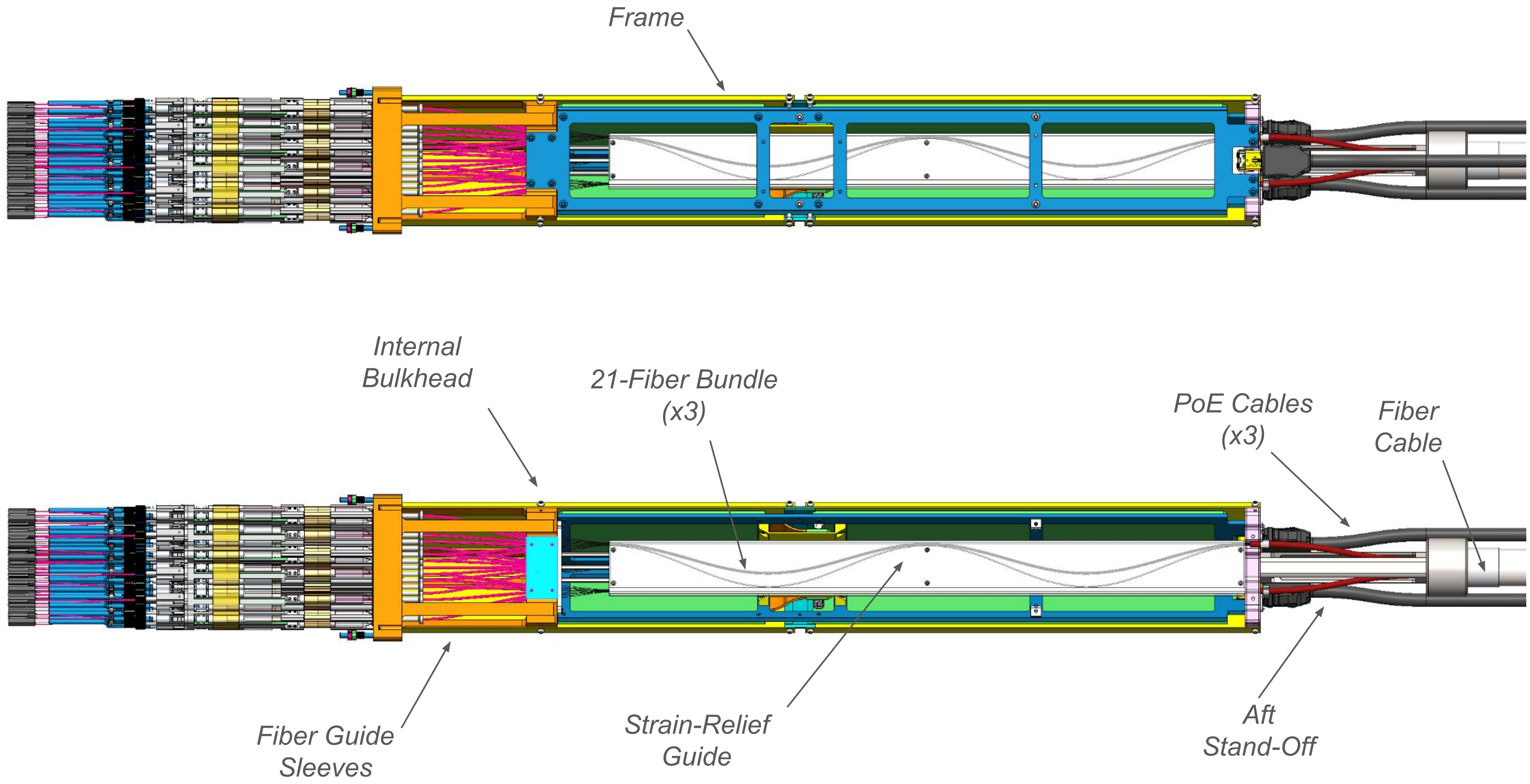


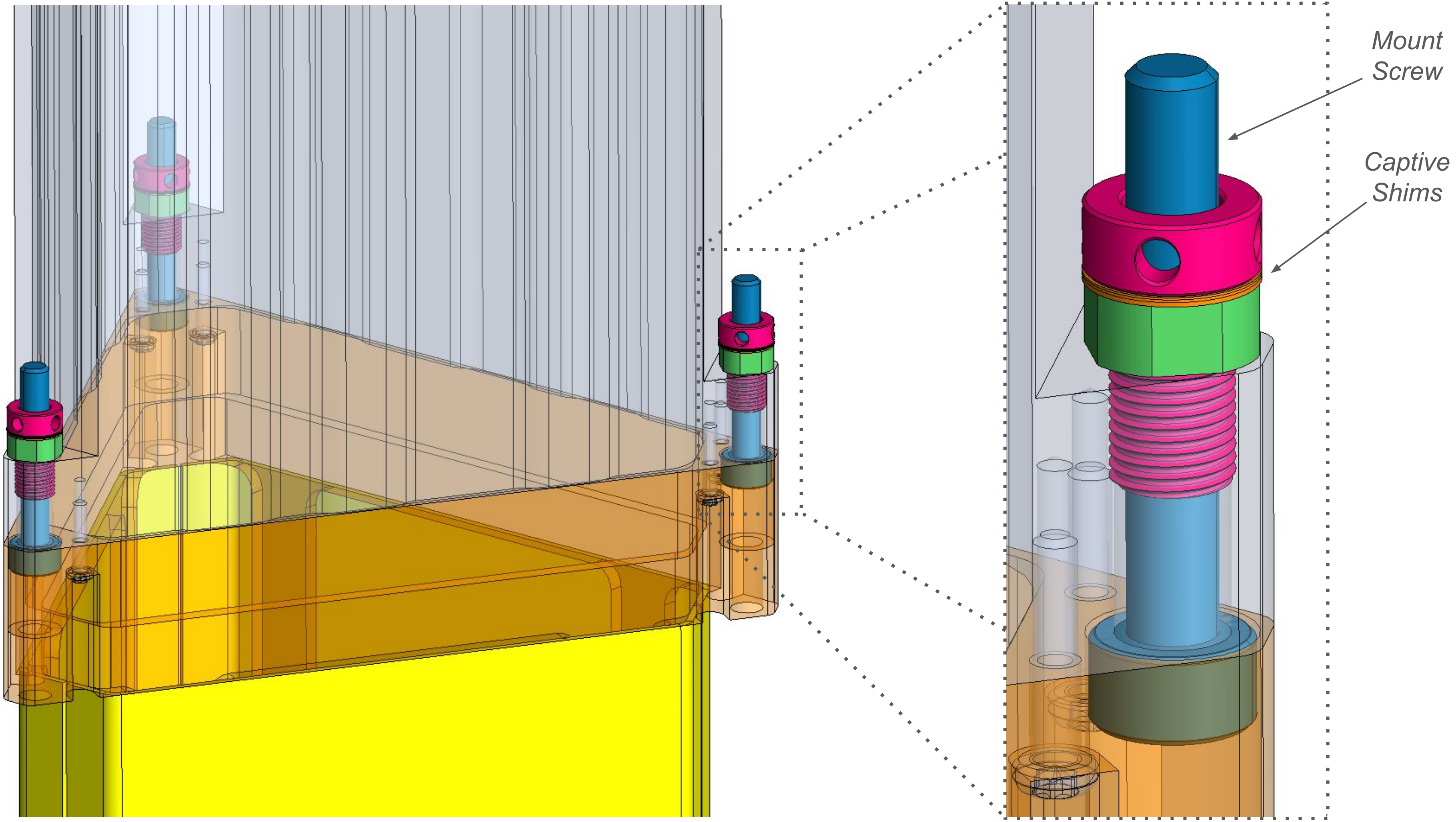


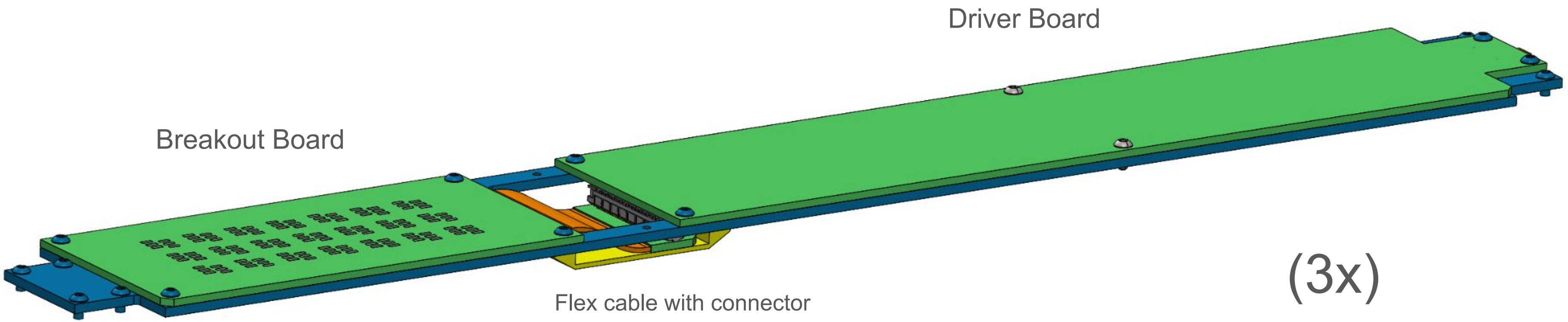
3 Fibers / Trillium × 21 Trilliums / Raft = 63 Fibers / Raft

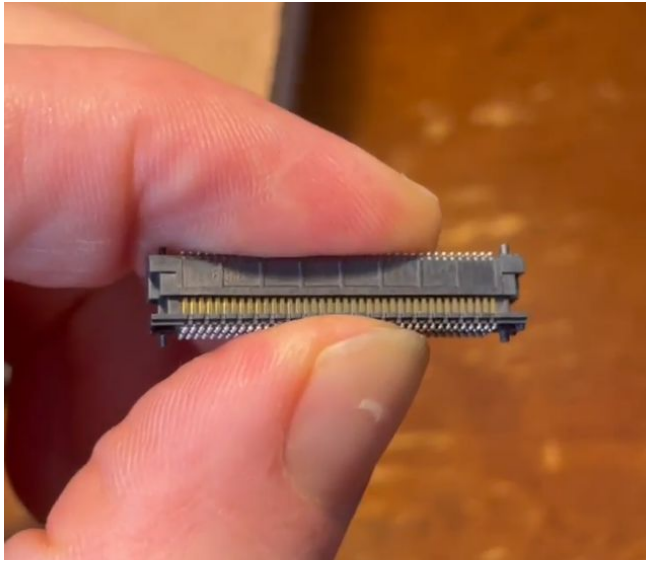


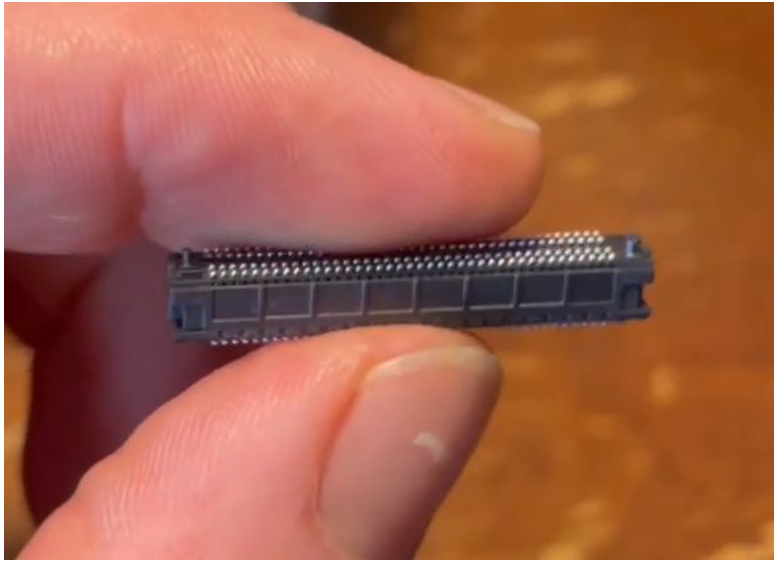
(3x)
Fiber Tips
Mounting Block for Positioners
Protective/Structural Facing
Shield Wall
Raft Mount Point (3x)
Aft Bulkhead (power, data, fibers)
Fiber Positioners
Breakout Board
Driver Board


Frame
Internal Bulkhead
21-Fiber Bundle (x3)
PoE Cables (x3)
Fiber Cable
Fiber Guide Sleeves
Strain-Relief Guide
Aft Stand-Off

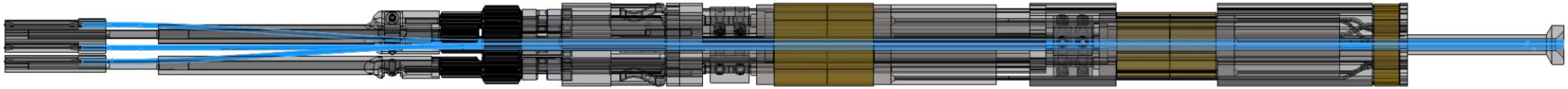

Mount
Screw
Captive
Shims



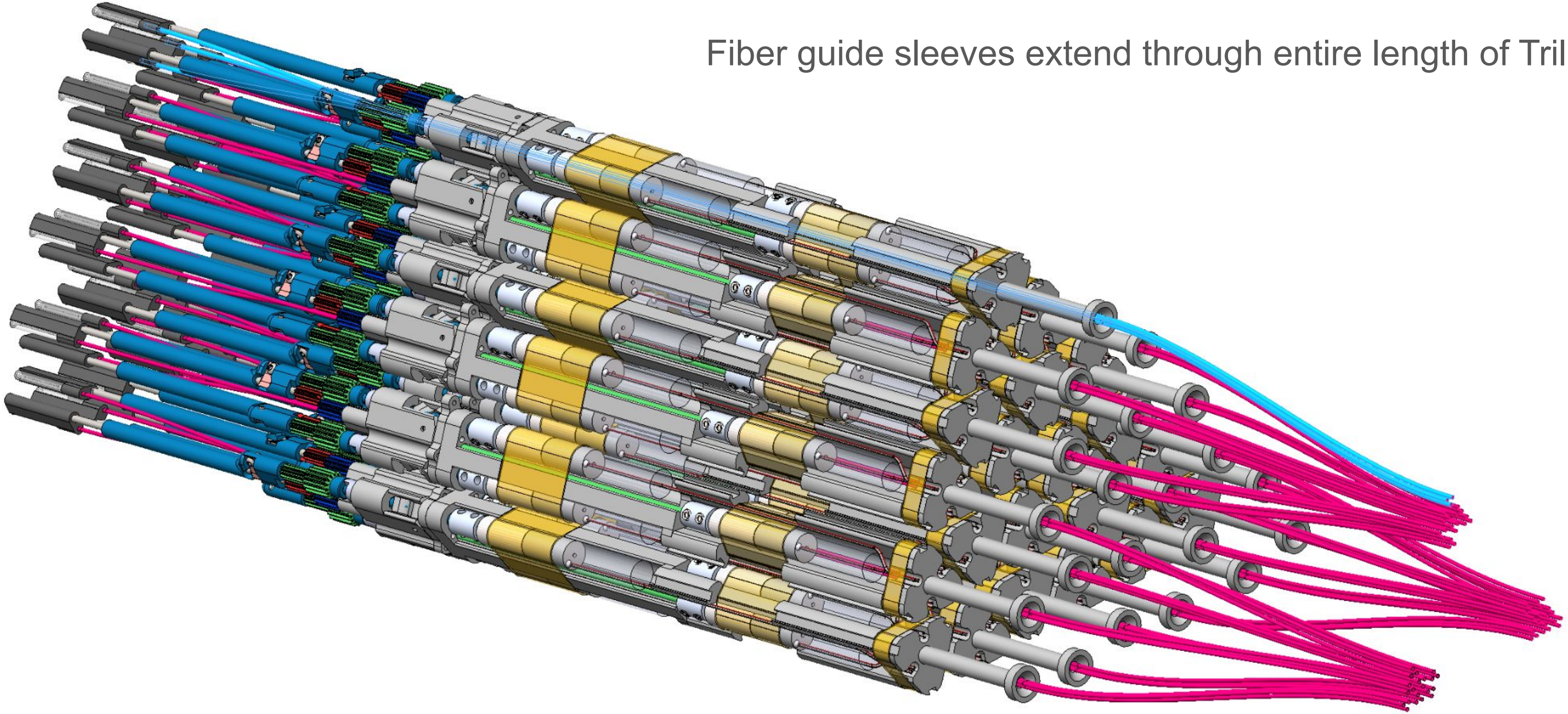


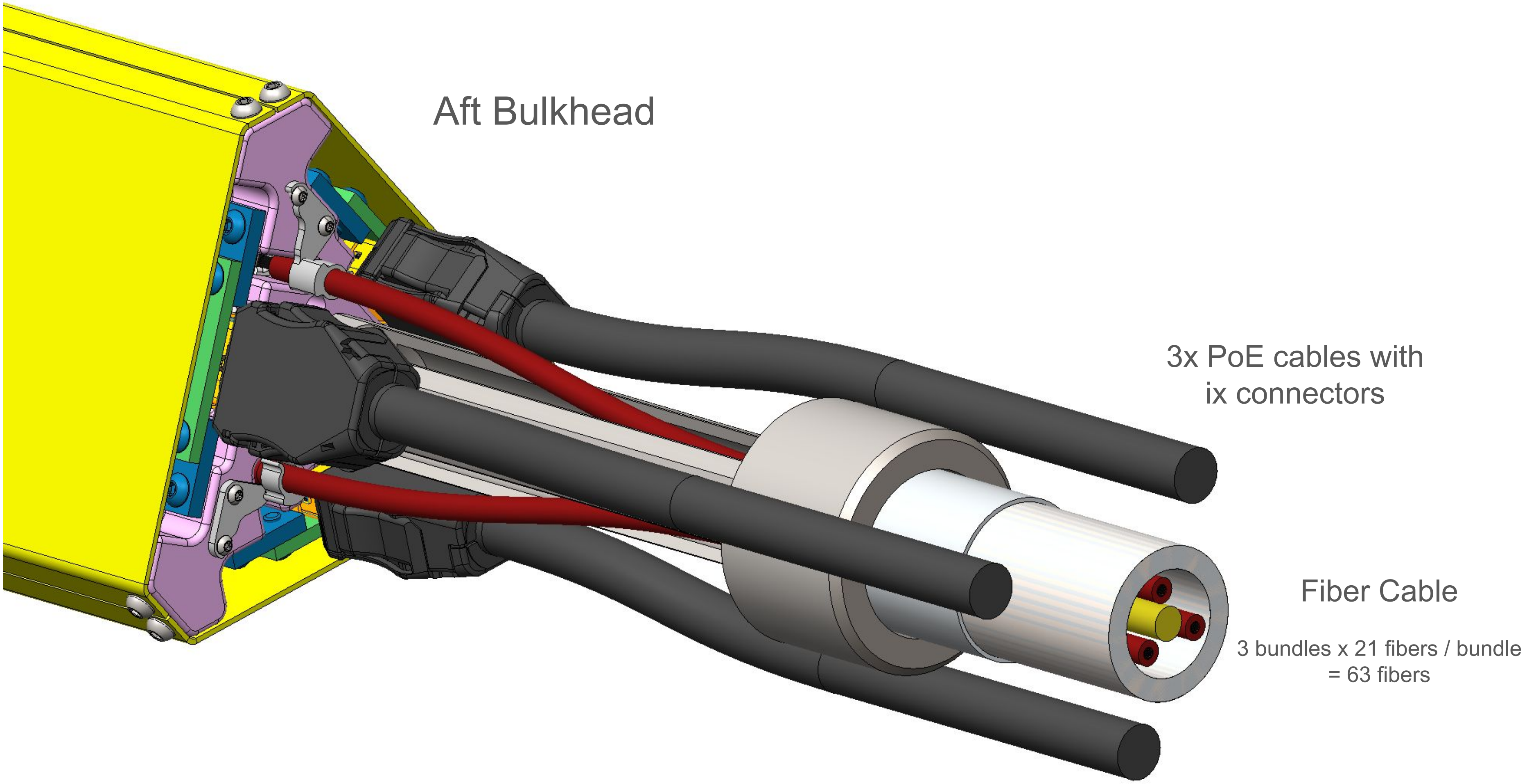


Samtec ADF6-40-03.5-L-4-2-A-TR



Fiber guide sleeves extend through entire length of Trilliums



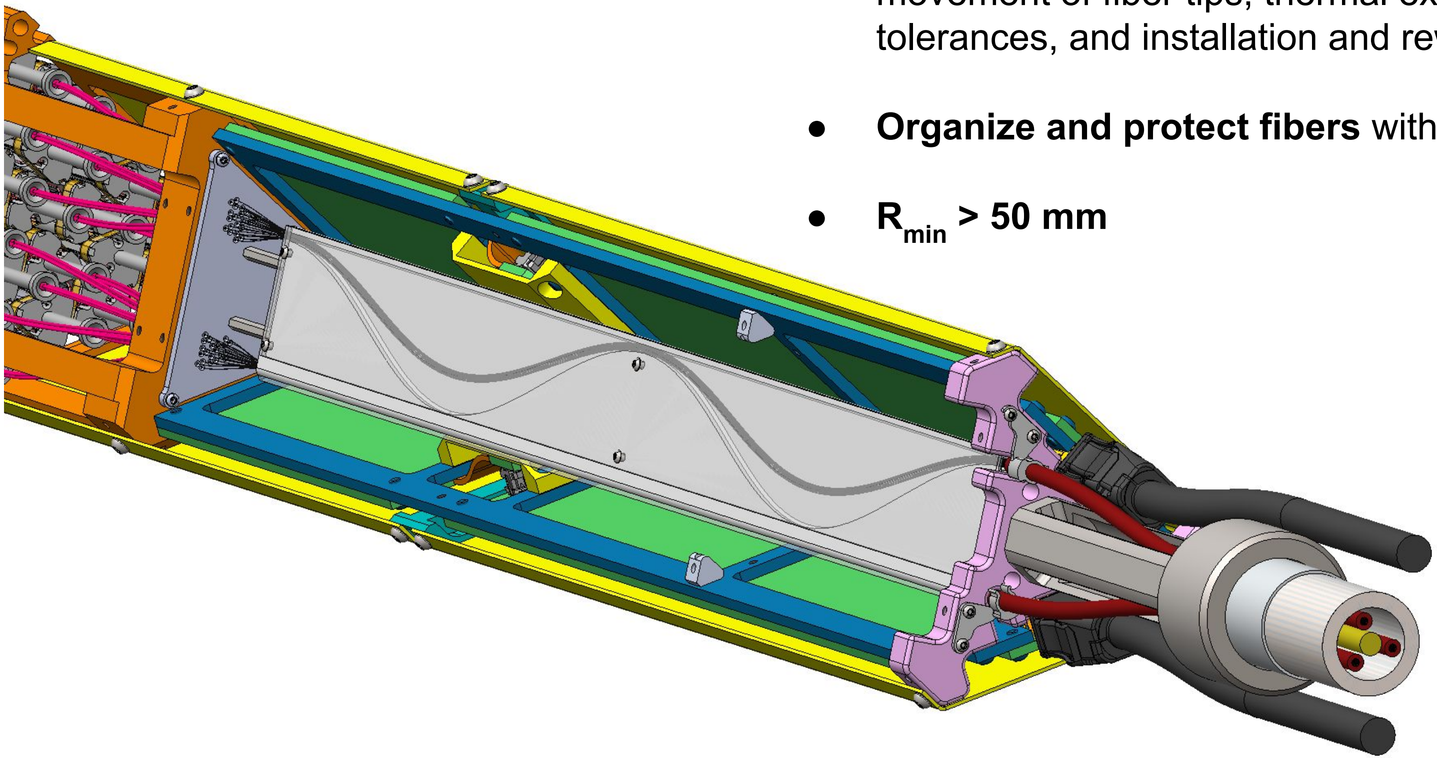

Aft Bulkhead
3x PoE cables with
ix connectors
Fiber Cable
3 bundles x 21 fibers / bundle
= 63 fibers

Fiber Slack / Strain Relief

- Provide **> 10 mm fiber slack** within raft to accommodate movement of fiber tips, thermal expansion, manufacturing tolerances, and installation and rework processes

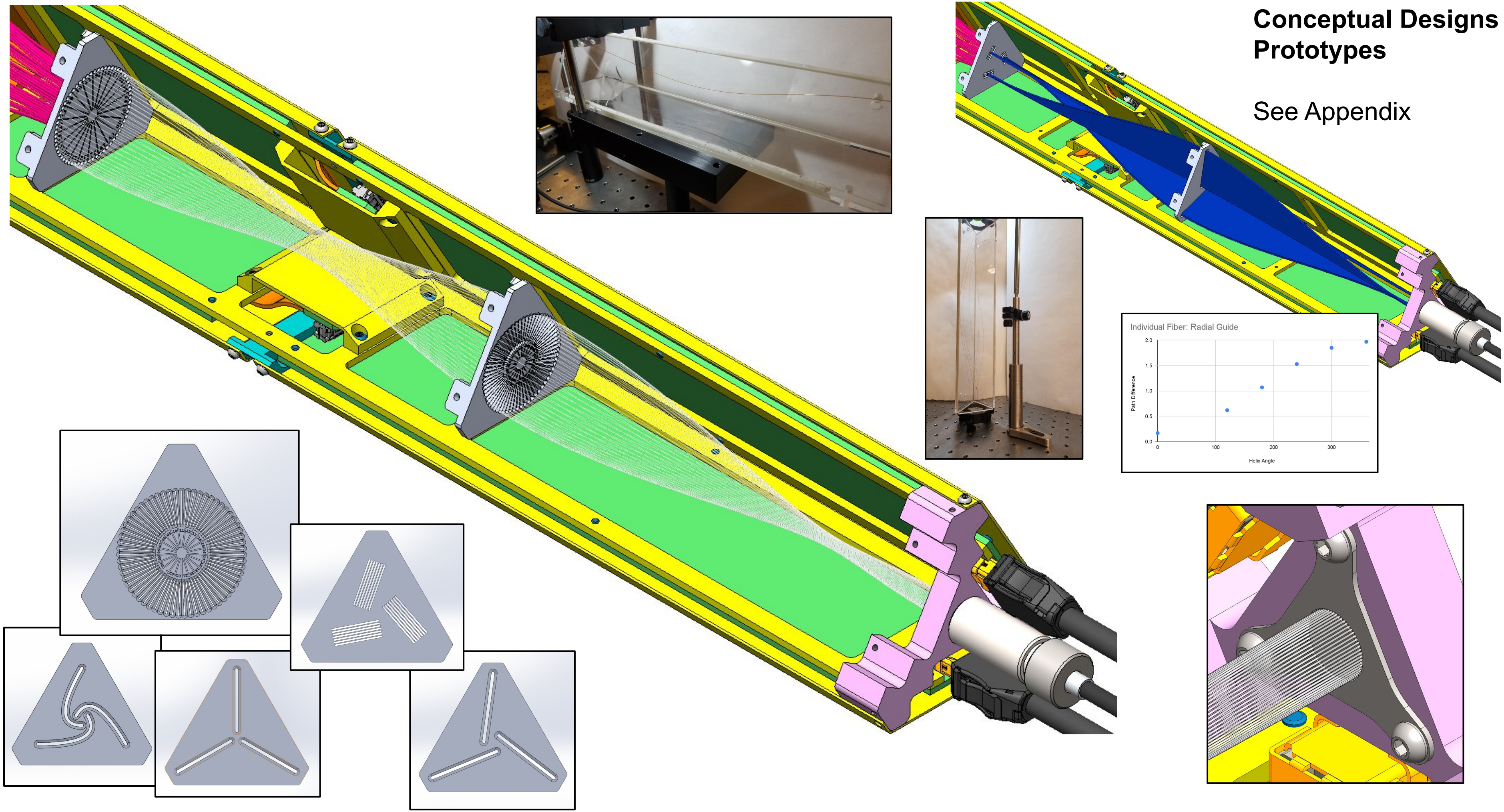
- **Organize and protect fibers** within raft

- **R_{min} > 50 mm**

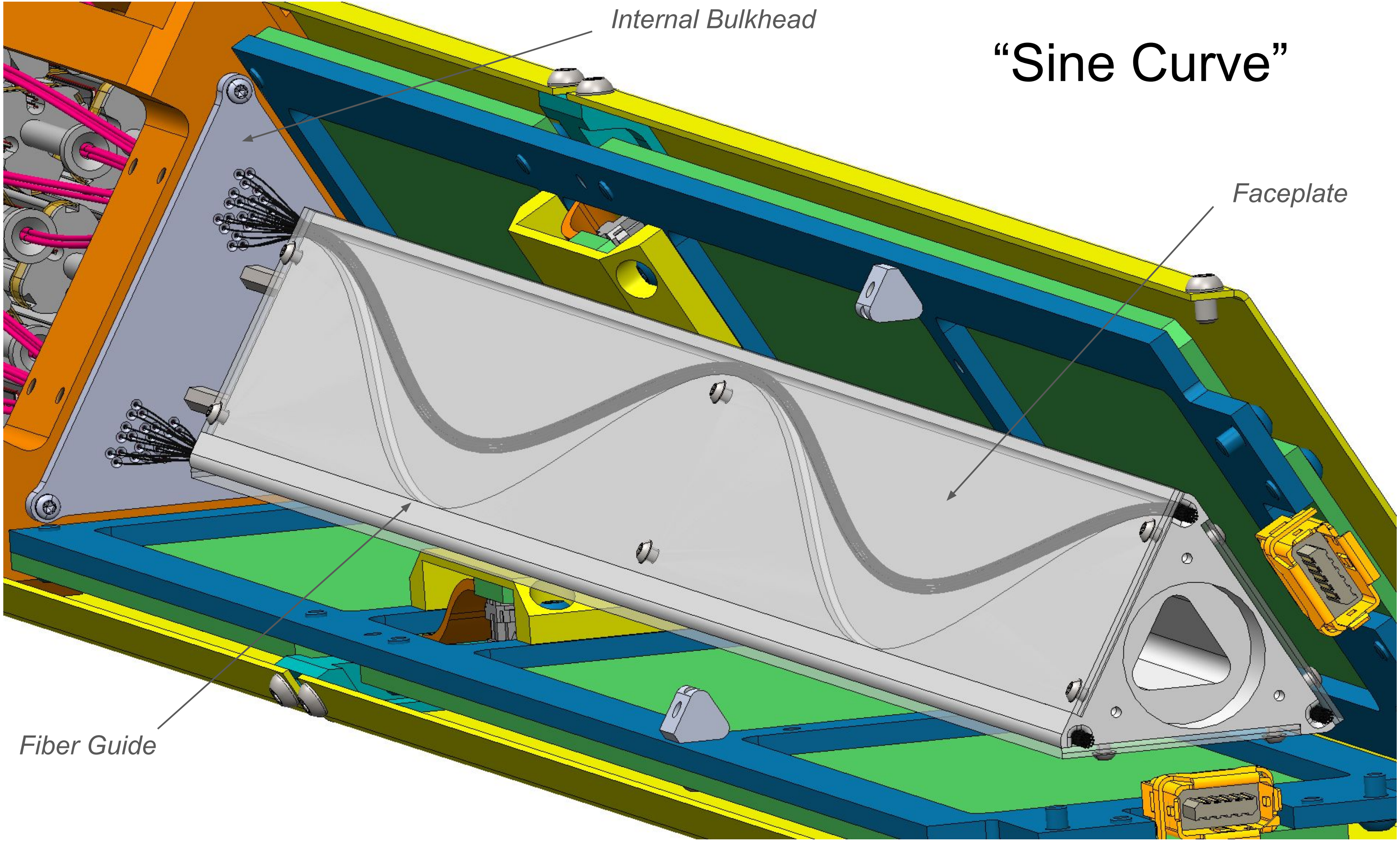


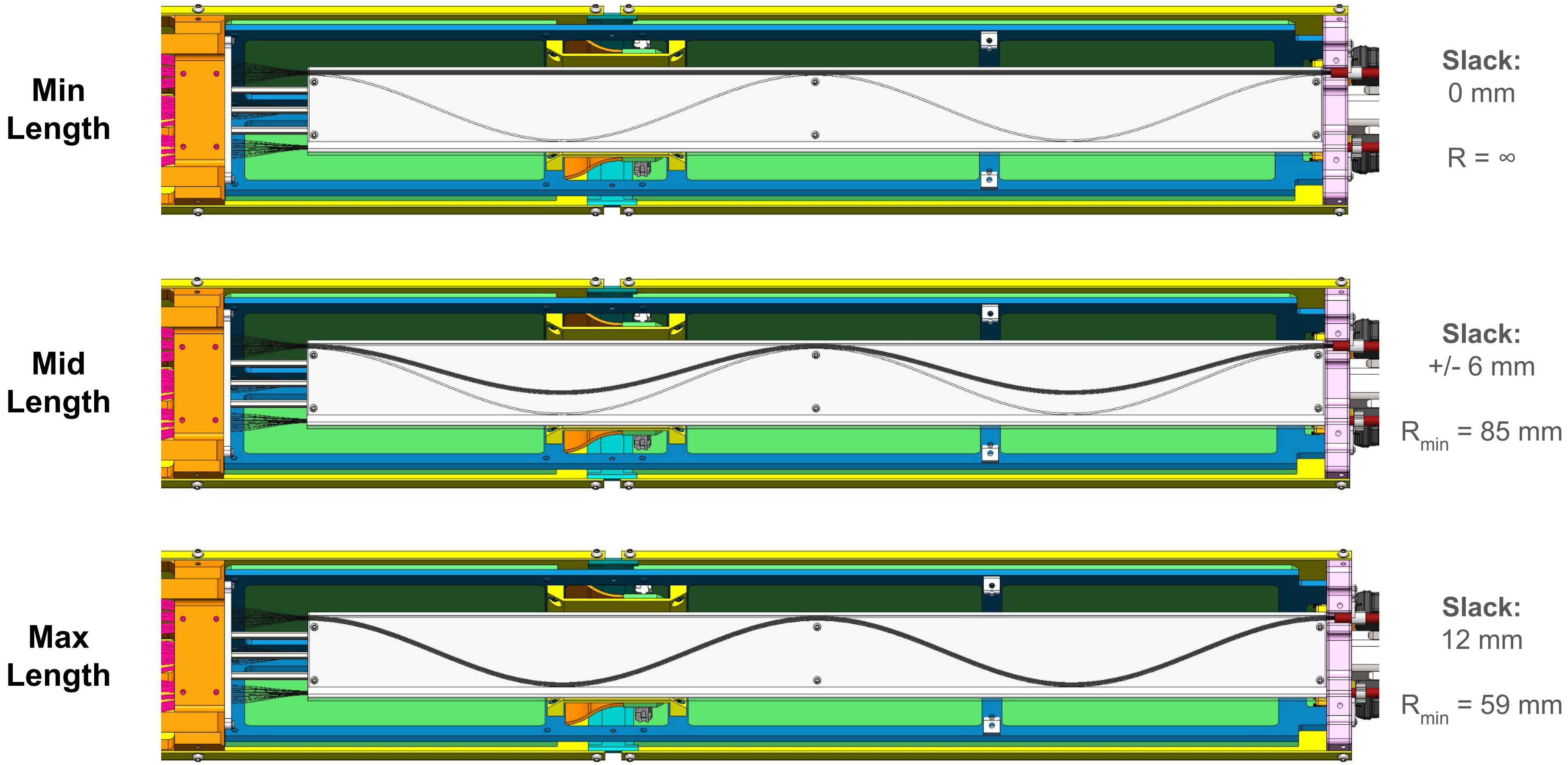
Conceptual Designs Prototypes

See Appendix



"Sine Curve"

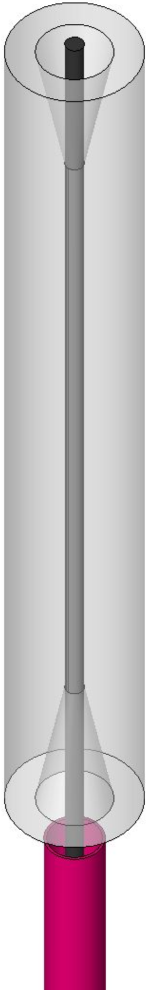



Min Length
Slack: 0 mm
R = ∞
Mid Length
Slack: +/- 6 mm
R_{min} = 85 mm
Max Length
Slack: 12 mm
R_{min} = 59 mm

Fiber Installation Process

“Push-to-Focus”

developed particularly with contributions from Travis Mandeville and Joe Silber



Key features:

- Disposable ferrule, reversibly attached to fiber arm
- Fiber inserted, focused, and UV-glued to ferrule

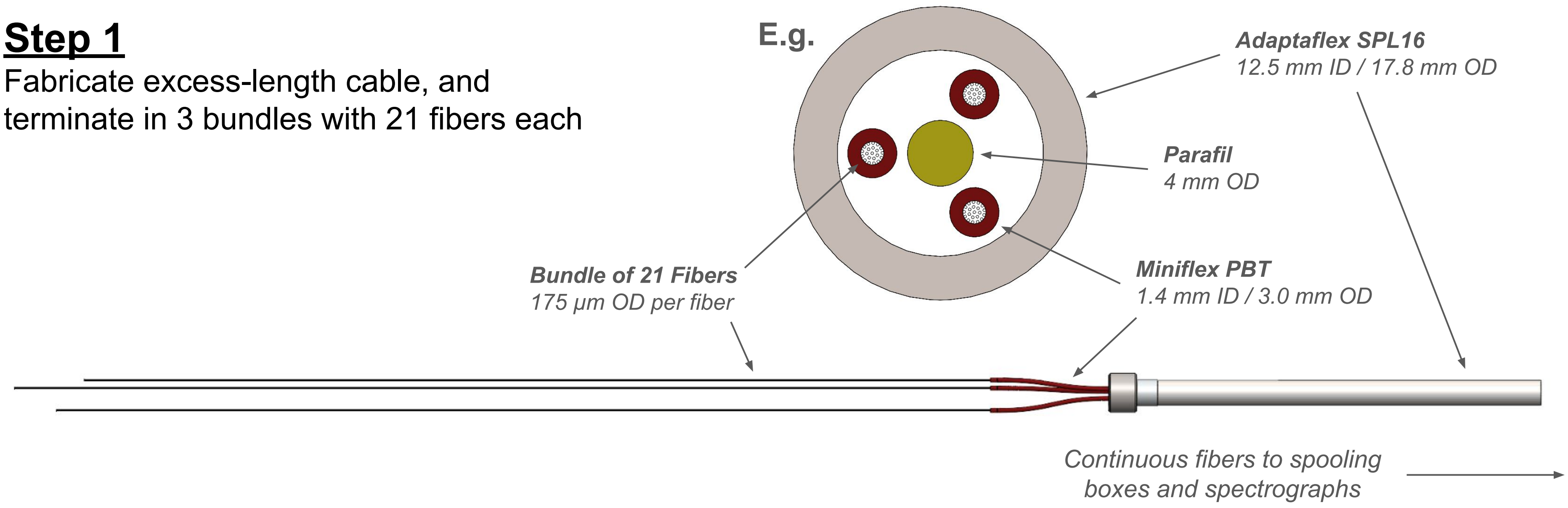
For rework:

- Cut fiber
- Throw away ferrule
- Splice new fiber
- Reinstall

Based on DESI ferrule, which remains the best option for FRD and alignment performance

Step 1

Fabricate excess-length cable, and terminate in 3 bundles with 21 fibers each

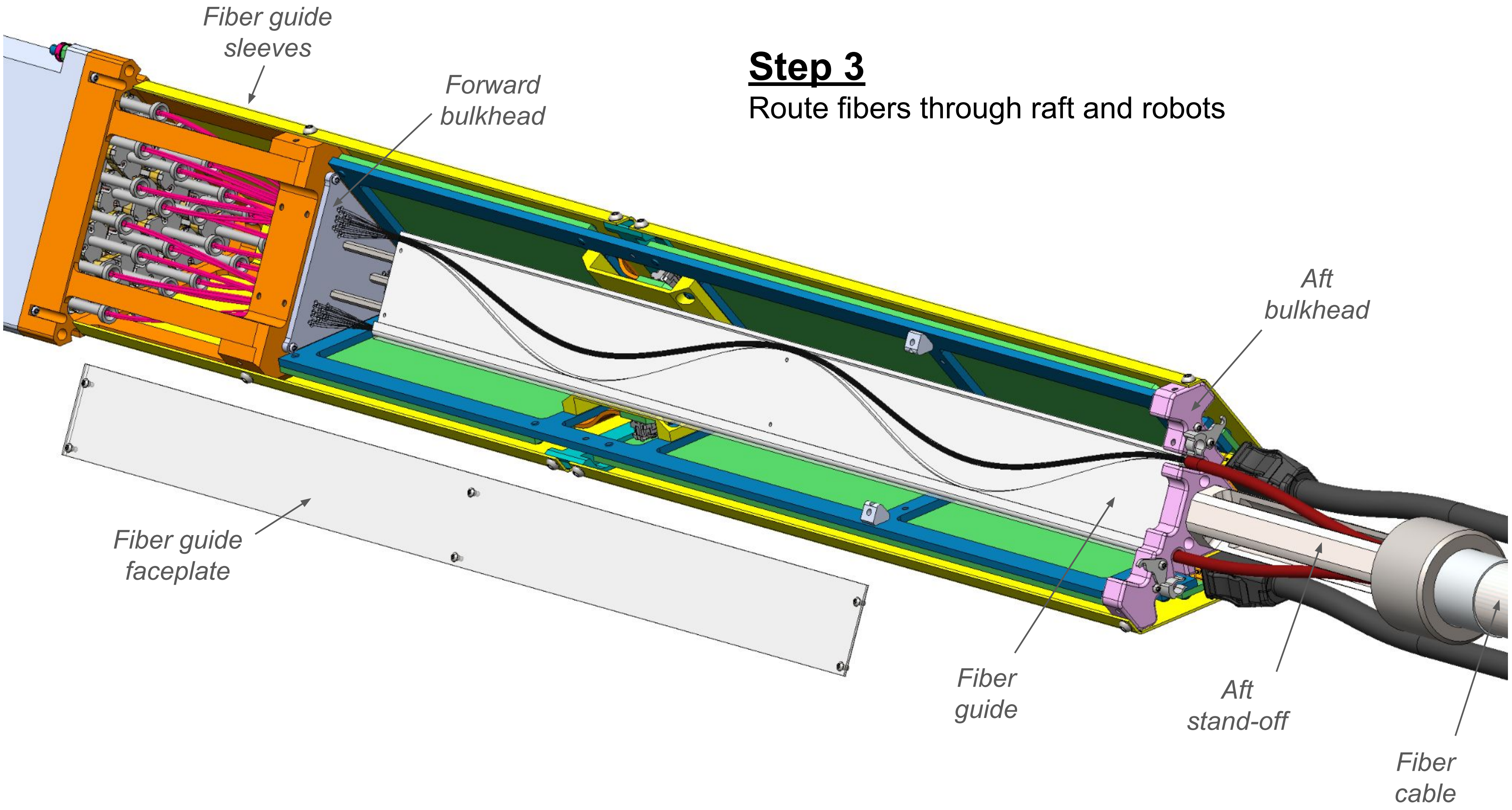


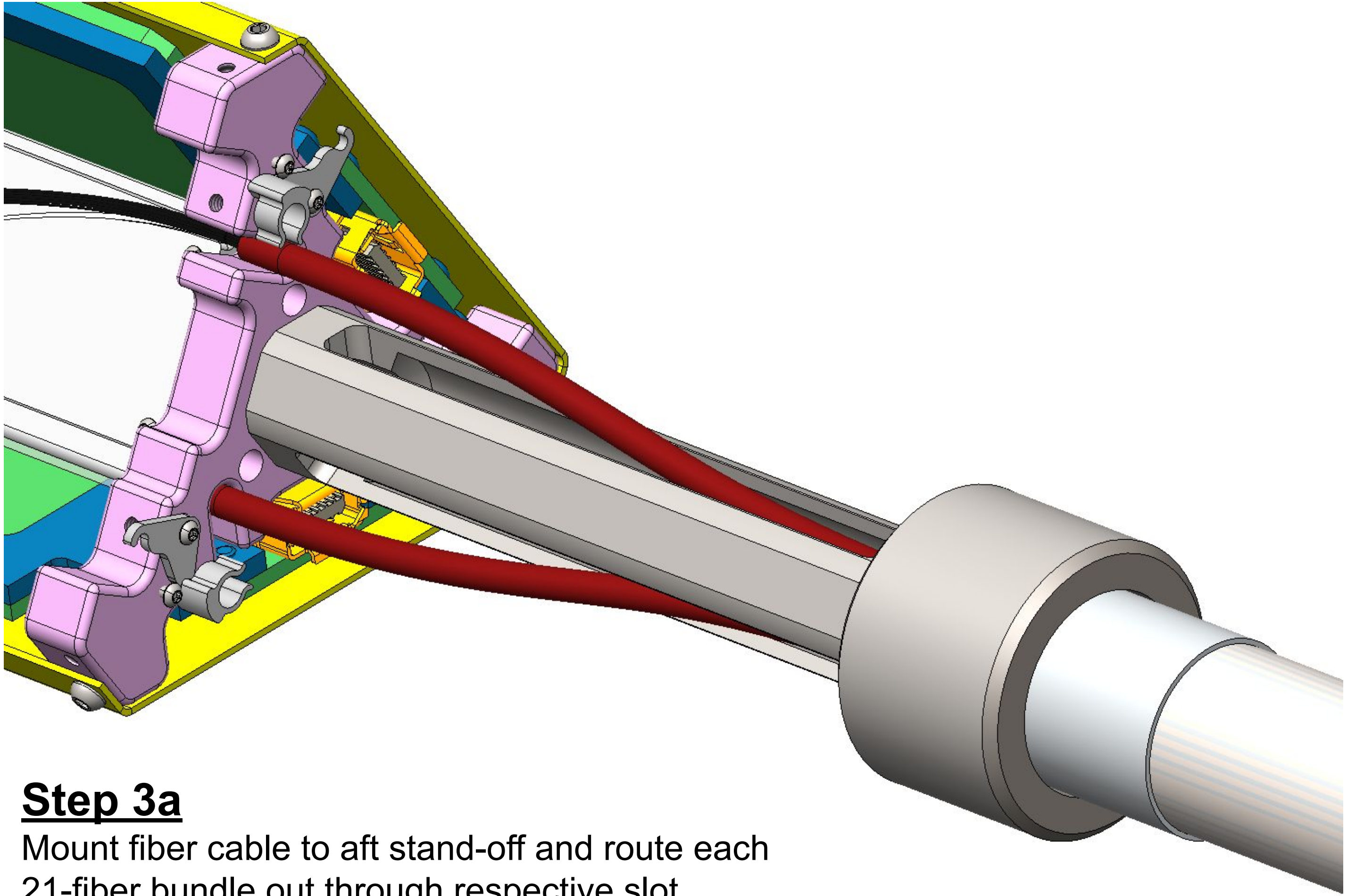
Step 2

Cleave fibers to length (+/- 3 mm)

Step 3

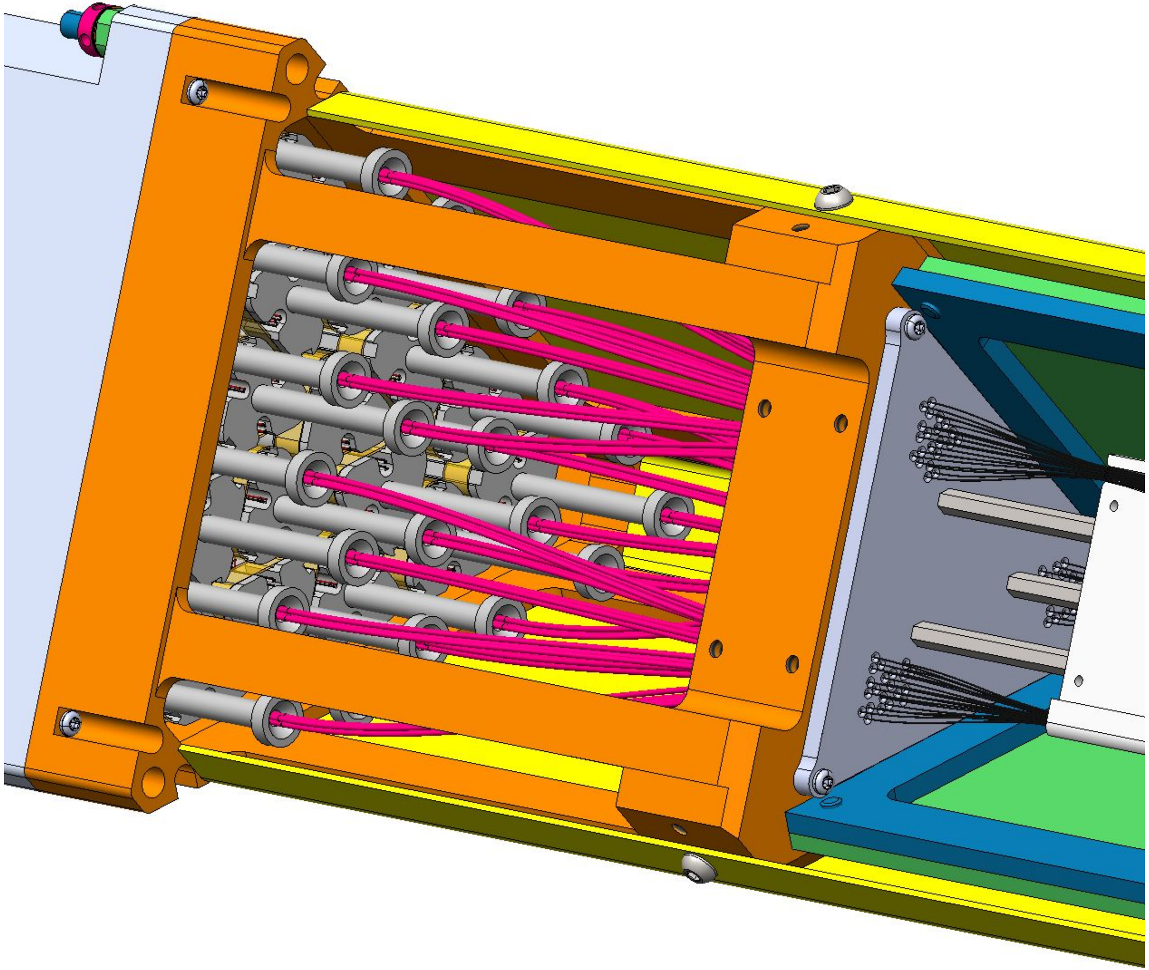
Route fibers through raft and robots





Step 3a

Mount fiber cable to aft stand-off and route each 21-fiber bundle out through respective slot

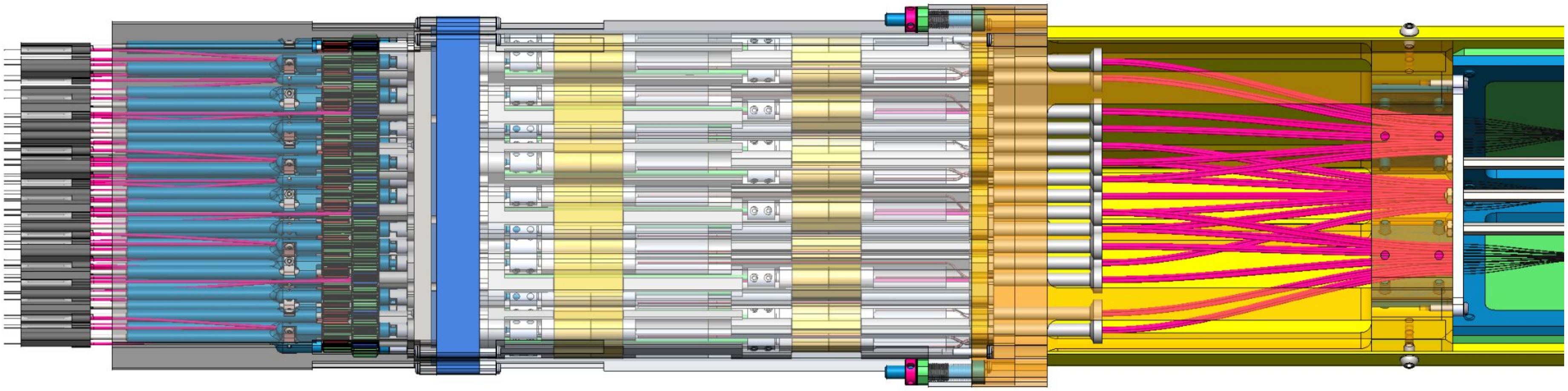


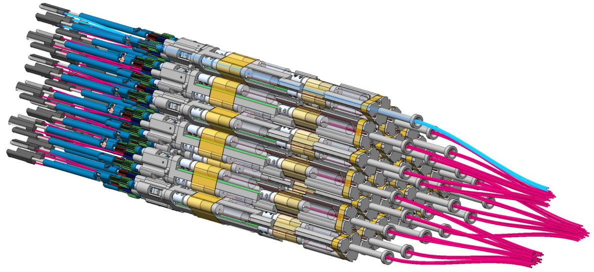
Step 3b

Route fibers through internal bulkhead and into individual fiber guide sleeves

Step 3c

Push fibers through fiber guide sleeves and through robots to forward end of raft

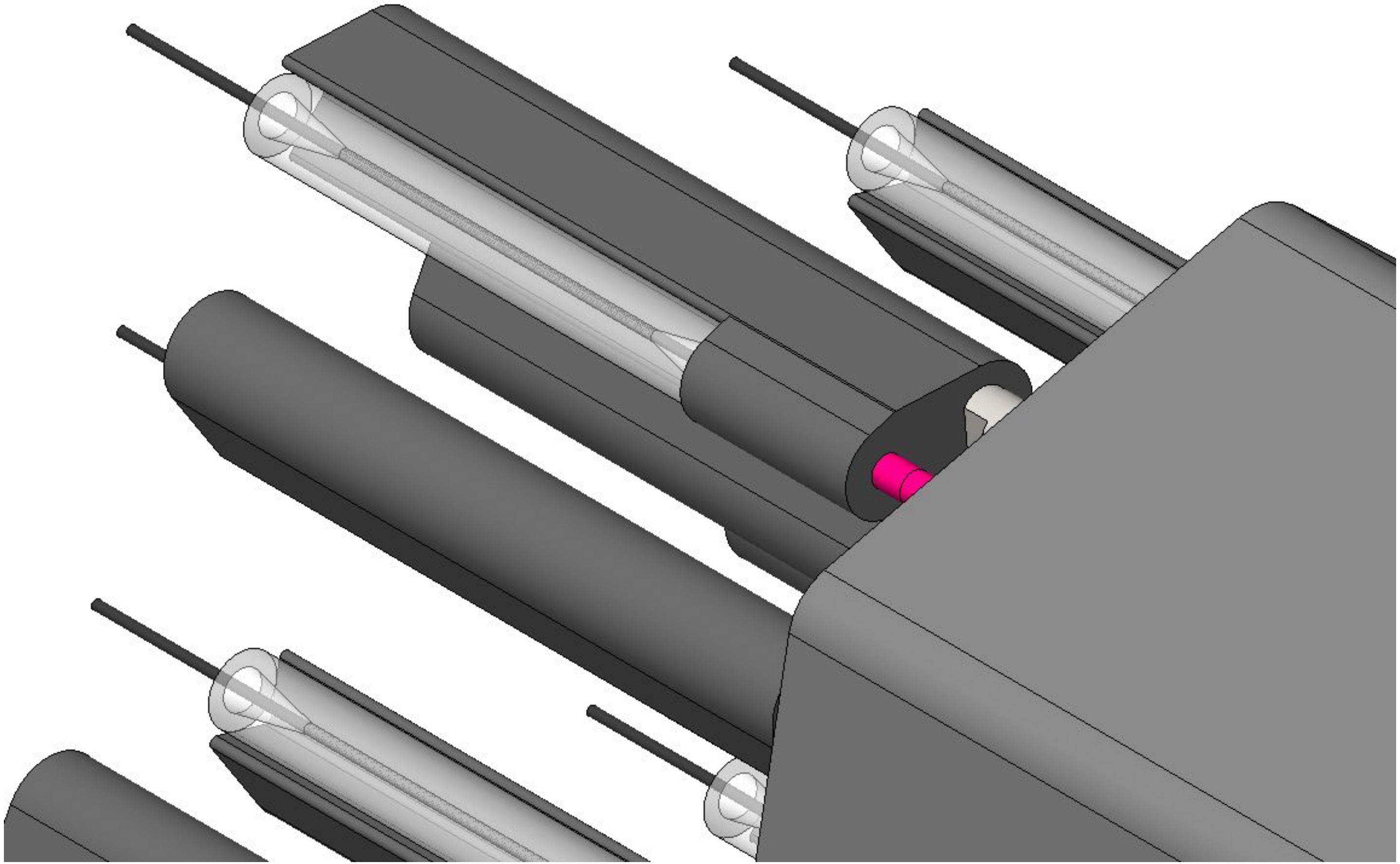




Fiber guide sleeves extend through entire length of robots

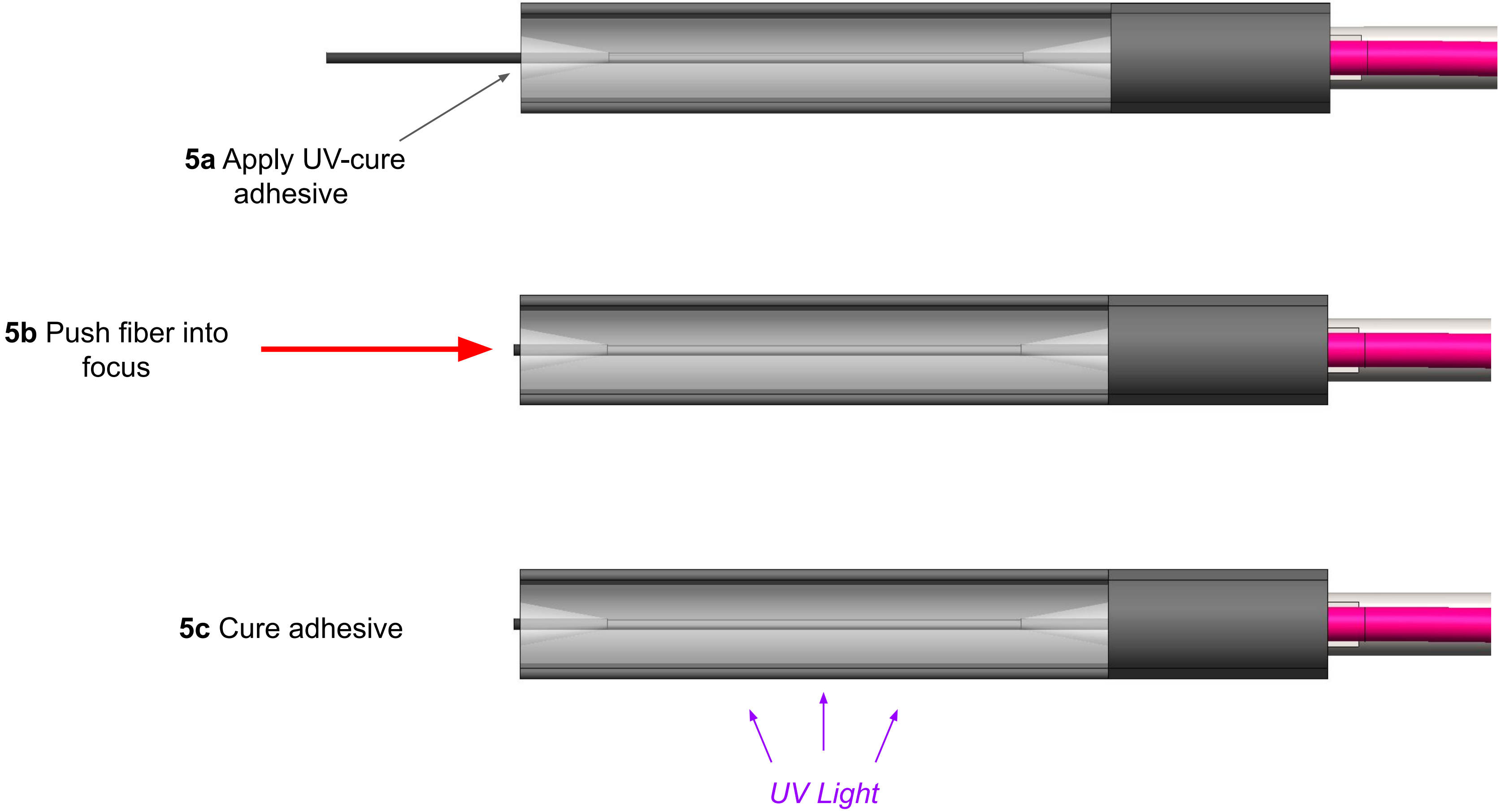
Step 4

Push fibers through ferrules past intended focal surface



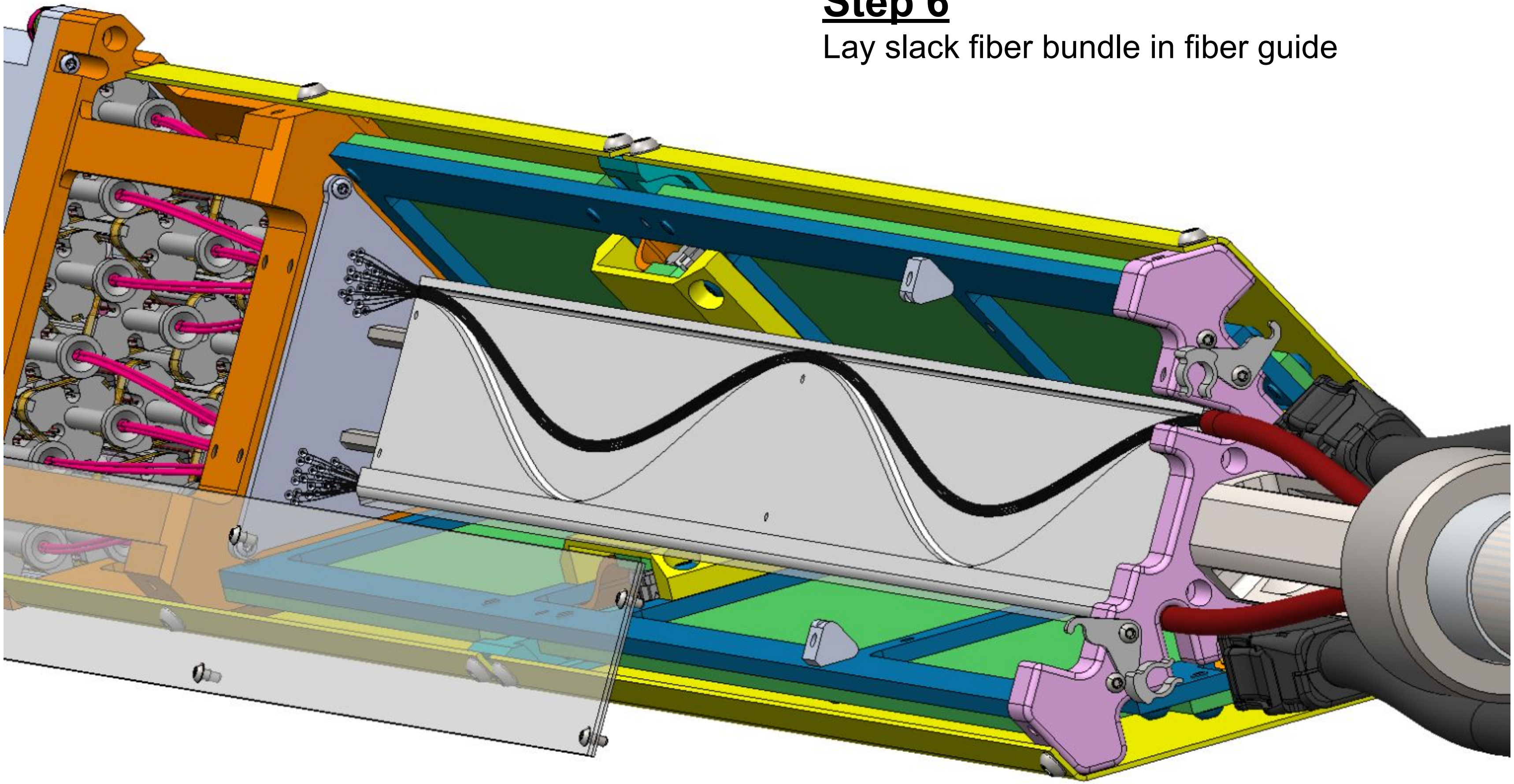
Step 5

Focus and secure fiber



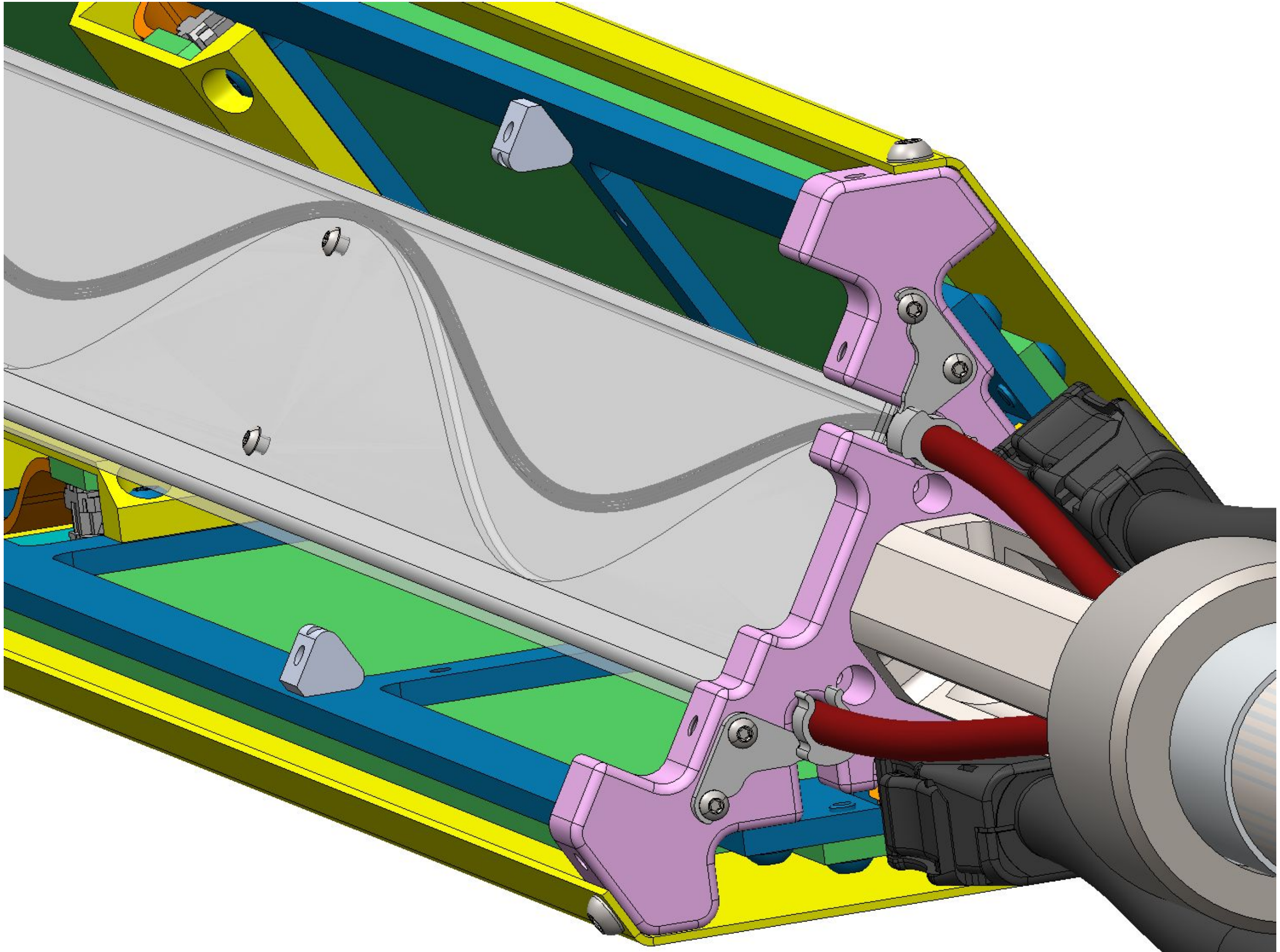
Step 6

Lay slack fiber bundle in fiber guide



Step 7

Secure fiber bundle with aft clip and fiber guide faceplate



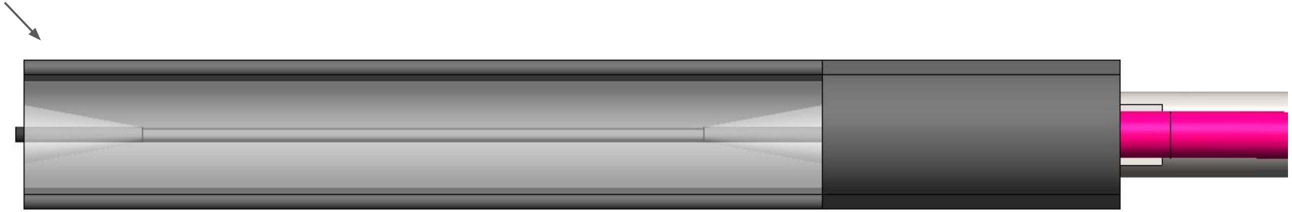
Rework Process

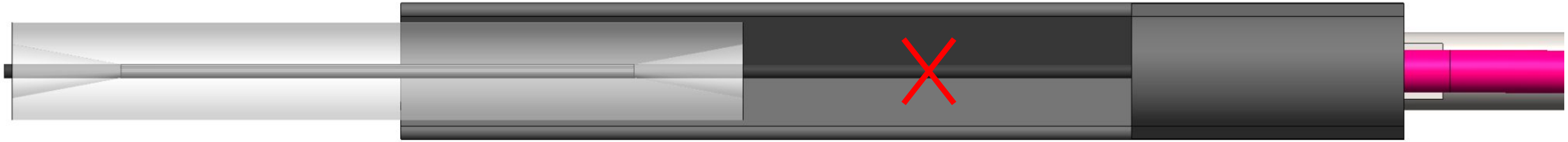
Rework

Step 8: Press-Fit Fiber Arm

Detach ferrule from fiber arm then cut fiber

8a Dissolve adhesive between ferrule and fiber arm



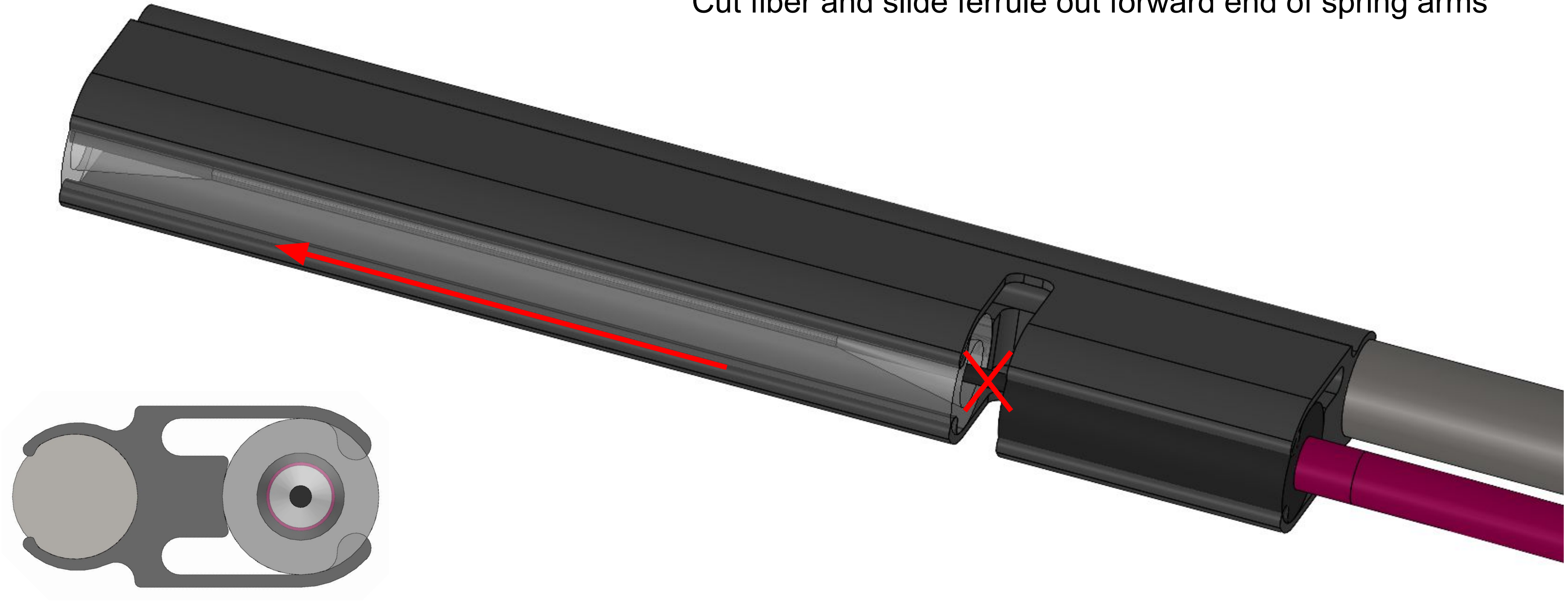


8b Pull ferrule and fiber ~5 mm forward and cut fiber

Rework

Step 8: EDM Fiber Arm

Cut fiber and slide ferrule out forward end of spring arms

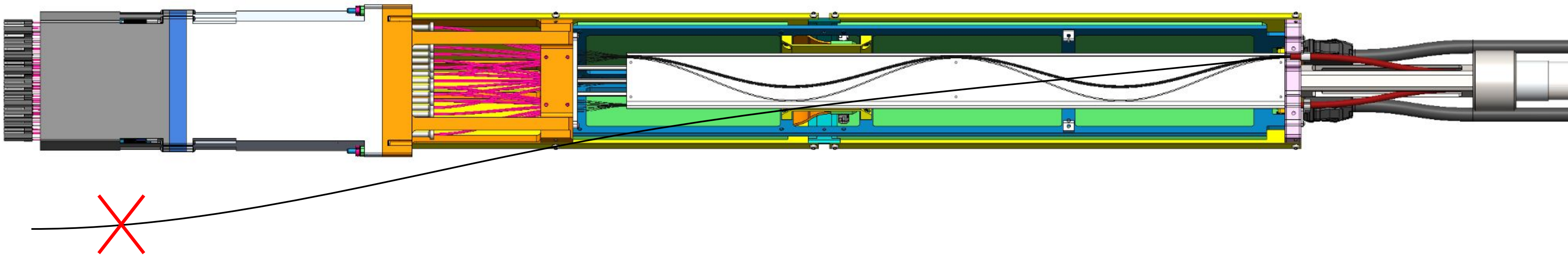


Top View

Rework

Step 9

Pull fiber back, out, and away from raft to aft bulkhead



Step 10

Cleave fiber to length in preparation for splicing

Step 11

Prepare new AR-coated fiber segment and cleave to length

Step 12

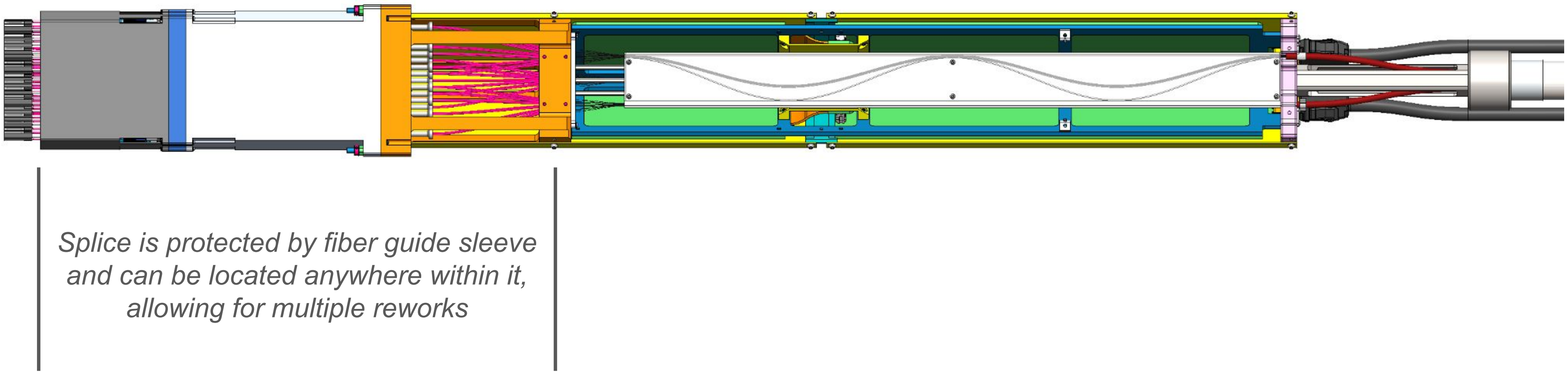
Splice new fiber segment with remainder of original fiber

Effects of AR coating and splicing on FRD roughly cancel out, although stability is diminished

Rework

Step 13

Start at **Step 3b** to reroute, resecure, refocus, and reglue the repaired fiber



Splice is protected by fiber guide sleeve and can be located anywhere within it, allowing for multiple reworks

Additional protection may be necessary

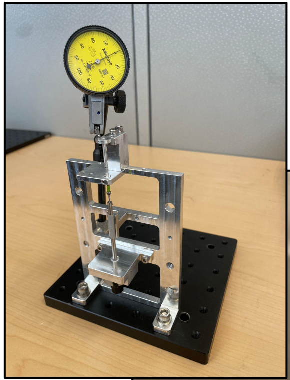
Fiber Arms

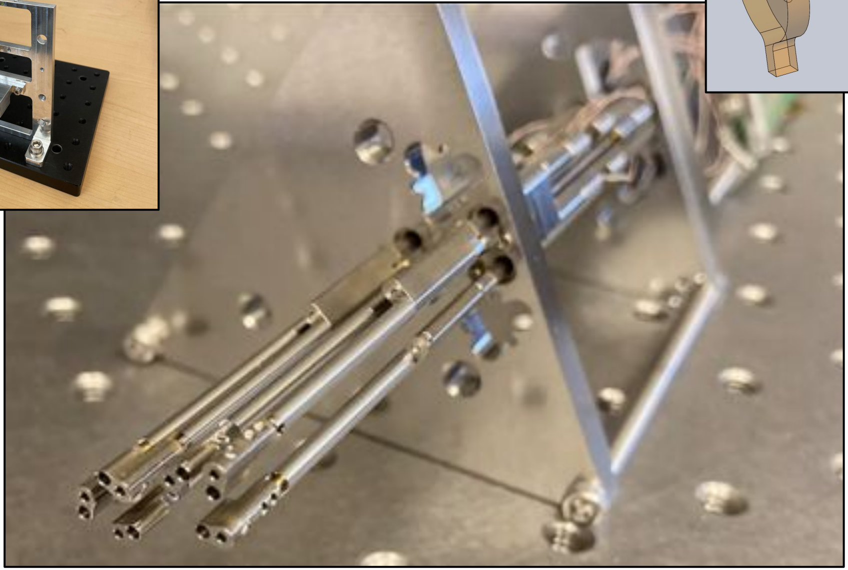
Reversibly connect fiber/ferrule to fiber positioner

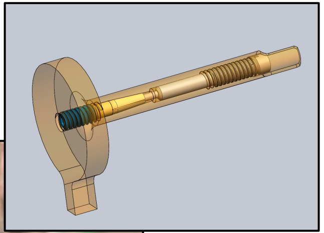
- Precise alignment
- Precise axial displacement
- Ease installation and rework

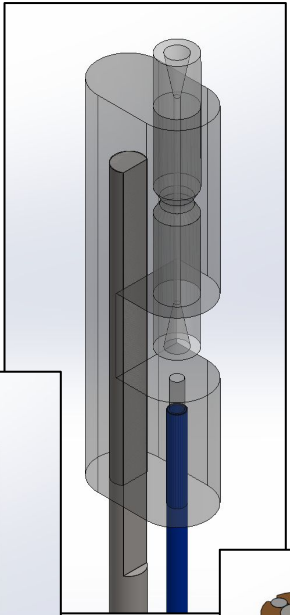
Conceptual Designs Prototypes

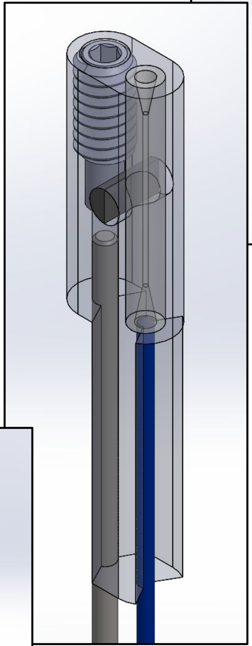
See Appendix

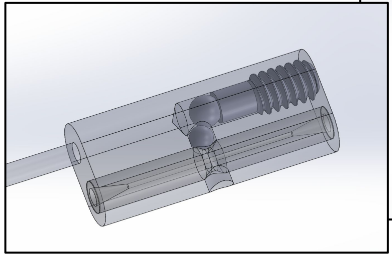


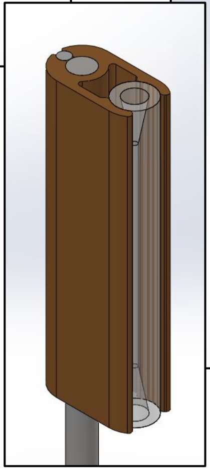


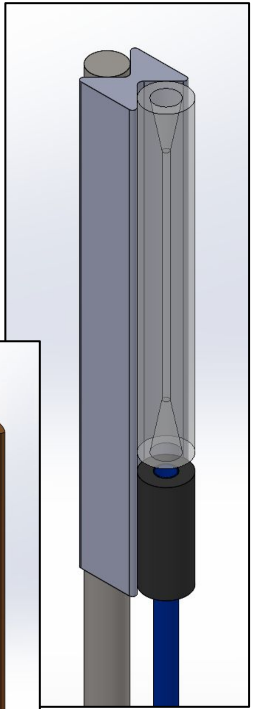


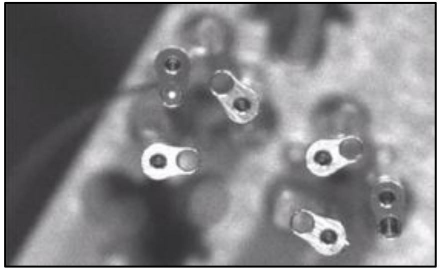




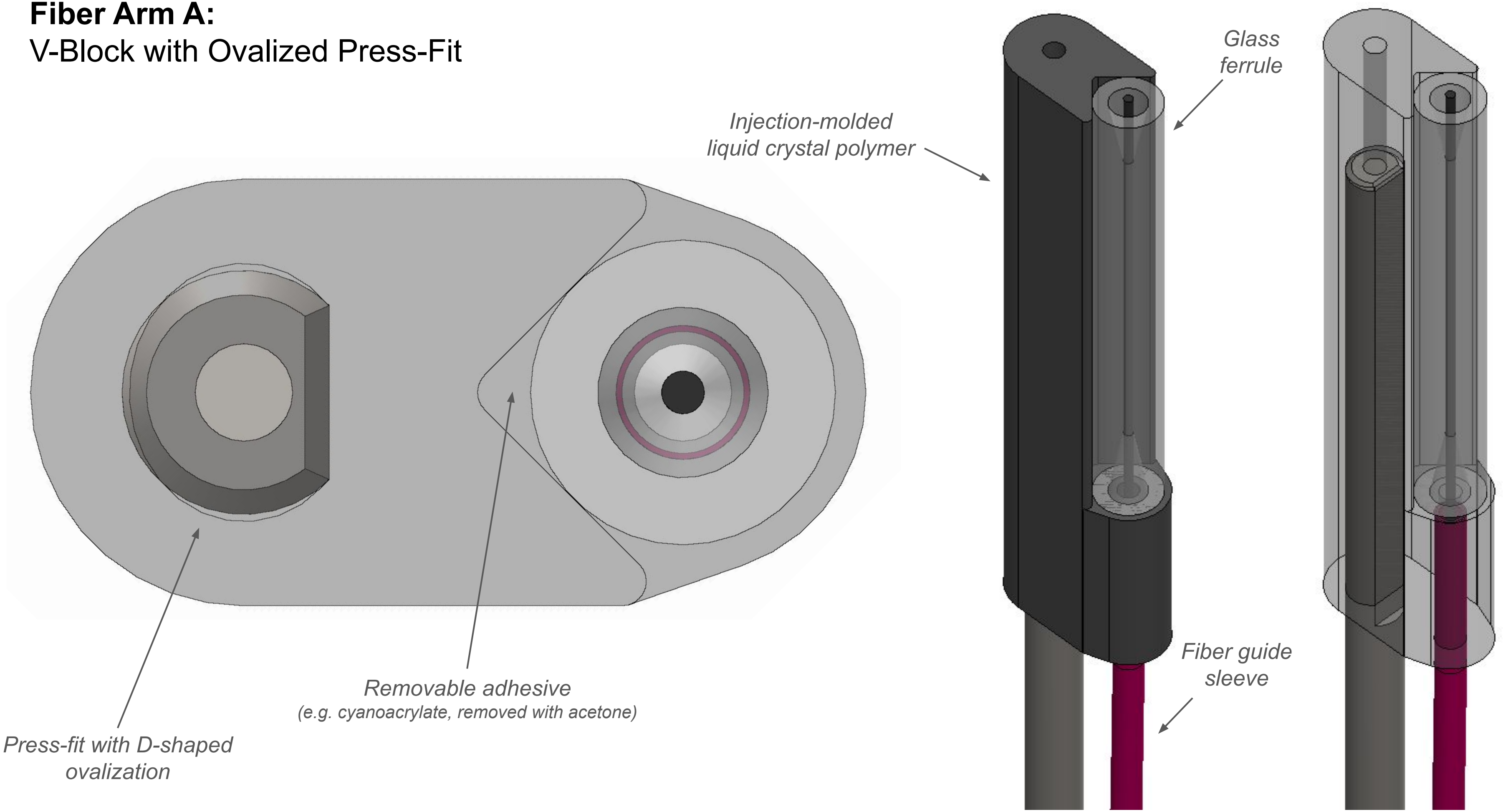




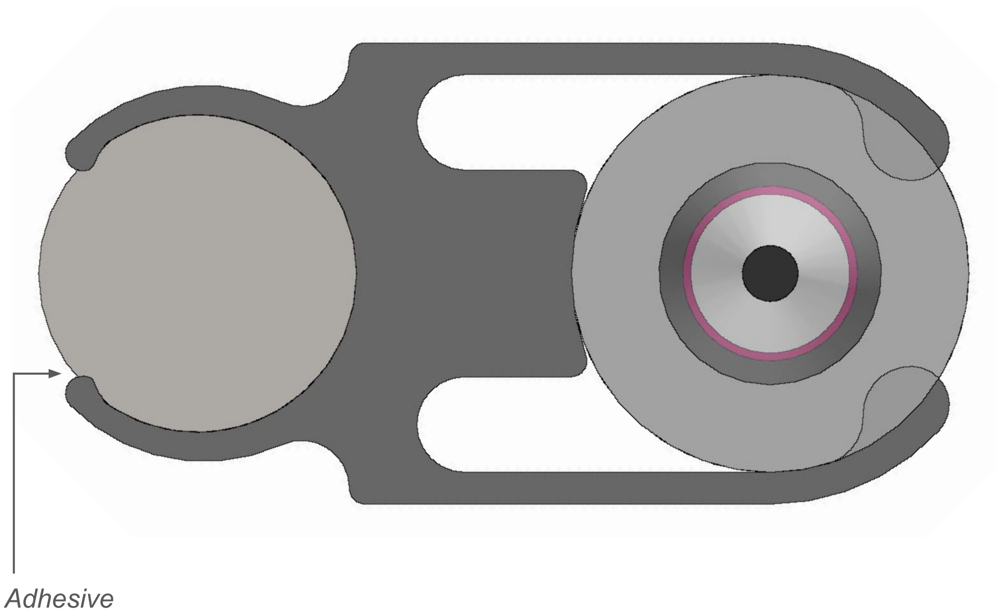


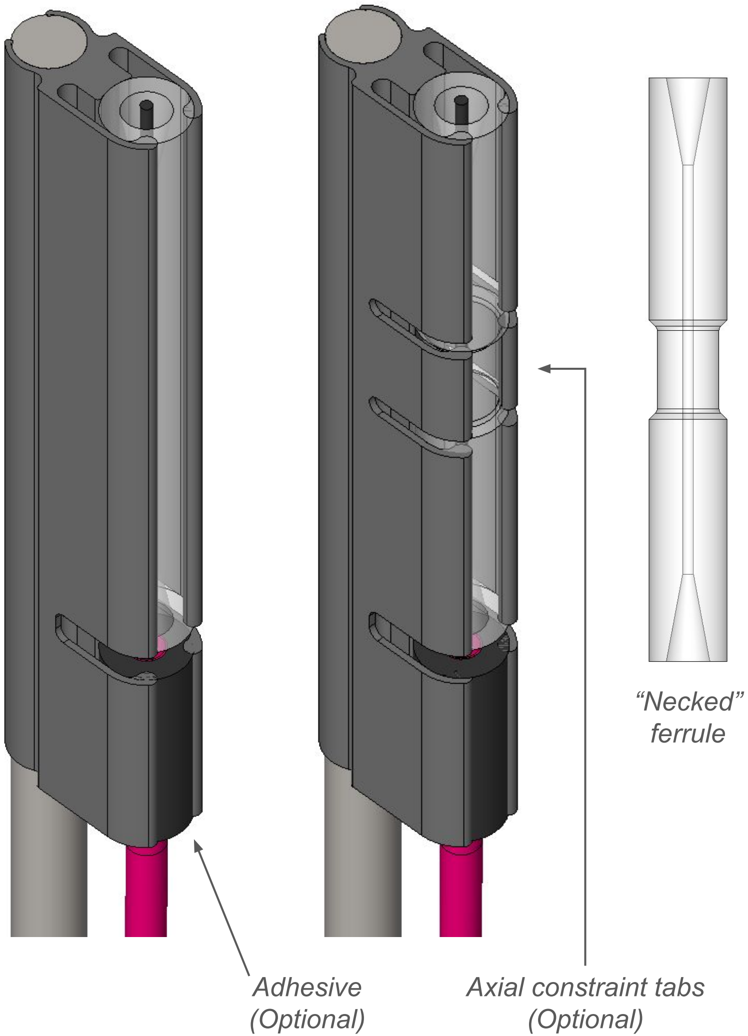


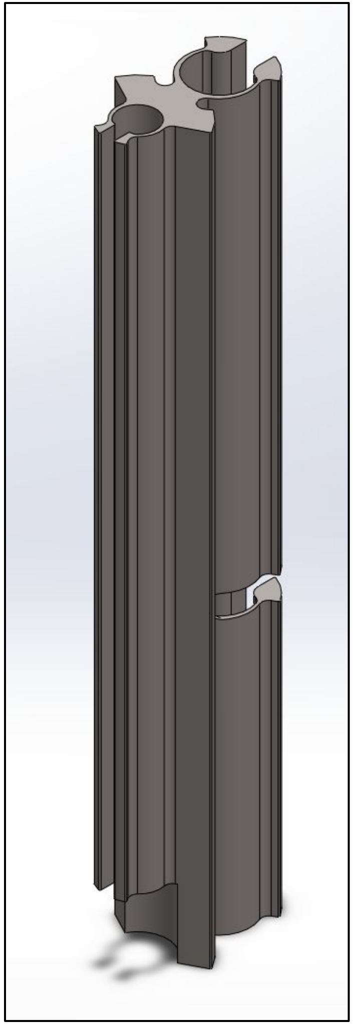
Fiber Arm A:
V-Block with Ovalized Press-Fit

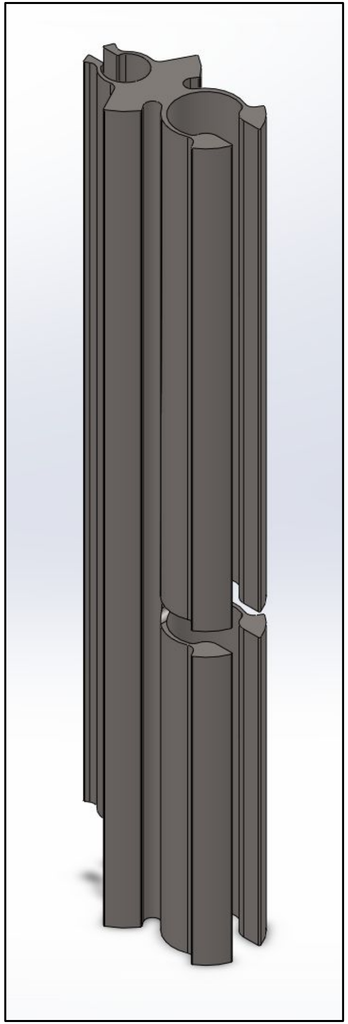


Fiber Arm B:
EDM with Spring Arms

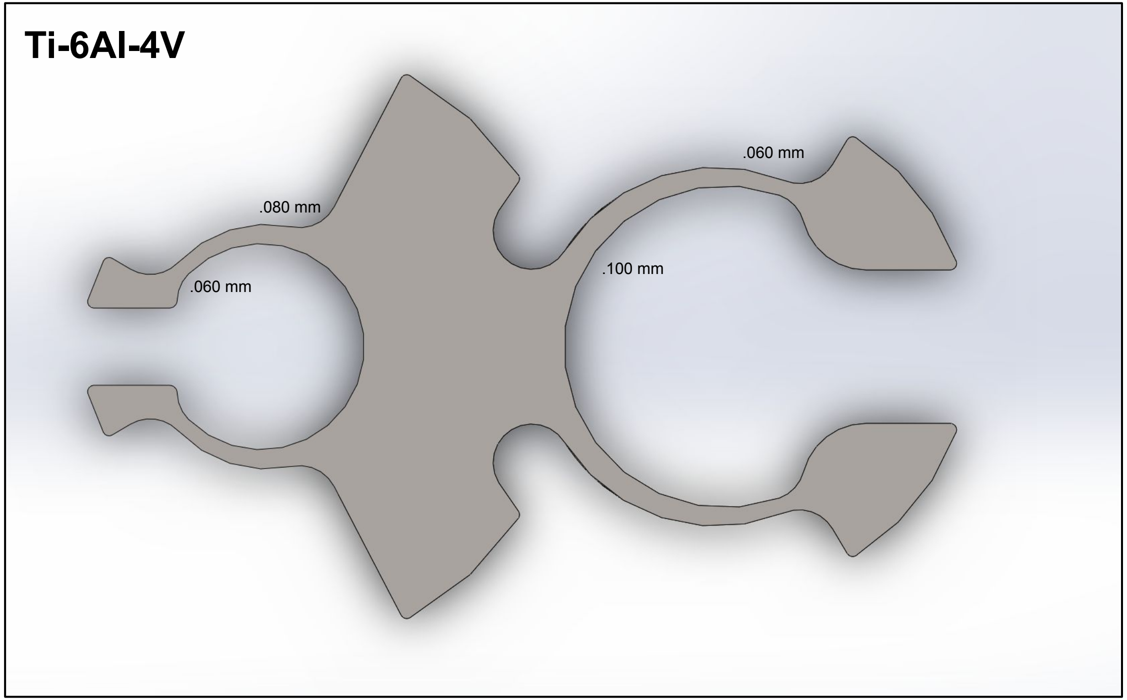




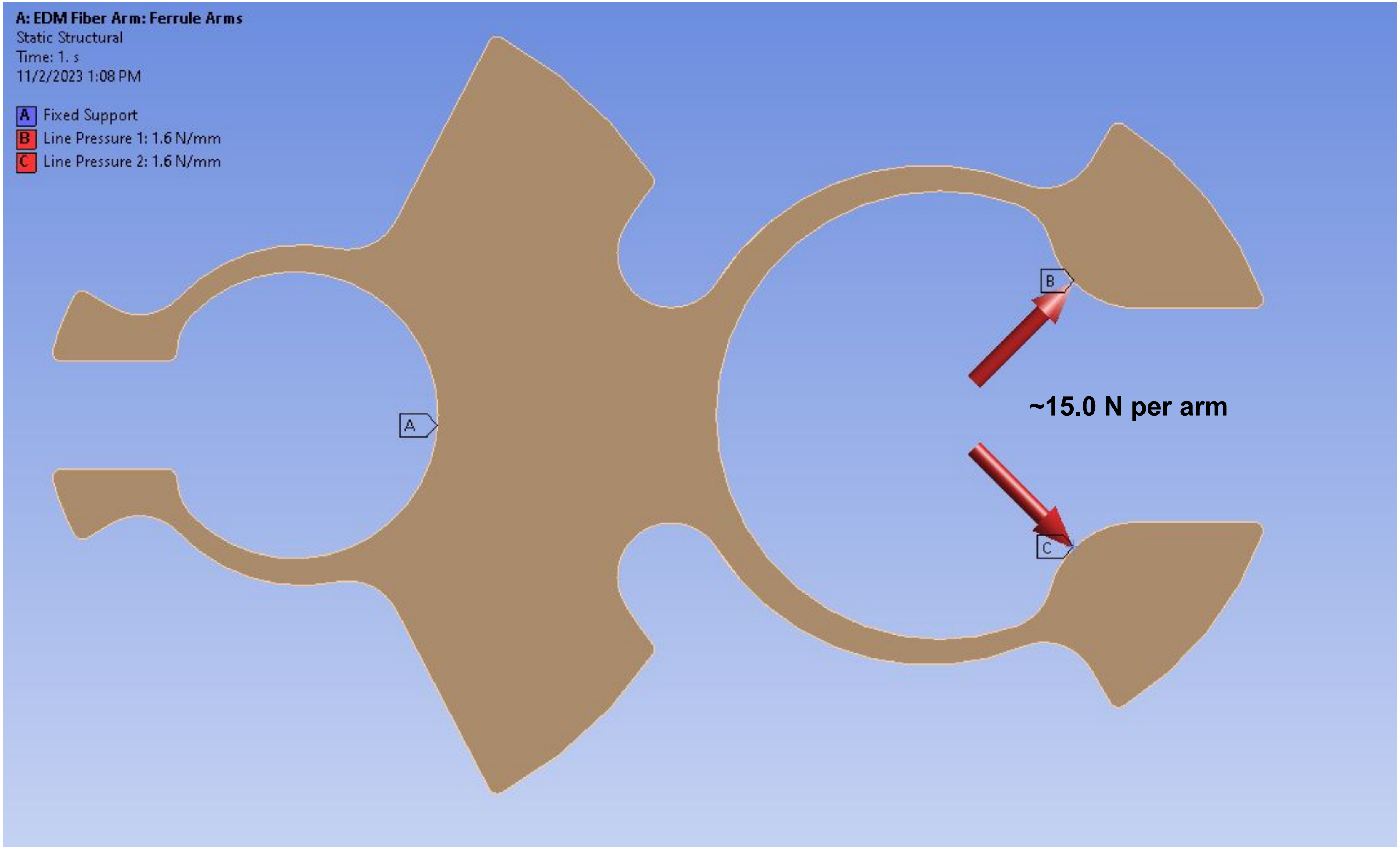


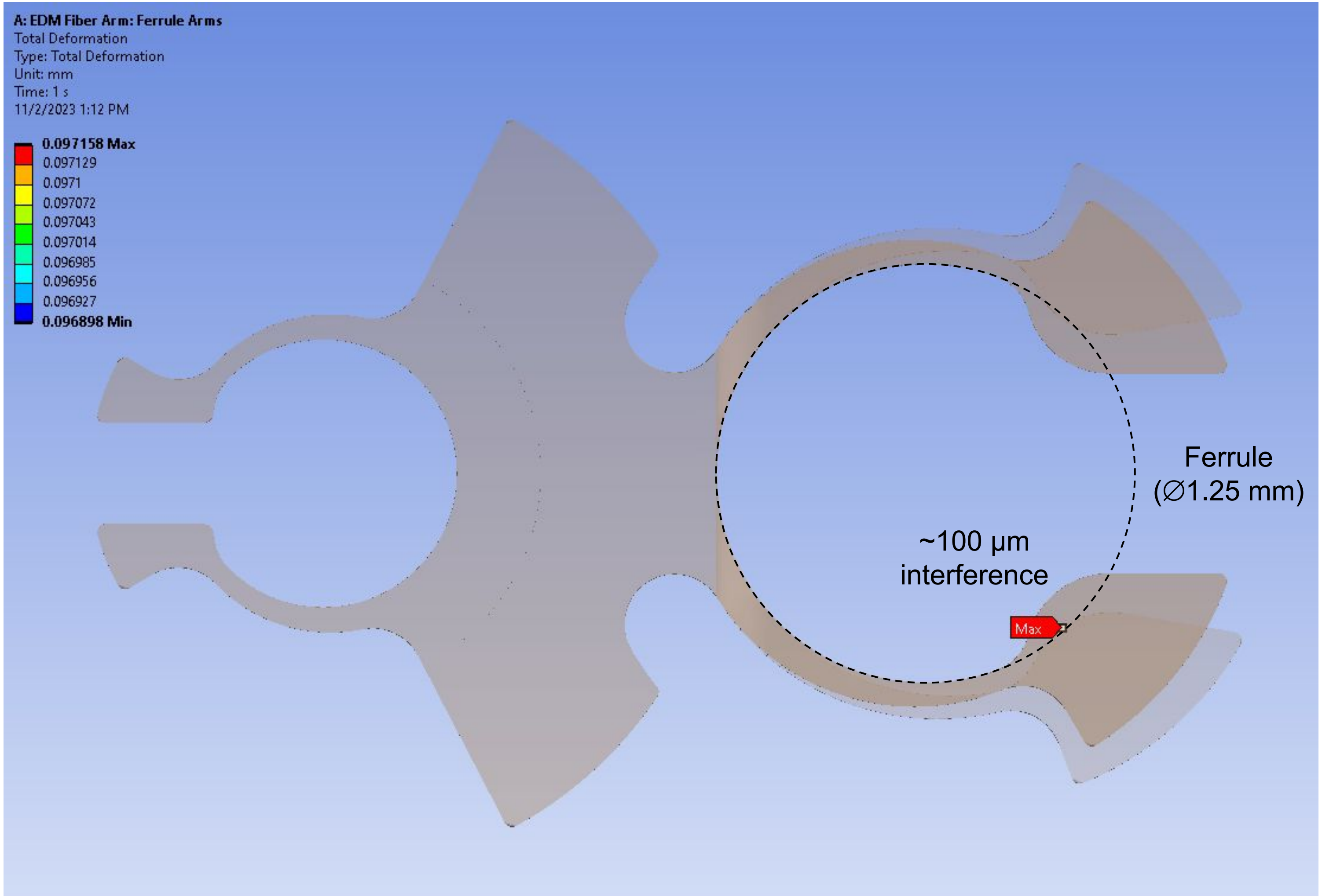


Prototype EDM Fiber Arm

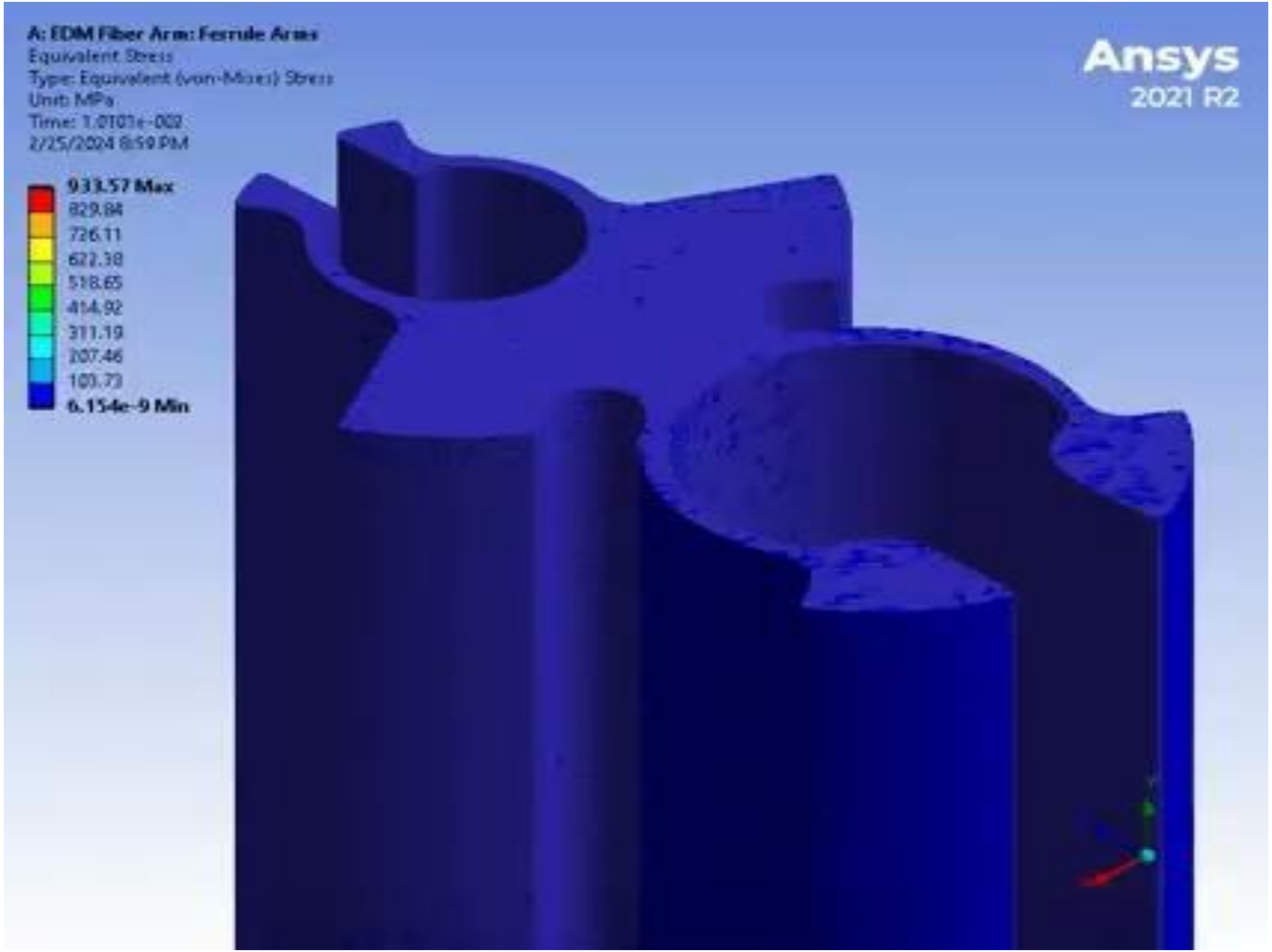


DE-1000-0460A

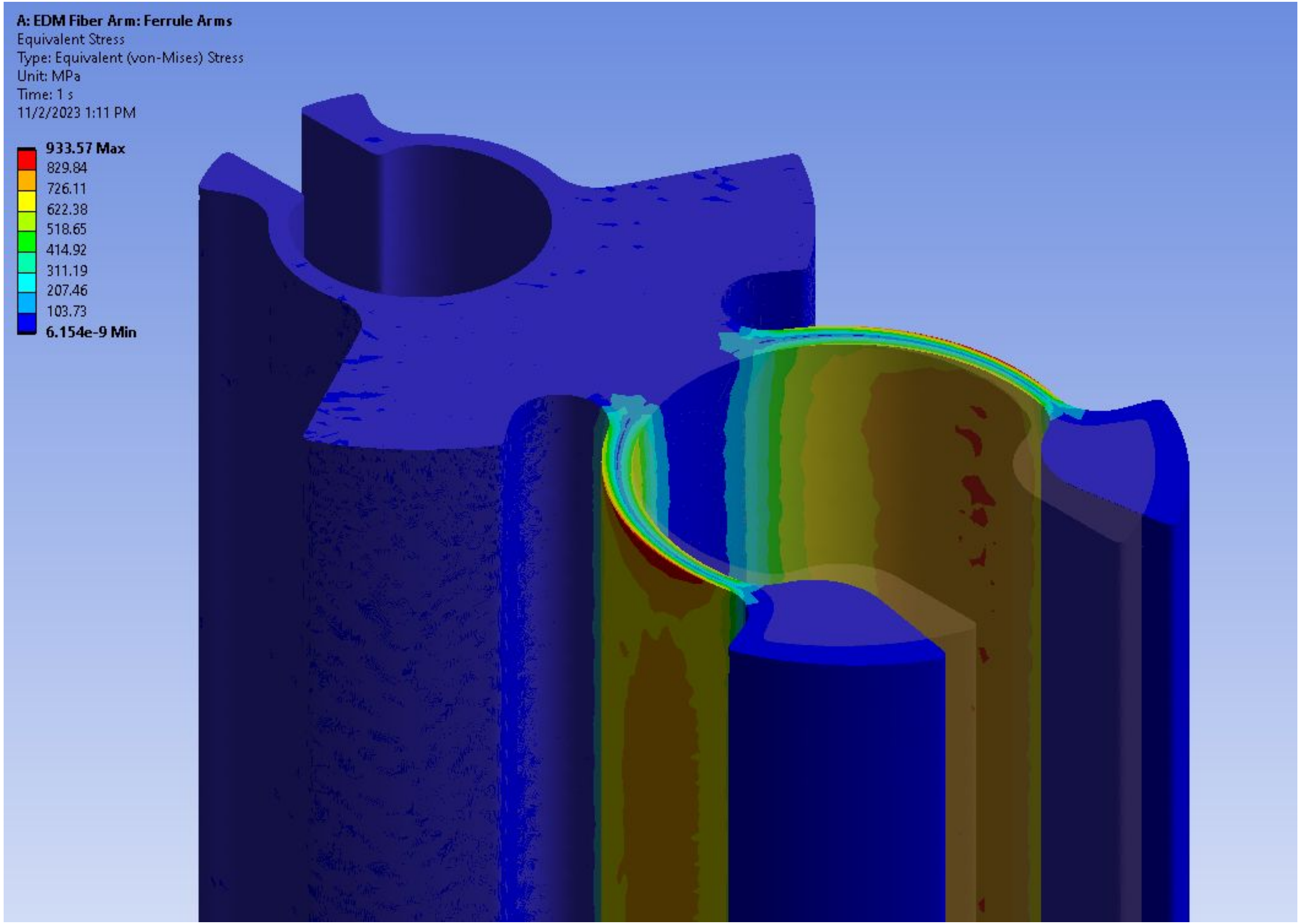

A: EDM Fiber Arm: Ferrule Arms
Static Structural
Time: 1. s
11/2/2023 1:08 PM
A Fixed Support
B Line Pressure 1: 1.6 N/mm
C Line Pressure 2: 1.6 N/mm
B
A
~15.0 N per arm
C



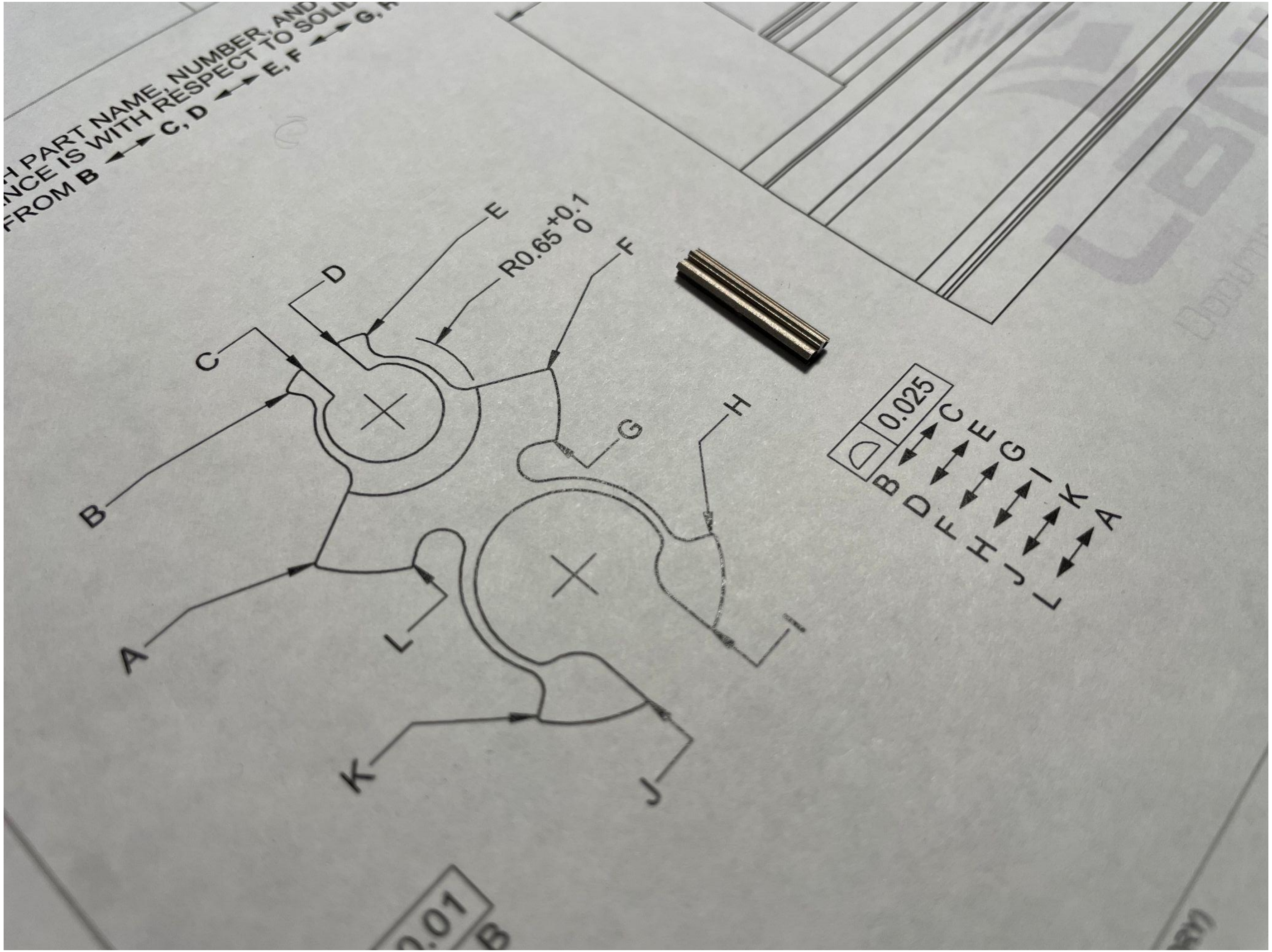
A: EDM Fiber Arm: Ferrule Arms
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1 s
11/2/2023 1:12 PM
0.097158 Max
0.097129
0.0971
0.097072
0.097043
0.097014
0.096985
0.096956
0.096927
0.096898 Min
Ferrule
(∅1.25 mm)
~100 μm
interference
Max



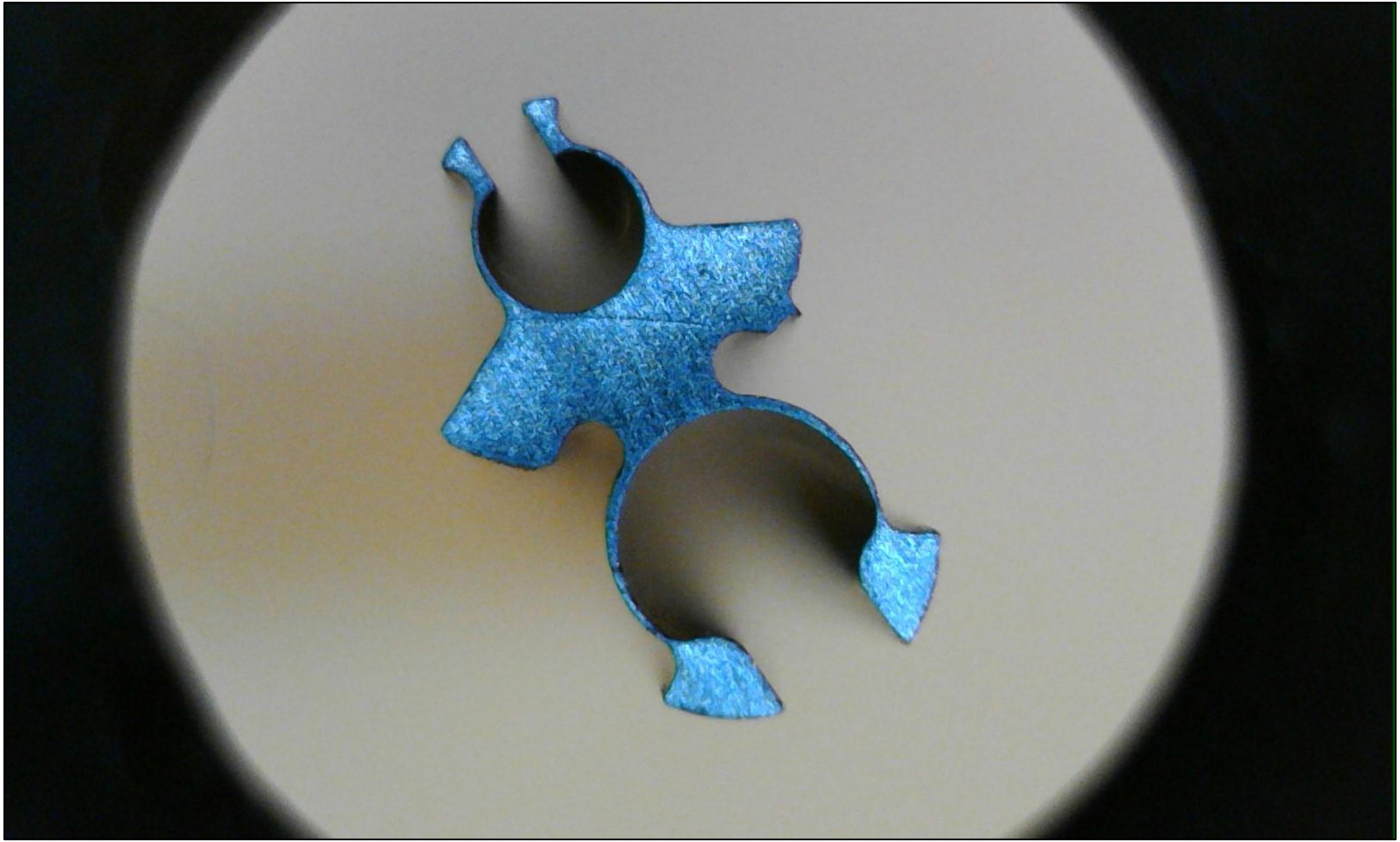
Arms are tapered to distribute stress

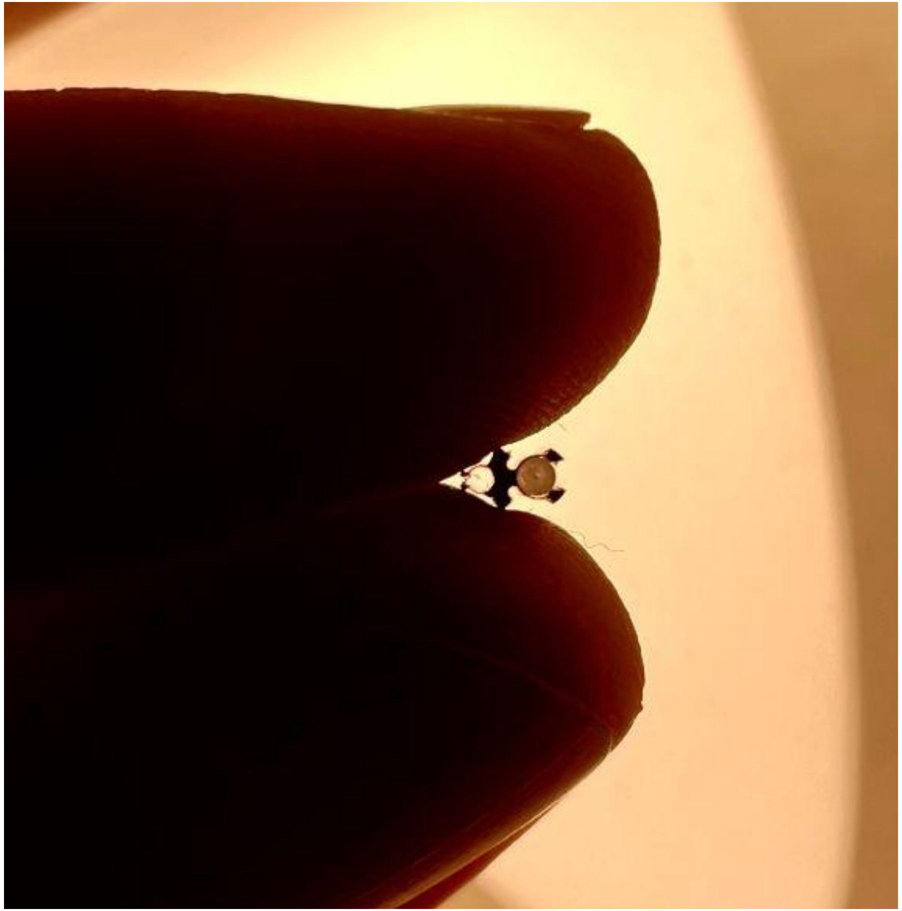
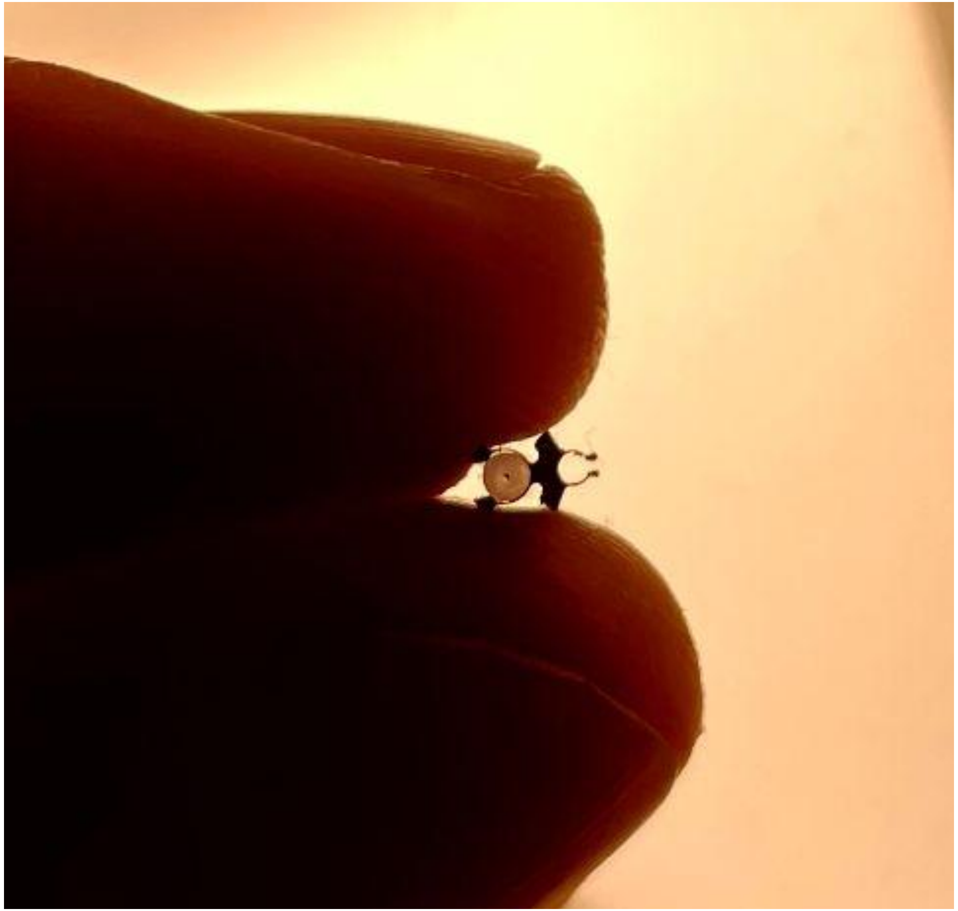


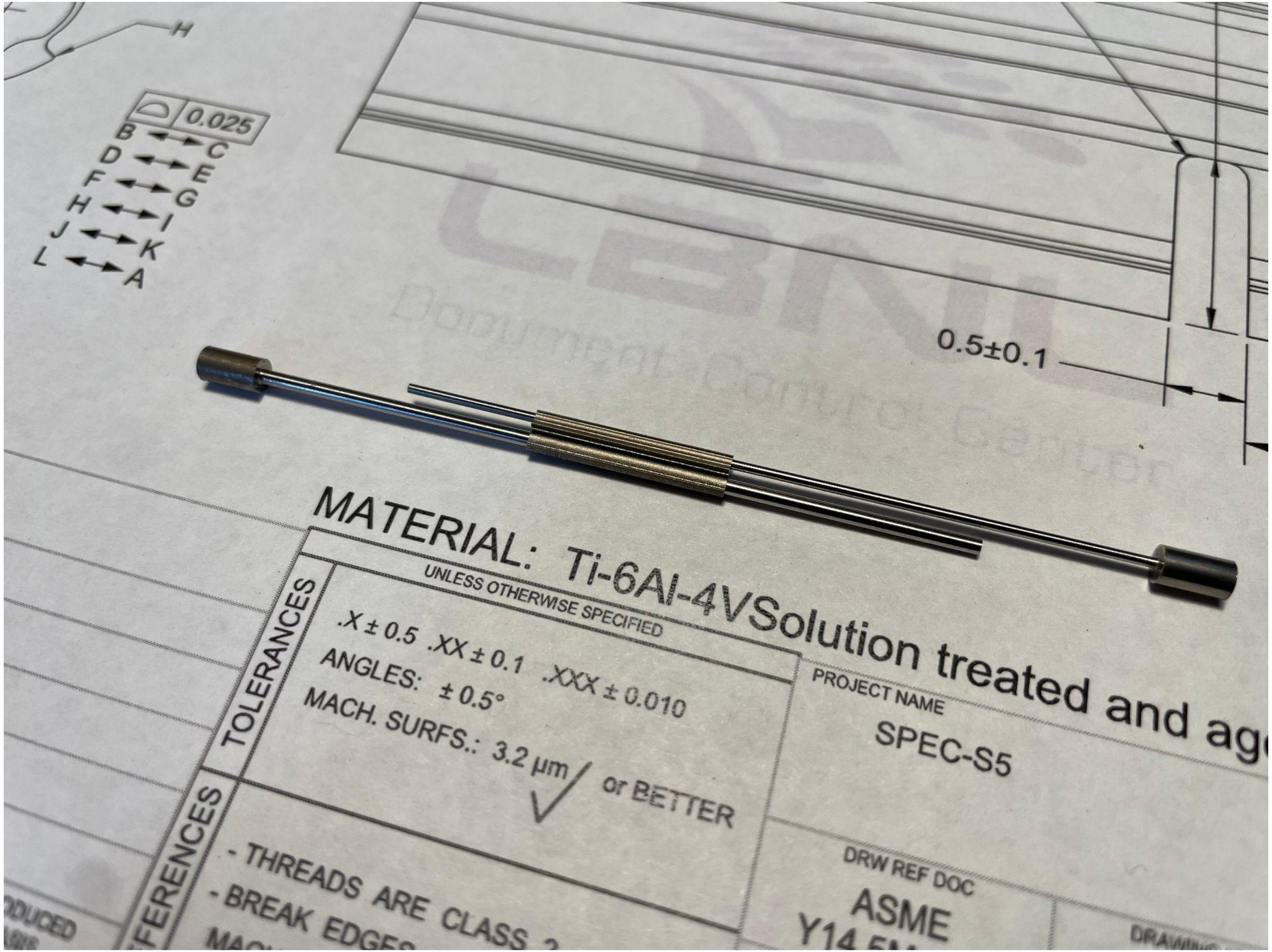
Arms are tapered to distribute stress



H PART NAME, NUMBER, AND
NCE IS WITH RESPECT TO SOLI
FROM B ↔ C, D ↔ E, F ↔ G, H
R0.65 +0.1 0
A
B
C
D
E
F
G
H
I
J
K
L
0.025
B ↔ C
D ↔ E
F ↔ G
H ↔ I
J ↔ K
L ↔ A
0.01
B

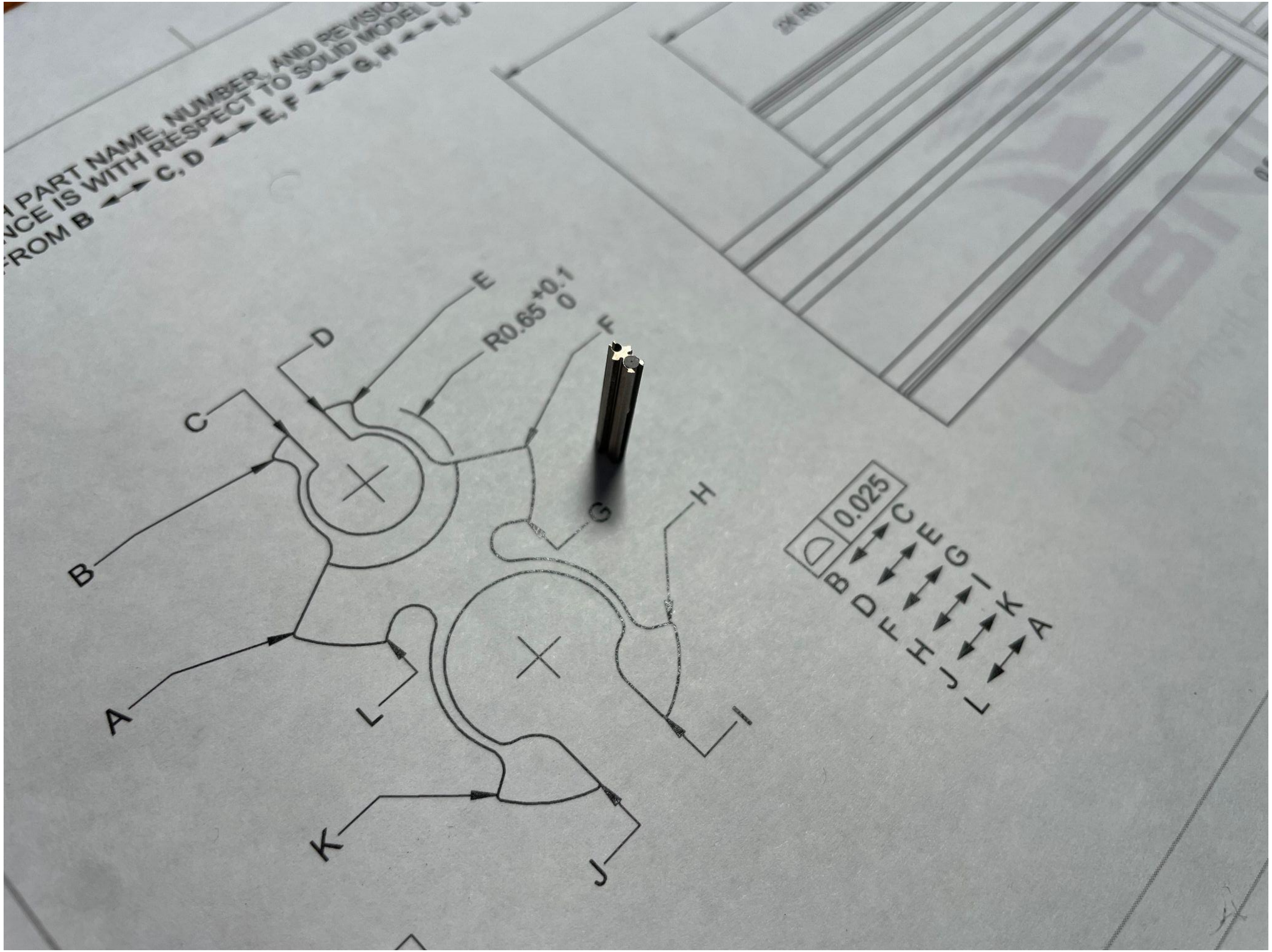




Relatively straightforward to QA

- Angular alignment
- Insertion forces



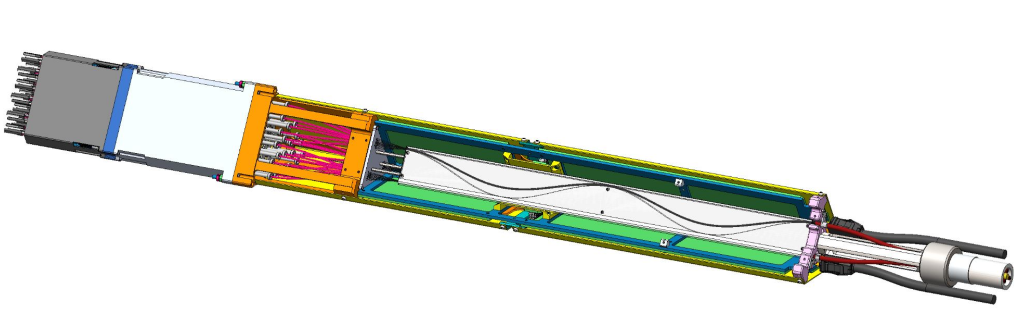
Stiction:

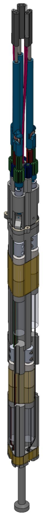
Ferrule

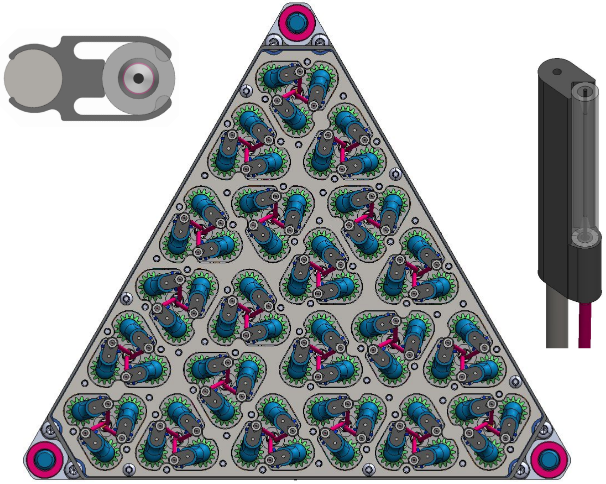
~3.1 N (0.7 lbf)

Shaft

~0.7 N (0.2 lbf)

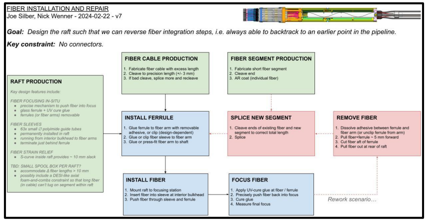


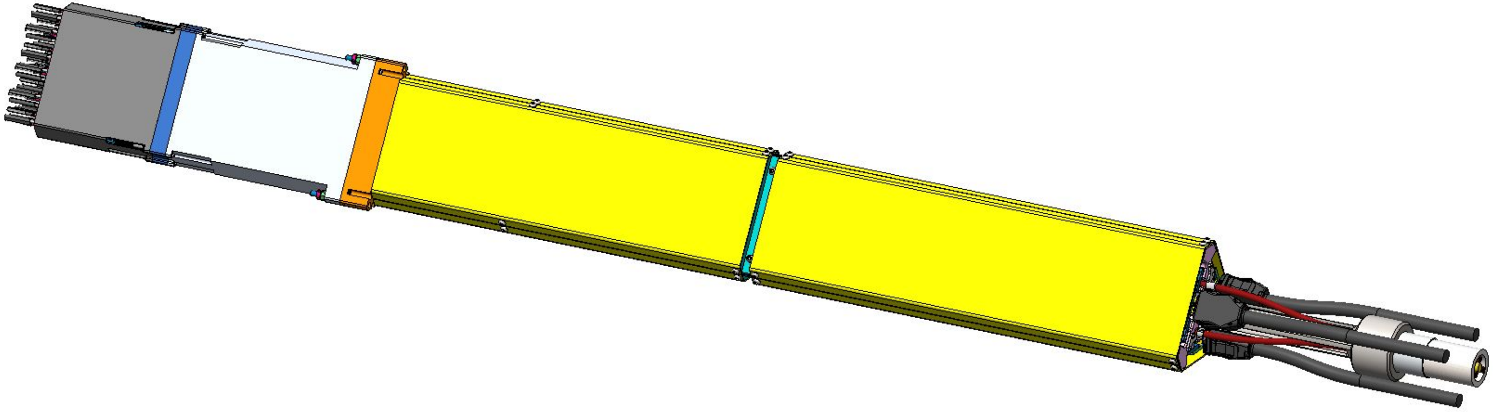




Summary

- Raft and positioner conceptual designs are well-developed
- Reversible fiber installation/repair processes are well-defined
- Several key systems have been prototyped
- **Next steps:** Build and test functional prototype raft





Acknowledgements

Joseph Silber[1], Travis Mandeville[2], David Schlegel[1], William Van Shourt[3], Ricardo Araujo[4], Charles Baltay[5], Robert Besuner[1], Emily Farr[6], Julien Guy[1], Jean-Paul Kneib[4], Maxime Rombach[4], Claire Poppett[3], Michael Schubnell[7], Markus Thurneysen[4], Sarah Tuttle[2], Greg Tarlè[7]

[1]Lawrence Berkeley National Laboratory (LBNL)
[2]University of Washington
[3]Space Sciences Laboratory (SSL)
[4]École Polytechnique Fédérale de Lausanne (EPFL)
[5]Yale University
[6]University of Colorado
[7]University of Michigan

References

- *Specification for high density fiber robot raft modules* (2024)
  https://zenodo.org/records/10688871

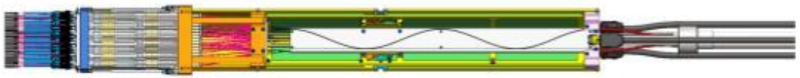
- *25,000 optical fiber positioning robots for next-generation cosmology* (2022)
  https://arxiv.org/abs/2212.07908

- *The Robotic Multi-Object Focal Plane System of the Dark Energy Spectroscopic Instrument (DESI)* (2022)
  https://arxiv.org/abs/2205.09014

Appendix

FIBER INSTALLATION AND REPAIR

Joe Silber, Nick Wenner - 2024-02-22 - v7



Goal: *Design the raft such that we can reverse fiber integration steps, i.e. always able to backtrack to an earlier point in the pipeline.*

Key constraint: *No connectors.*

RAFT PRODUCTION

Key design features include:

FIBER FOCUSING IN-SITU
- *precise mechanism to push fiber into focus*
- *glass ferrule + UV cure glue*
- *ferrules (or fiber arms) removable*

FIBER SLEEVES
- *63x small ∅ polyimide guide tubes*
- *permanently installed in raft*
- *running from interior bulkhead to fiber arms*
- *terminate just behind ferrule*

FIBER STRAIN RELIEF
- *S-curve inside raft provides ~ 10 mm slack*

TBD: SMALL SPOOL BOX PER RAFT?
- *accommodate Δ fiber lengths > 10 mm*
- *possibly include a DESI-like axial foam-and-combs constraint so that long fiber (in cable) can't tug on segment within raft*

FIBER CABLE PRODUCTION

1. Fabricate fiber cable with excess length
2. Cleave to precision length (+/- 3 mm)
3. If bad cleave, splice more and recleave

FIBER SEGMENT PRODUCTION

1. Fabricate short fiber segment
2. Cleave end
3. AR coat (individual fiber)

INSTALL FERRULE

1. Glue ferrule to fiber arm with removable adhesive, or clip (design-dependent)
2. Glue or clip fiber sleeve to fiber arm
3. Glue or press-fit fiber arm to shaft

SPLICE NEW SEGMENT

1. Cleave ends of existing fiber and new segment to correct total length
2. Splice

REMOVE FIBER

1. Dissolve adhesive between ferrule and fiber arm (or unclip ferrule from arm)
2. Pull fiber+ferrule ~ 5 mm forward
3. Cut fiber aft of ferrule
4. Pull fiber out at rear of raft

INSTALL FIBER

1. Mount raft to focusing station
2. Insert fiber into sleeve at interior bulkhead
3. Push fiber through sleeve and ferrule

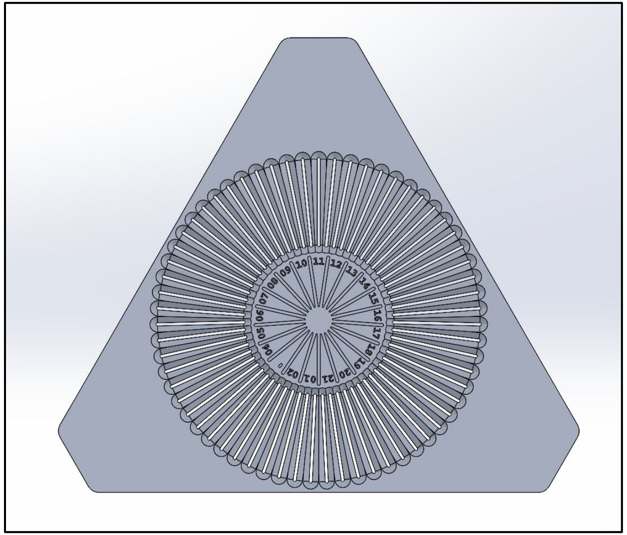
FOCUS FIBER

1. Apply UV-cure glue at fiber / ferrule
2. Precisely push fiber back into focus
3. Cure glue
4. Measure final focus

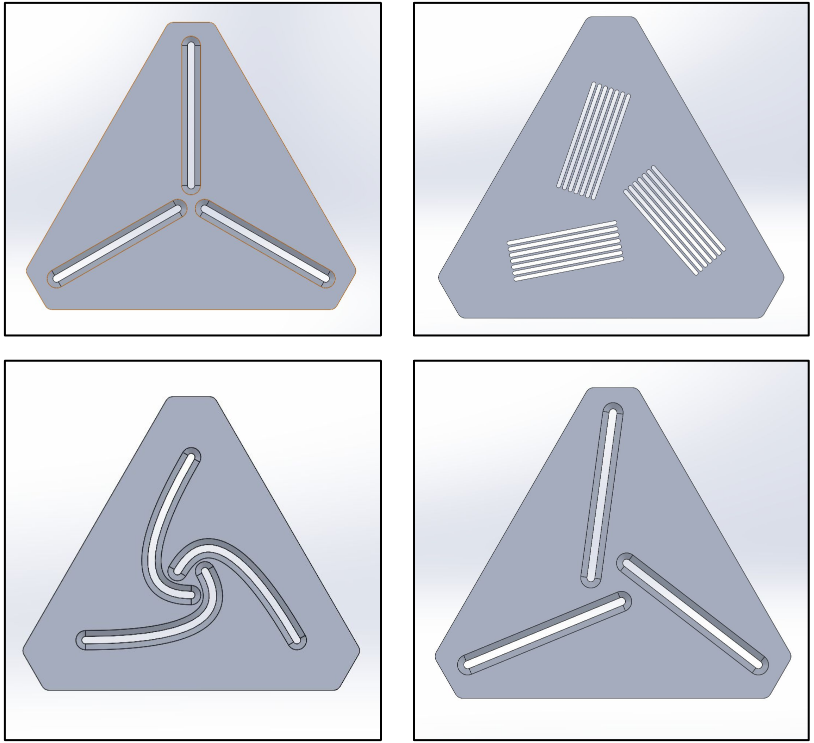
Rework scenario…

Alternative Fiber Strain Relief Designs

Fiber Guide Examples

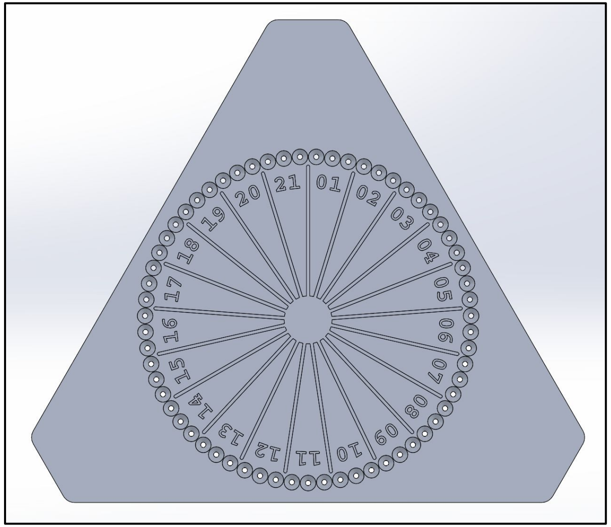


Individual Fibers

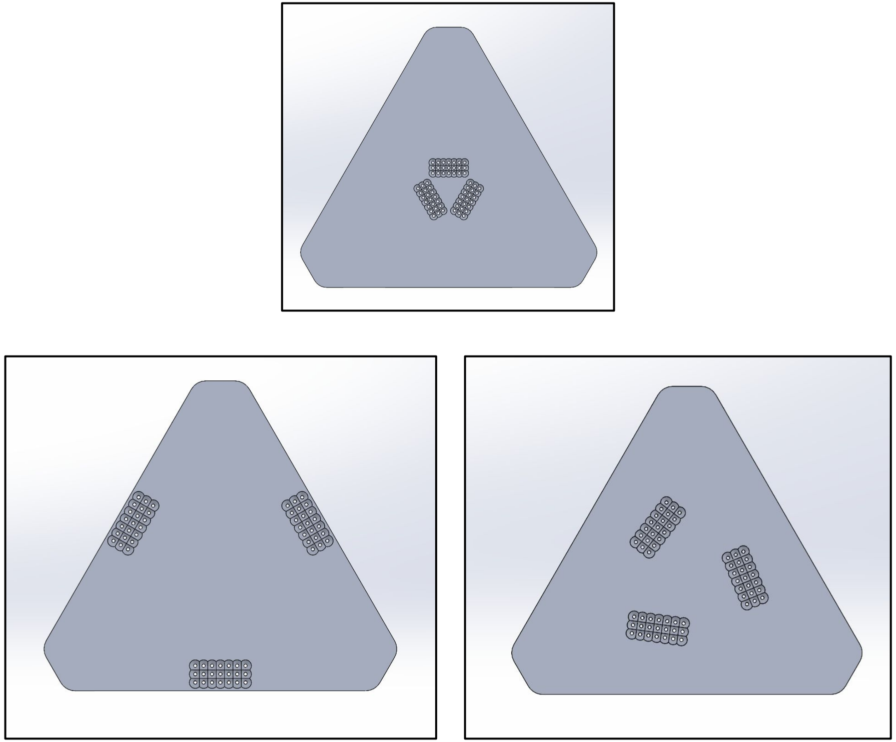


Bundled Fibers (21 ea)

Forward Bulkhead Examples

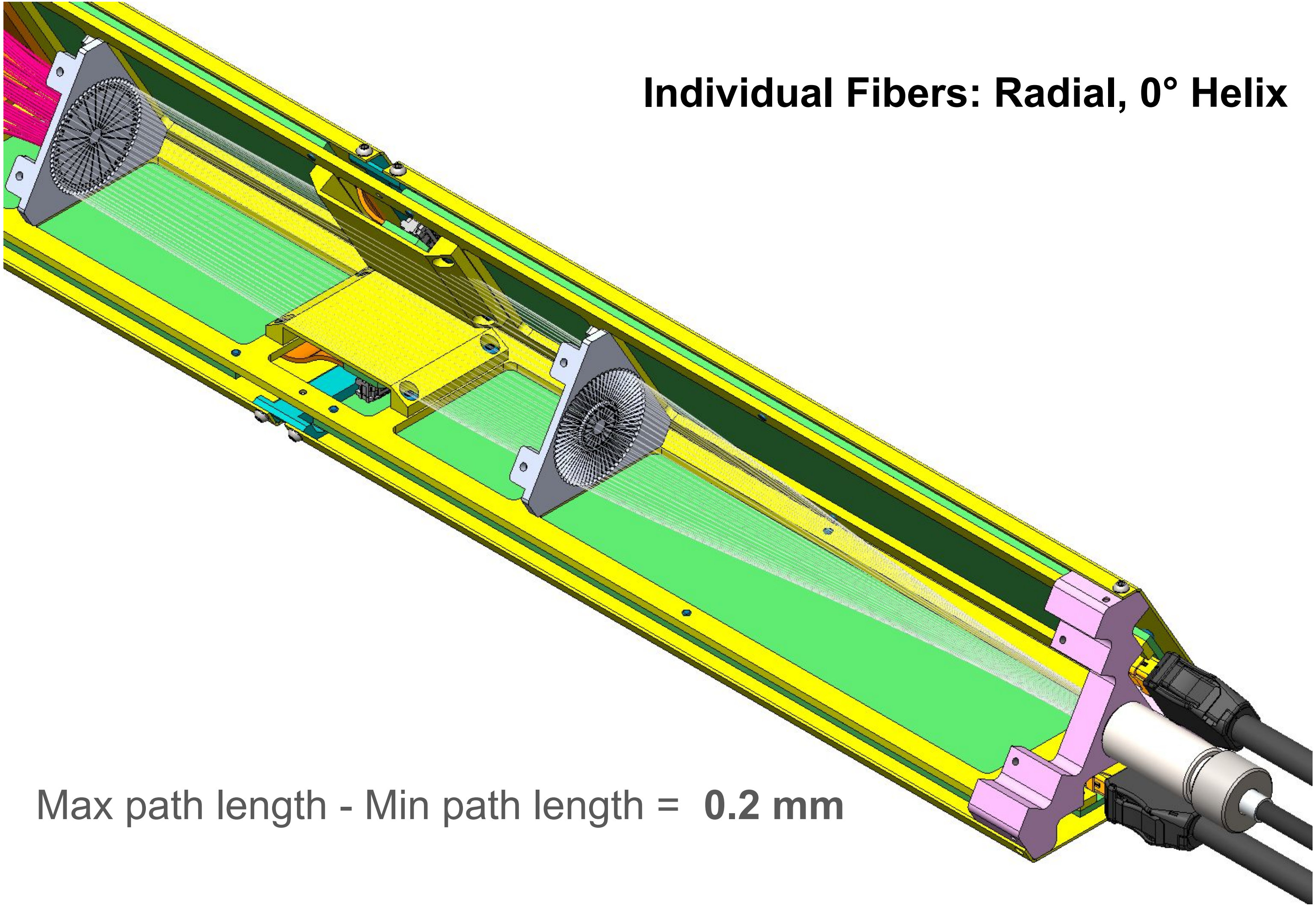


Individual Fibers



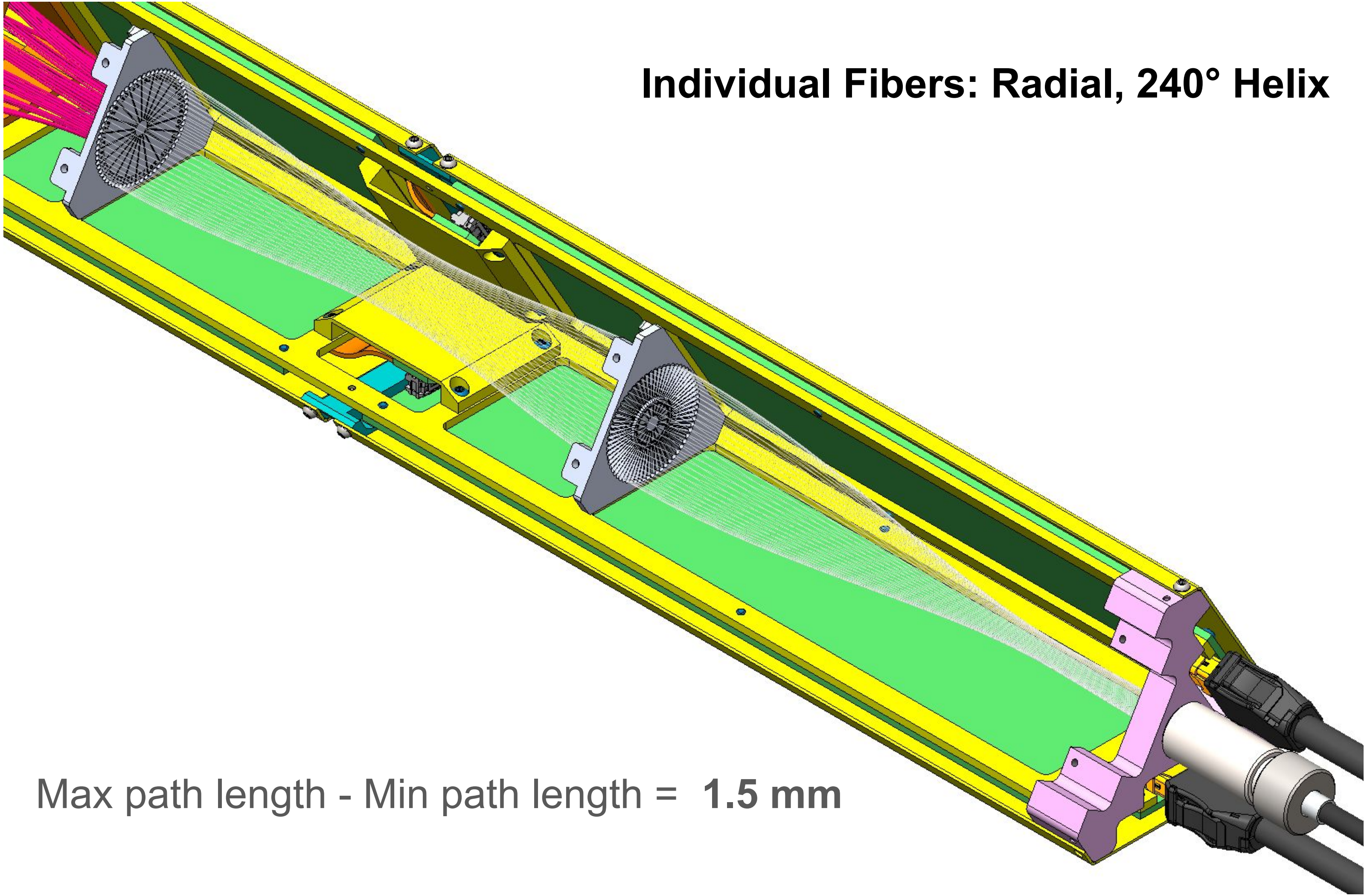
Bundled Fibers (21 ea)

Individual Fibers: Radial, 0° Helix



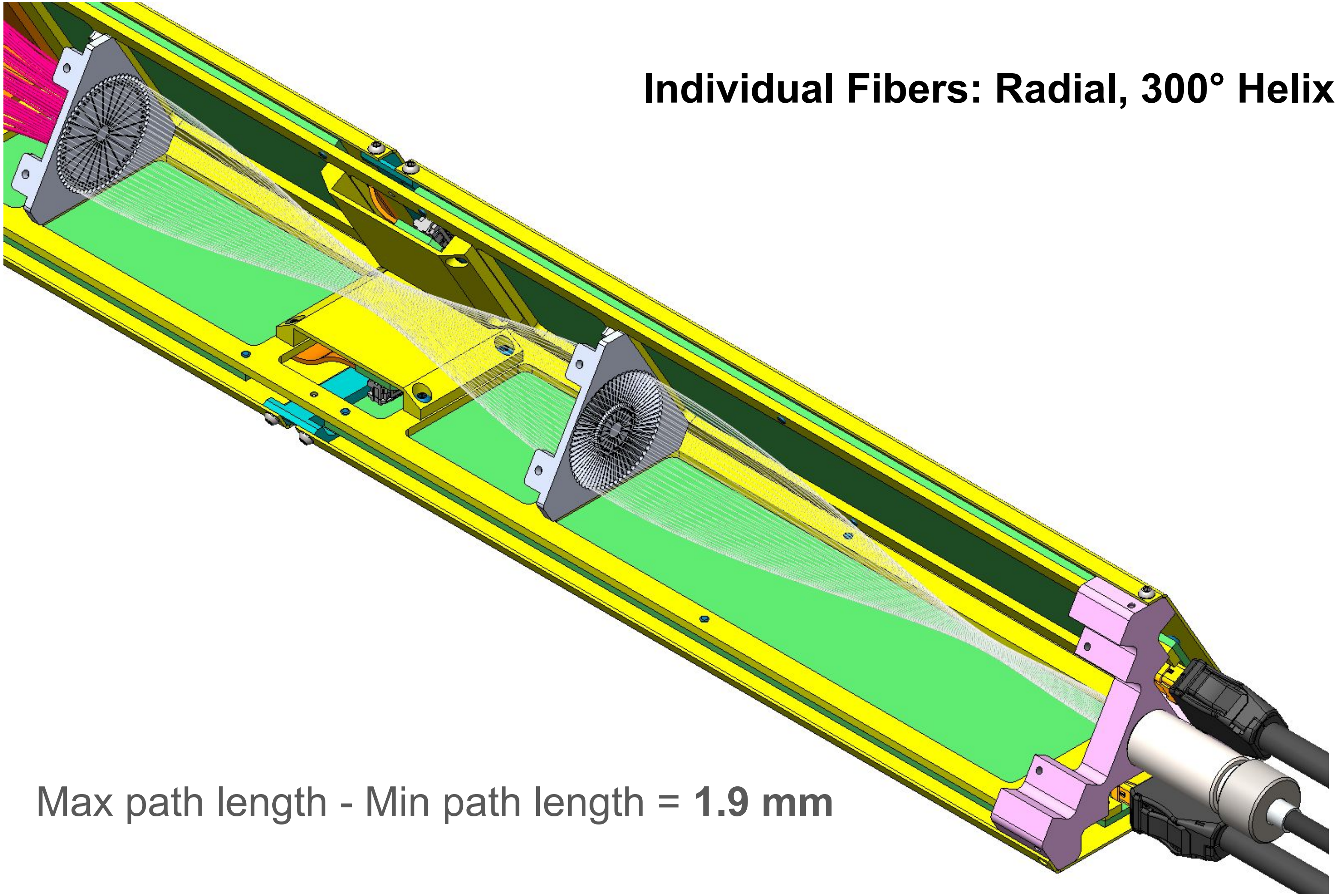
Max path length - Min path length = **0.2 mm**

Individual Fibers: Radial, 240° Helix



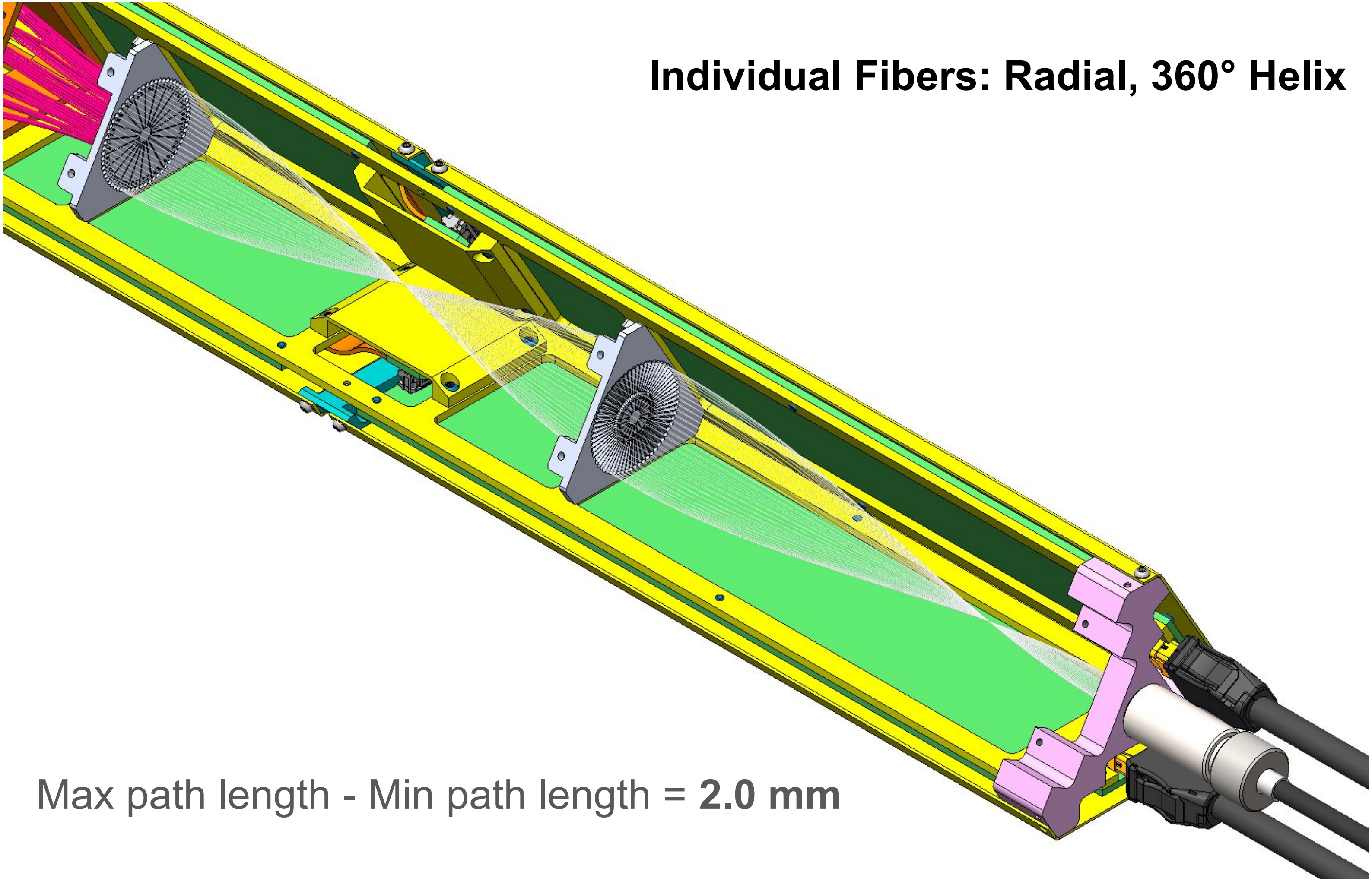
Max path length - Min path length = **1.5 mm**

Individual Fibers: Radial, 300° Helix

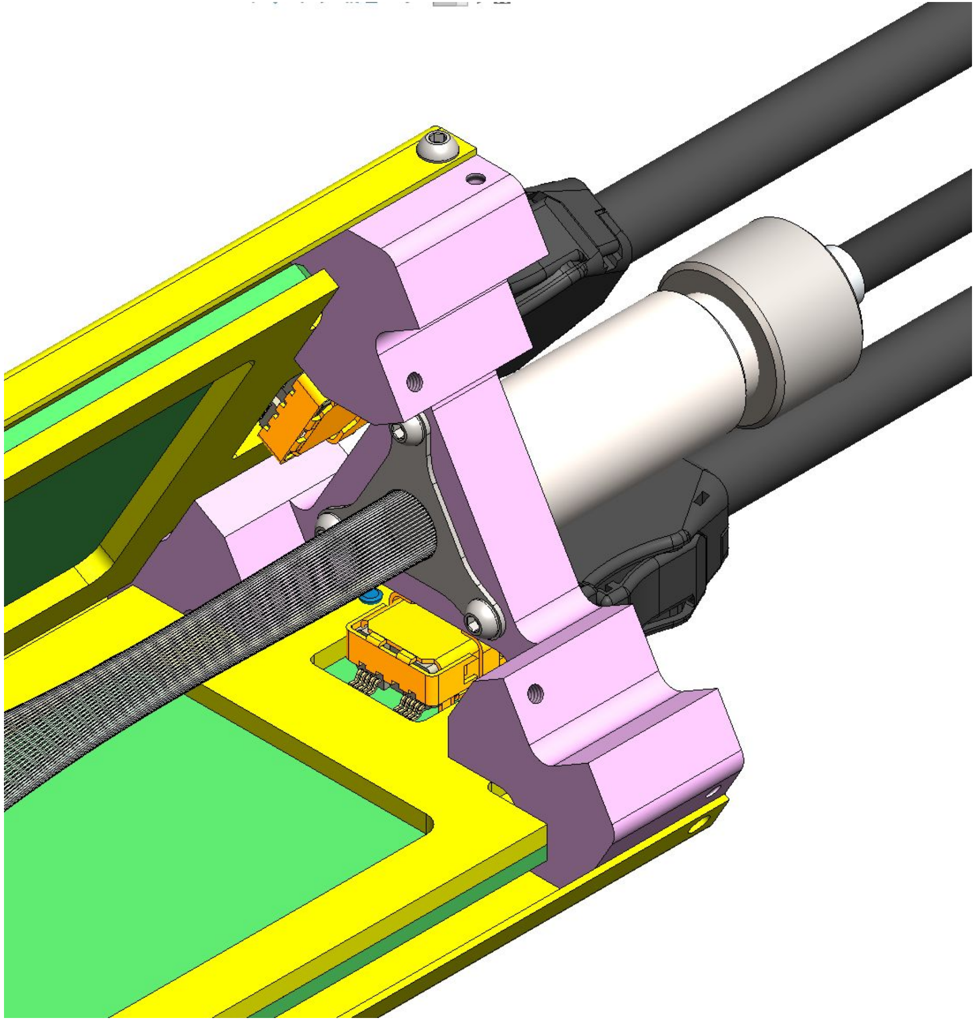


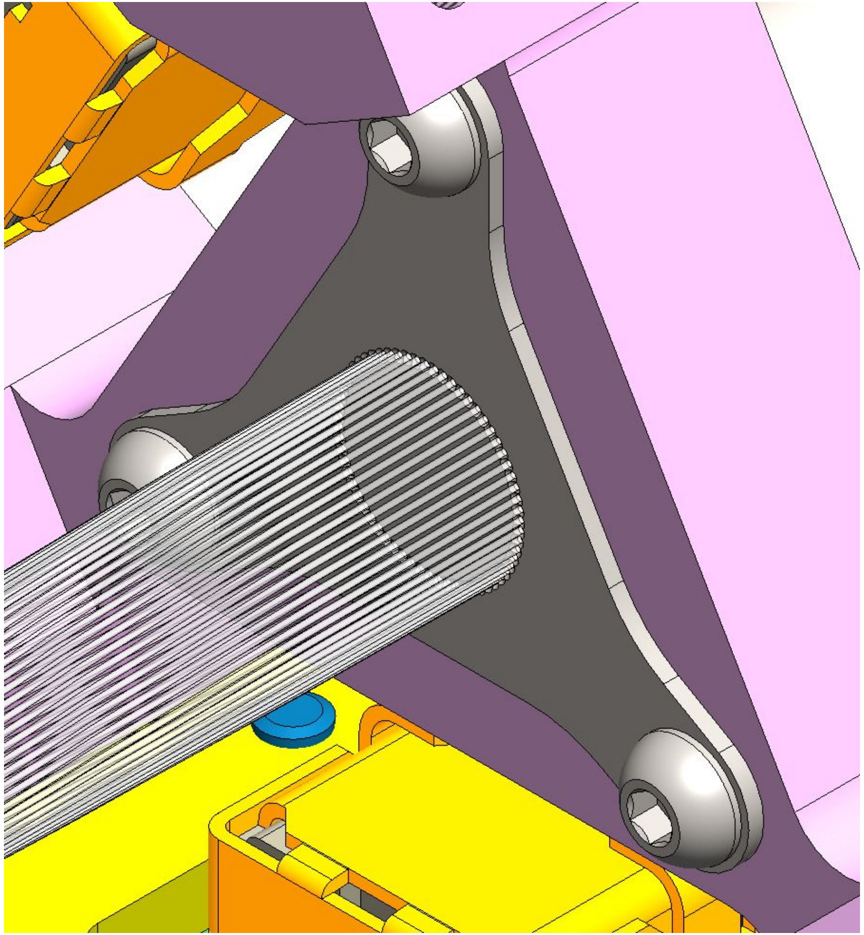
Max path length - Min path length = **1.9 mm**

Individual Fibers: Radial, 360° Helix

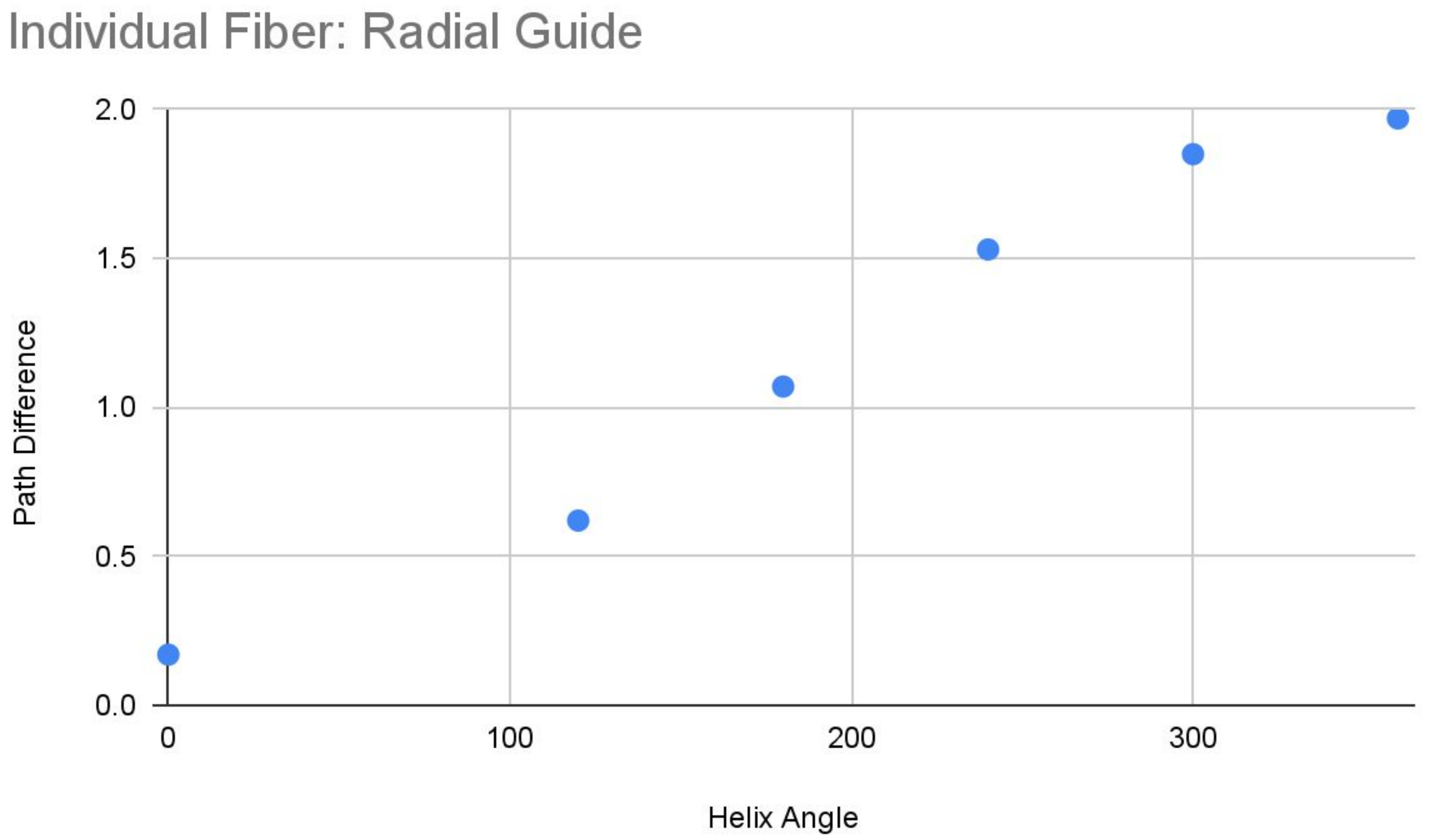


Max path length - Min path length = **2.0 mm**

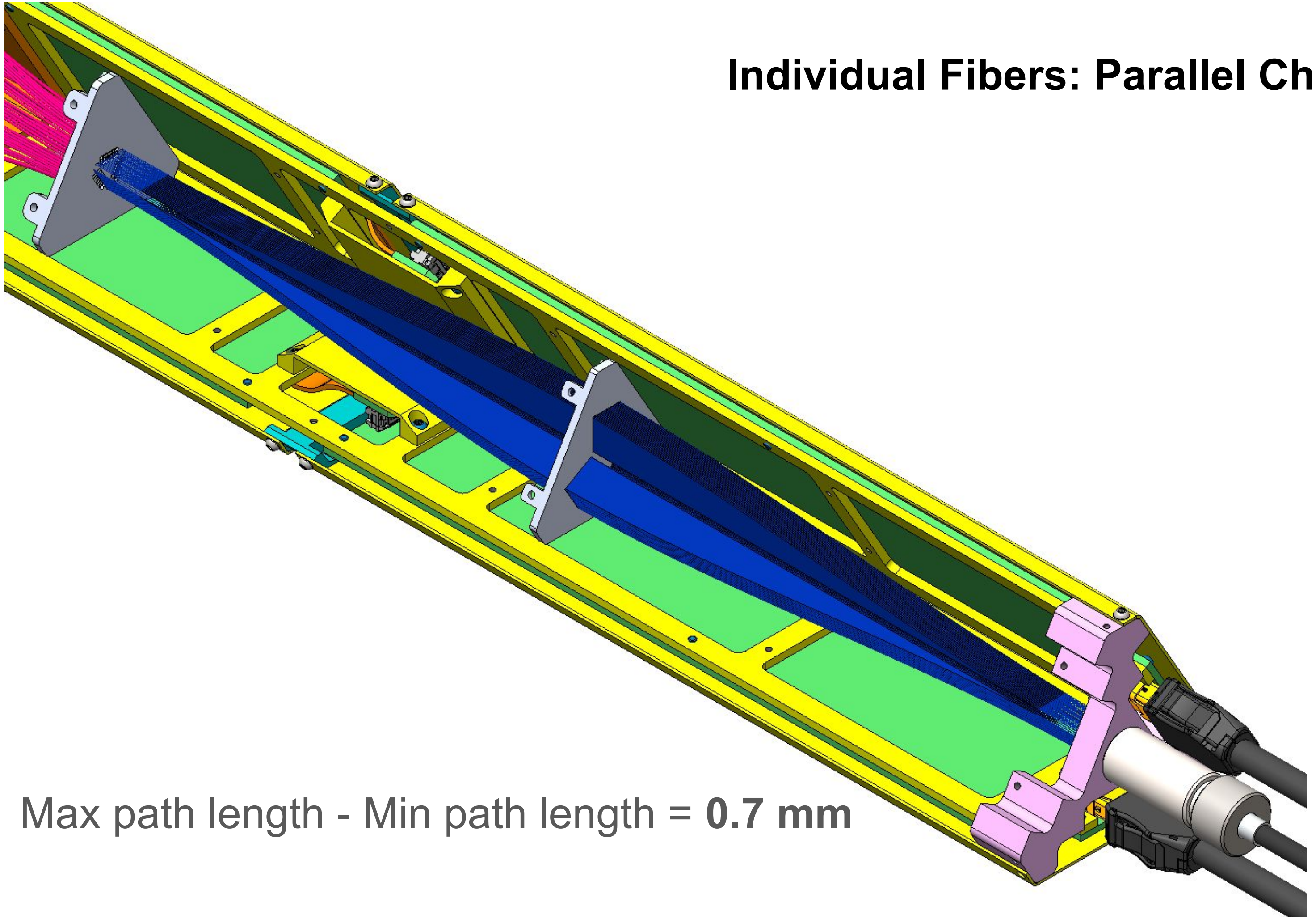





Kathryn Lybarger

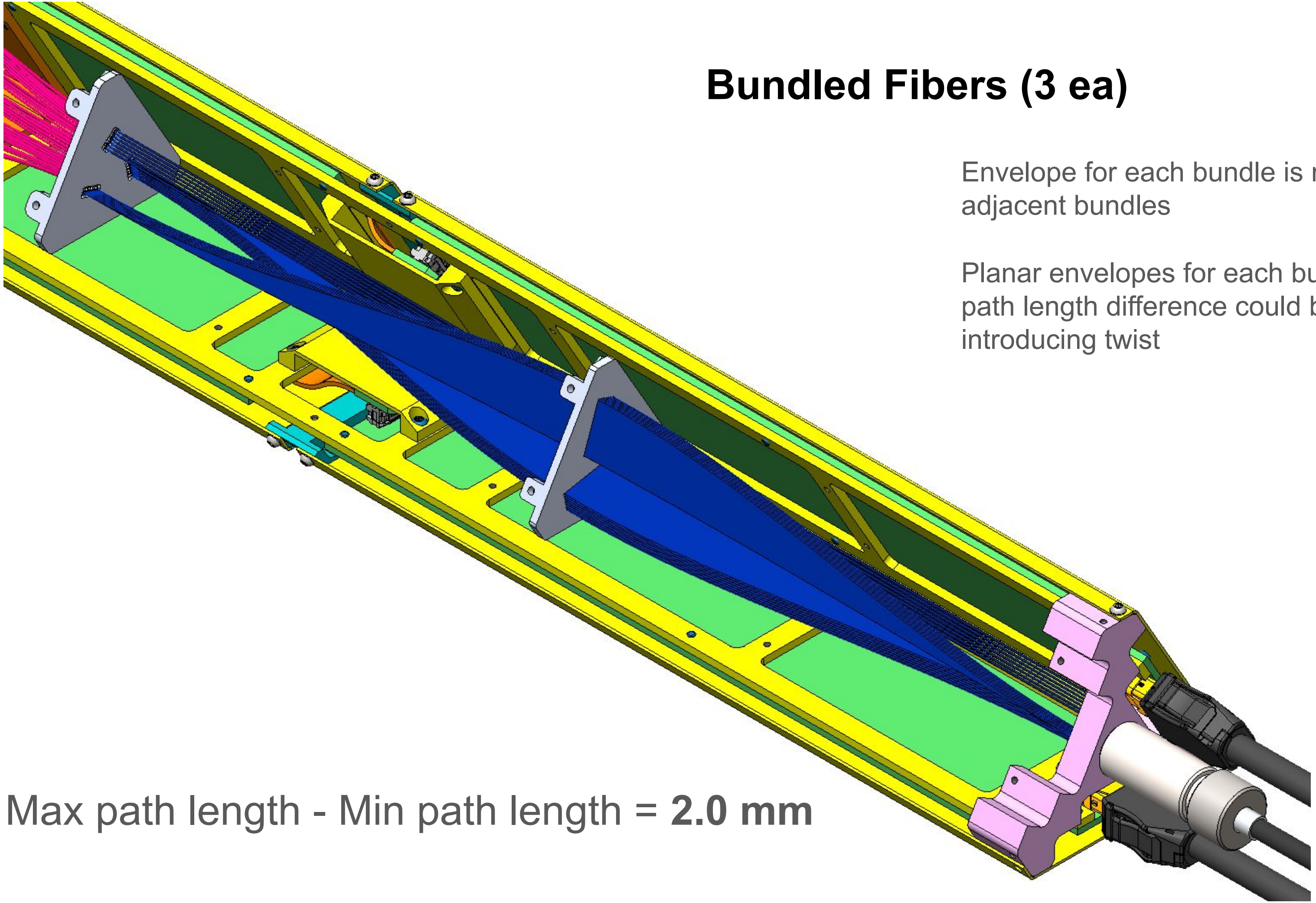

Individual Fiber: Radial Guide
Path Difference
2.0
1.5
1.0
0.5
0.0
0
100
200
300
Helix Angle

Individual Fibers: Parallel Channels



Max path length - Min path length = **0.7 mm**

Bundled Fibers (3 ea)

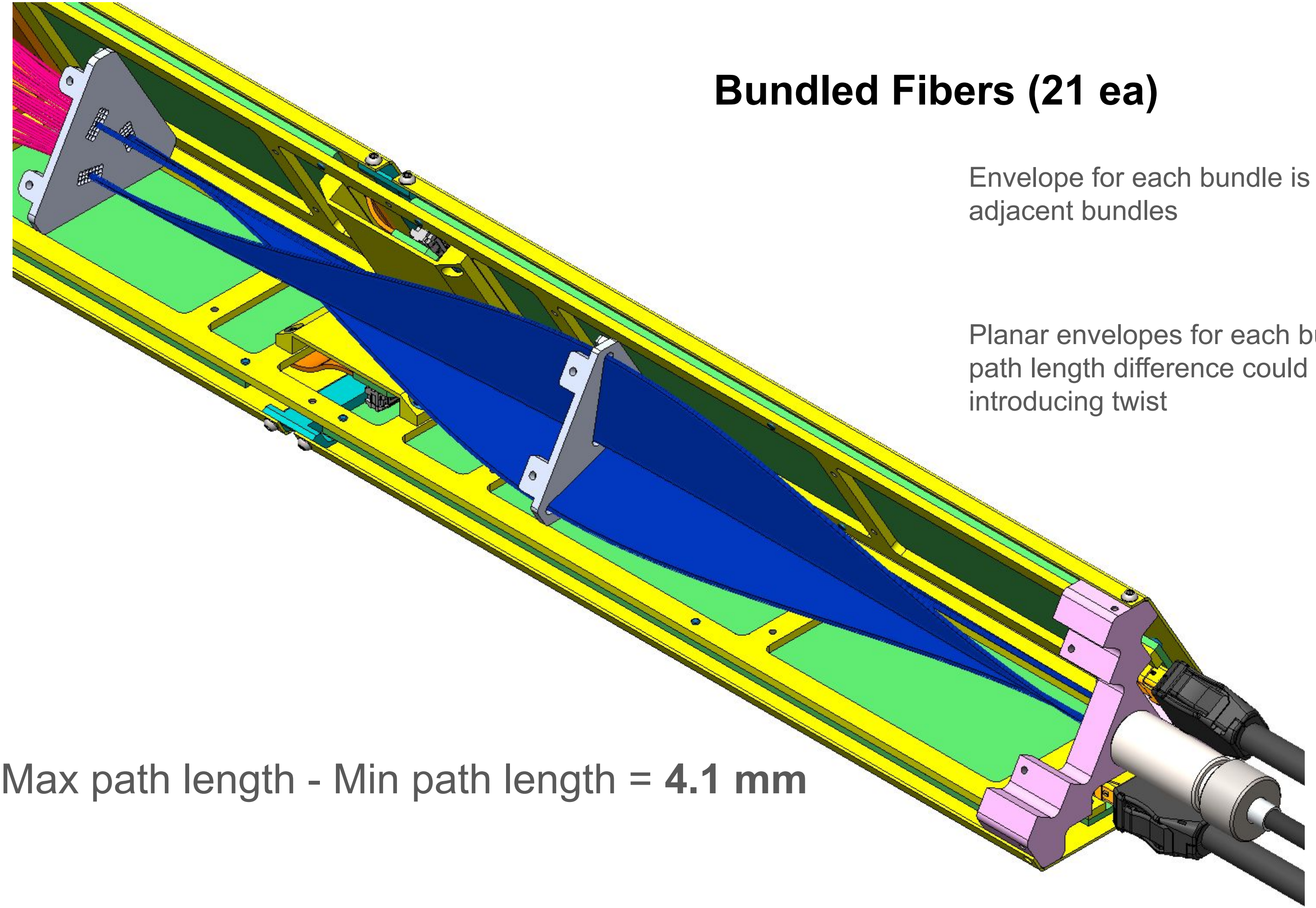


Envelope for each bundle is non-intersecting with adjacent bundles

Planar envelopes for each bundle are shown. Larger path length difference could be achieved by introducing twist

Max path length - Min path length = **2.0 mm**

Bundled Fibers (21 ea)

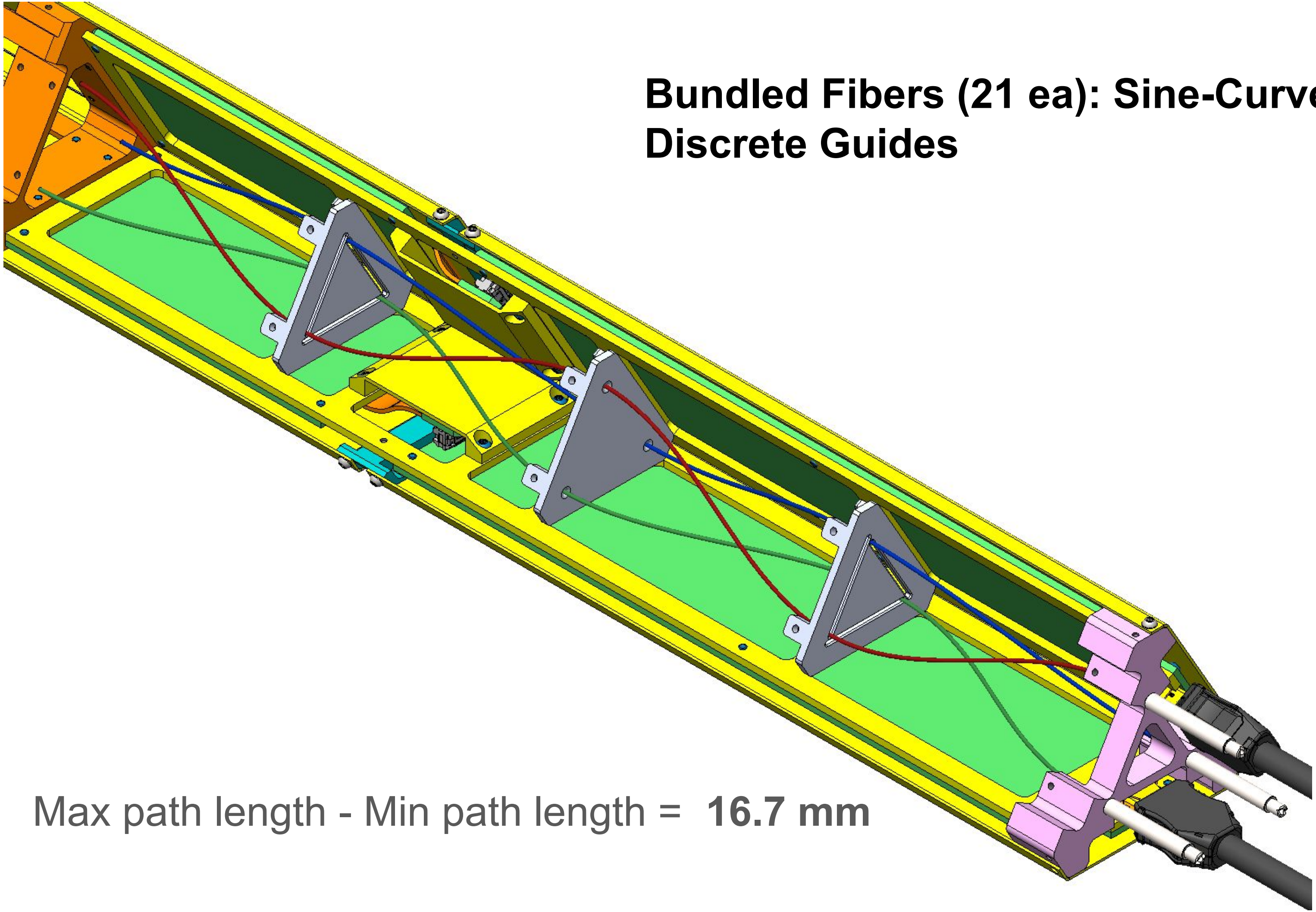


Envelope for each bundle is non-intersecting with adjacent bundles

Planar envelopes for each bundle are shown. Larger path length difference could be achieved by introducing twist

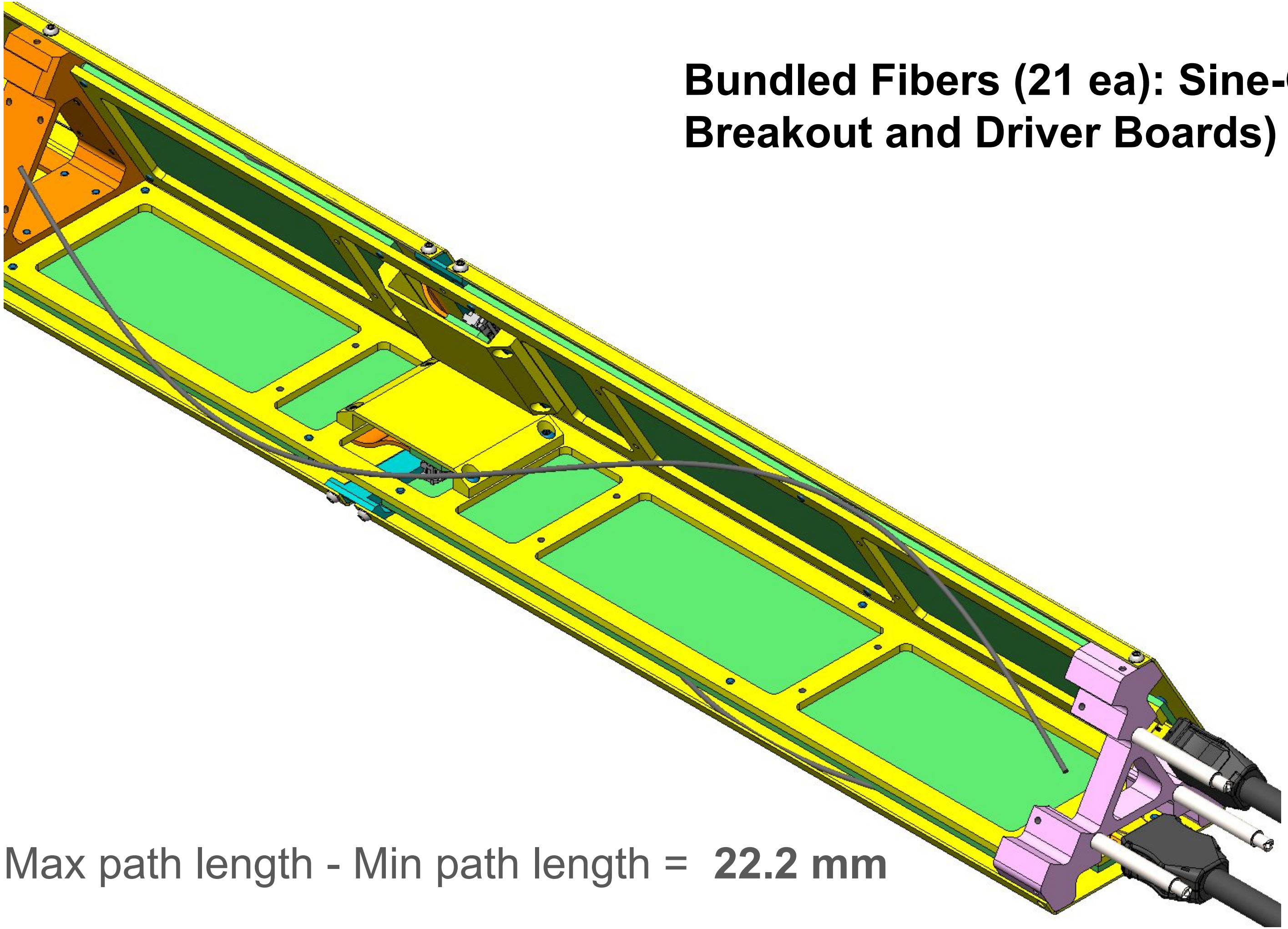
Max path length - Min path length = **4.1 mm**

Bundled Fibers (21 ea): Sine-Curve with Discrete Guides



Max path length - Min path length = **16.7 mm**

Bundled Fibers (21 ea): Sine-Curve (Outside Breakout and Driver Boards)

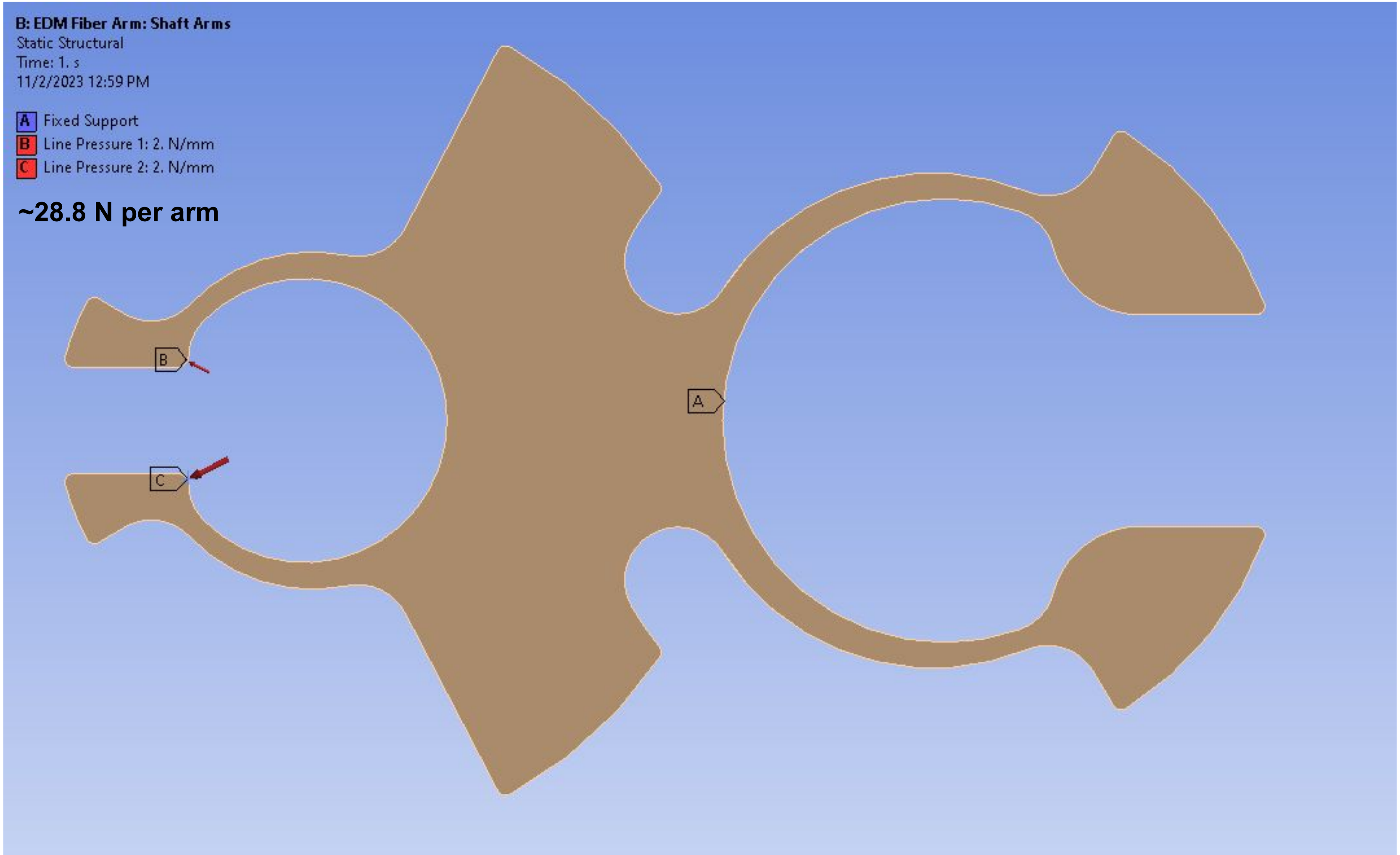


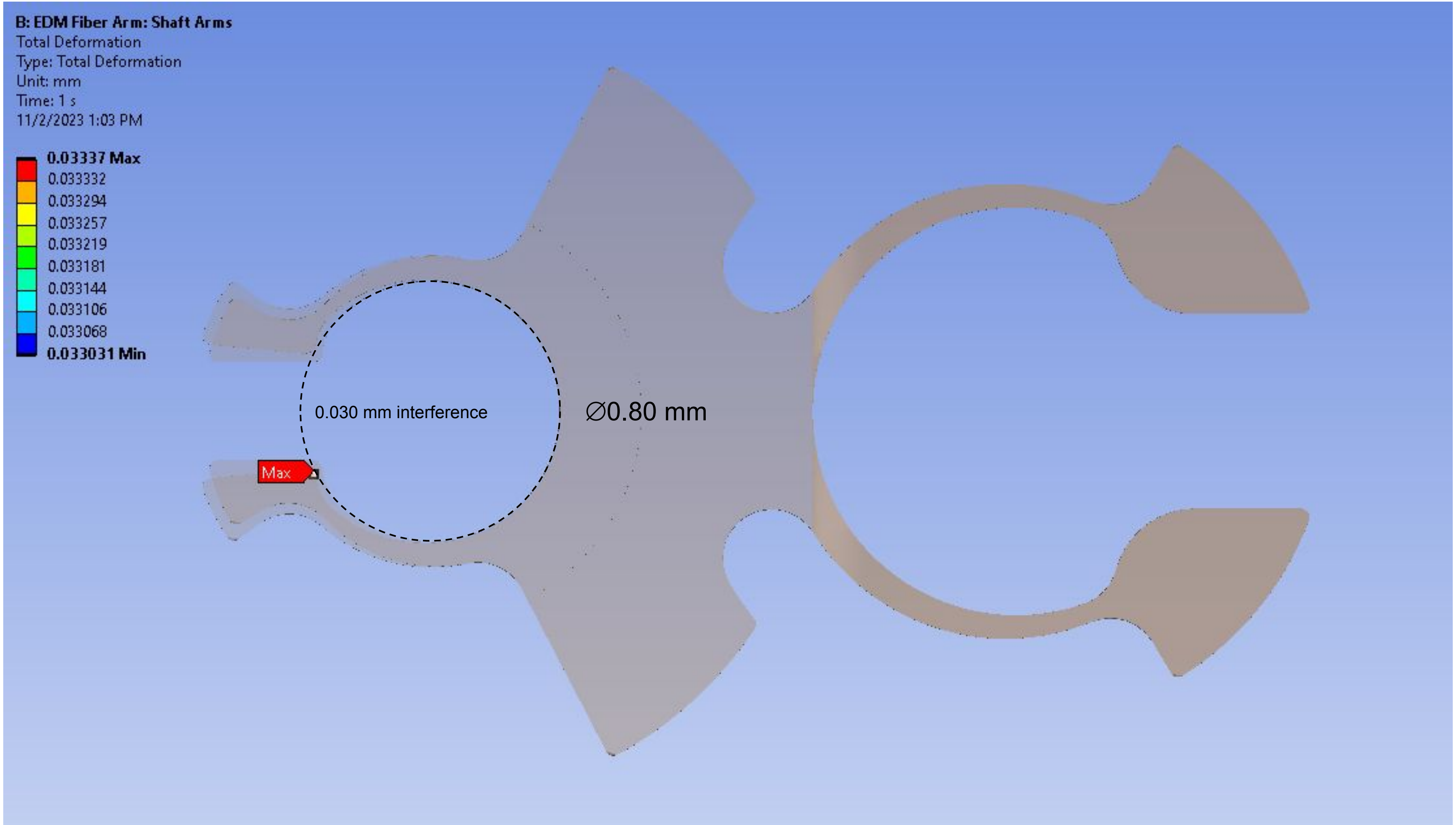
Max path length - Min path length = **22.2 mm**

Alternative Fiber Arm Designs

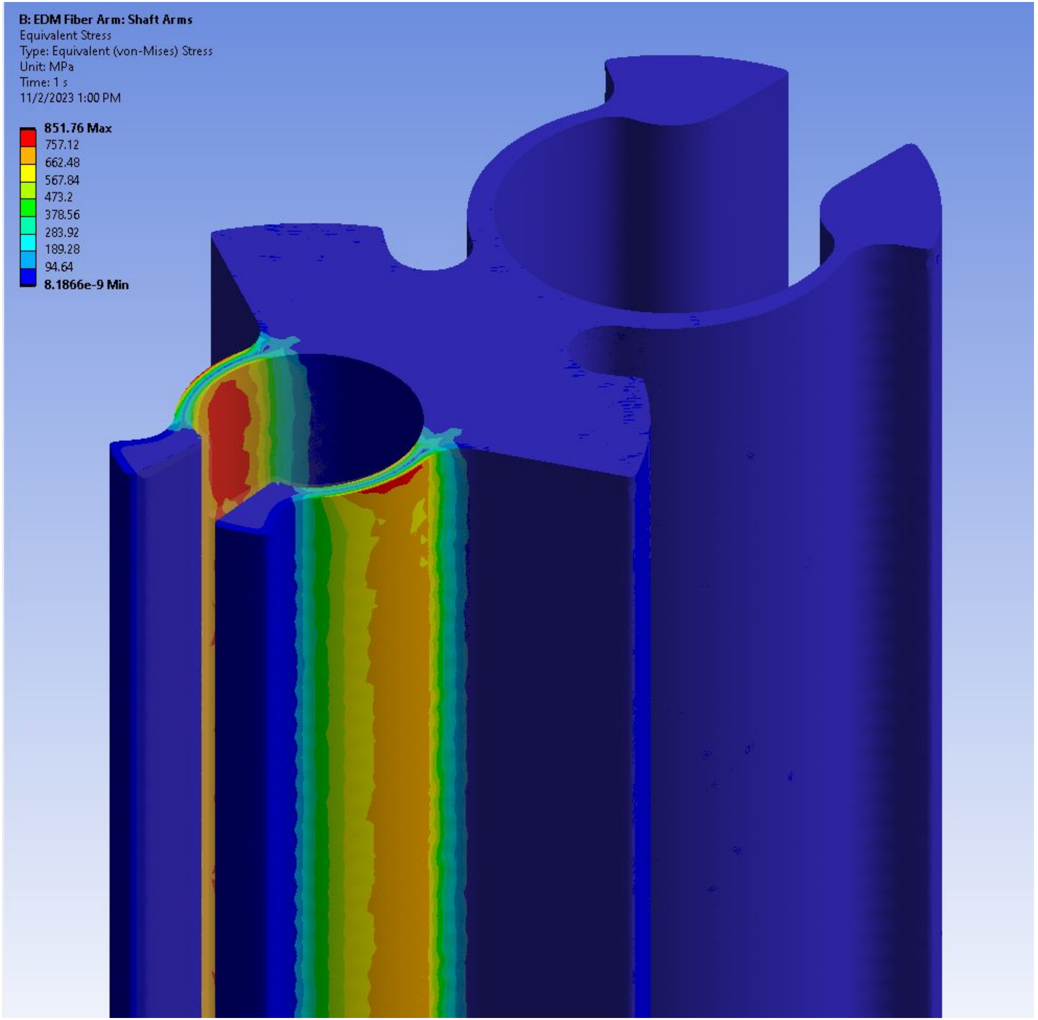
EDM Fiber Arm (DE-1000-0460A)

Ferrule Arms: 0.060 mm - 0.100 mm taper
Shaft Arms: 0.060 mm - 0.080 mm taper


B: EDM Fiber Arm: Shaft Arms
Static Structural
Time: 1. s
11/2/2023 12:59 PM
A Fixed Support
B Line Pressure 1: 2. N/mm
C Line Pressure 2: 2. N/mm
~28.8 N per arm
A
B
C



B: EDM Fiber Arm: Shaft Arms
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1 s
11/2/2023 1:03 PM
0.03337 Max
0.033332
0.033294
0.033257
0.033219
0.033181
0.033144
0.033106
0.033068
0.033031 Min
Max
0.030 mm interference
∅0.80 mm



B: EDM Fiber Arm: Shaft Arms
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1 s
11/2/2023 1:00 PM
851.76 Max
757.12
662.48
567.84
473.2
378.56
283.92
189.28
94.64
8.1866e-9 Min

Stiction: Glass Ferrule

~3.1 N

Insufficient forces?

Risks of low repeatability: Surface finishes, presence of lubricants, spring material properties, spring and ferrule geometries…

→ Increase forces, add features to constrain ferrule axially, and/or use adhesive

Stiction: Steel pin in shaft hole

~0.7 N

Not well constrained axially on shaft

→ Increase forces and/or use adhesive

Adhesive may be necessary for reliable axial constraint

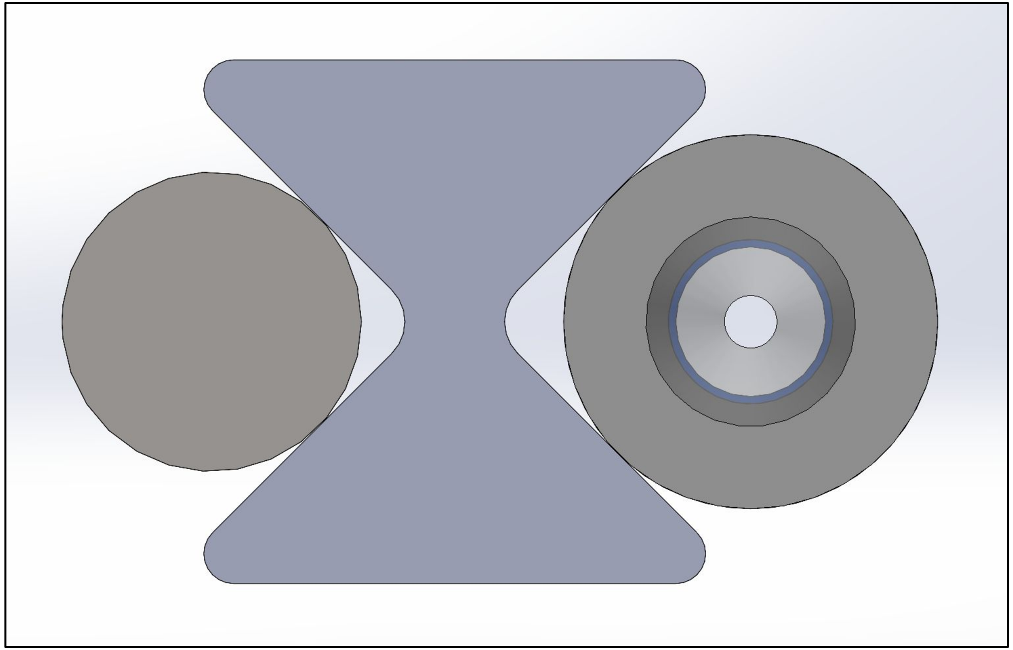
A D-shaped shaft could be used for rotational constraint, but springs could be overcome, and adhesive may still be necessary

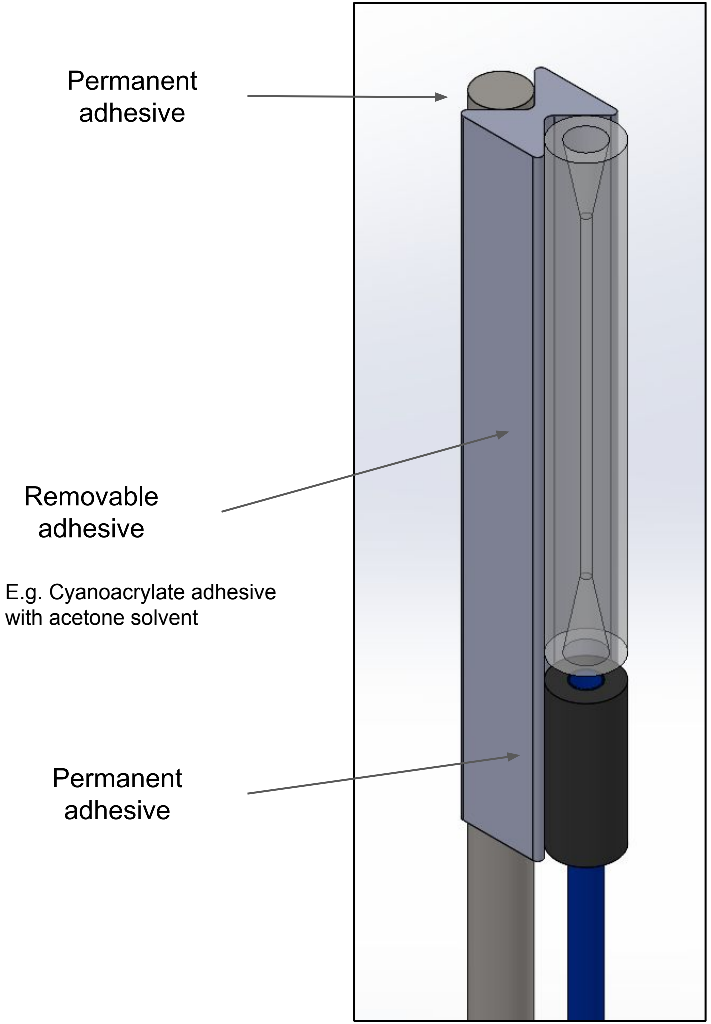
Stiction: Steel pin in ferrule hole

~2.7 N

Other Conceptual Designs

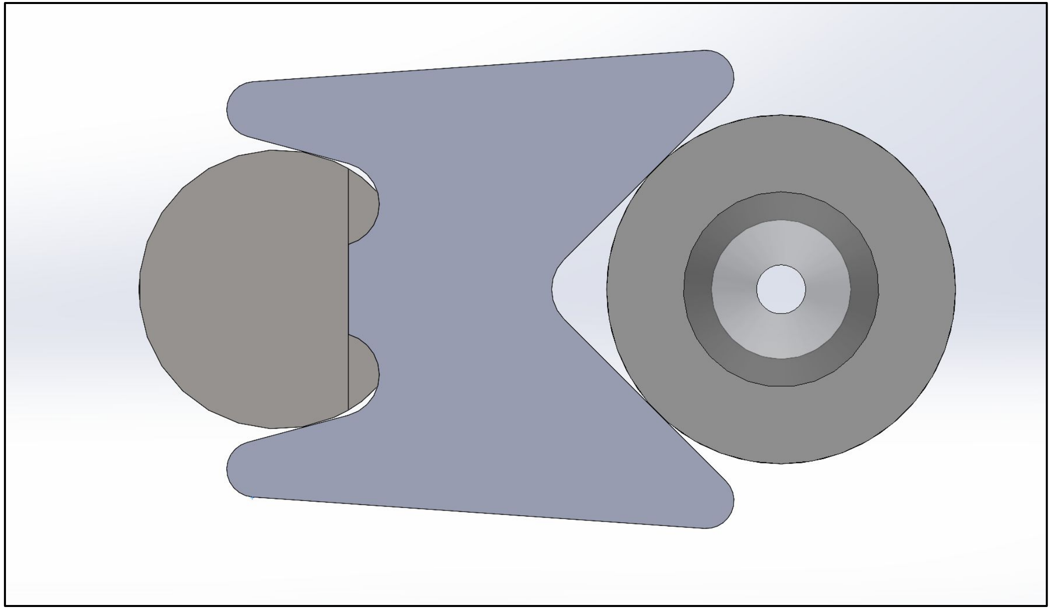
V-Block with Adhesives



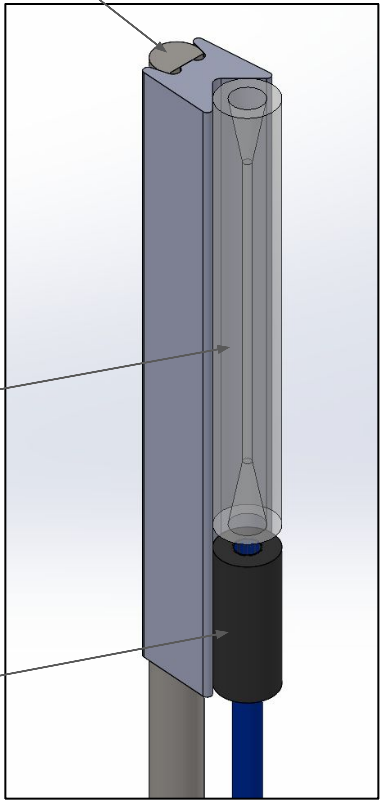


Alignment with stop at the aft end of the beta shaft is set with tooling, then glued

W-Block with Adhesives



Permanent glue



Removable glue

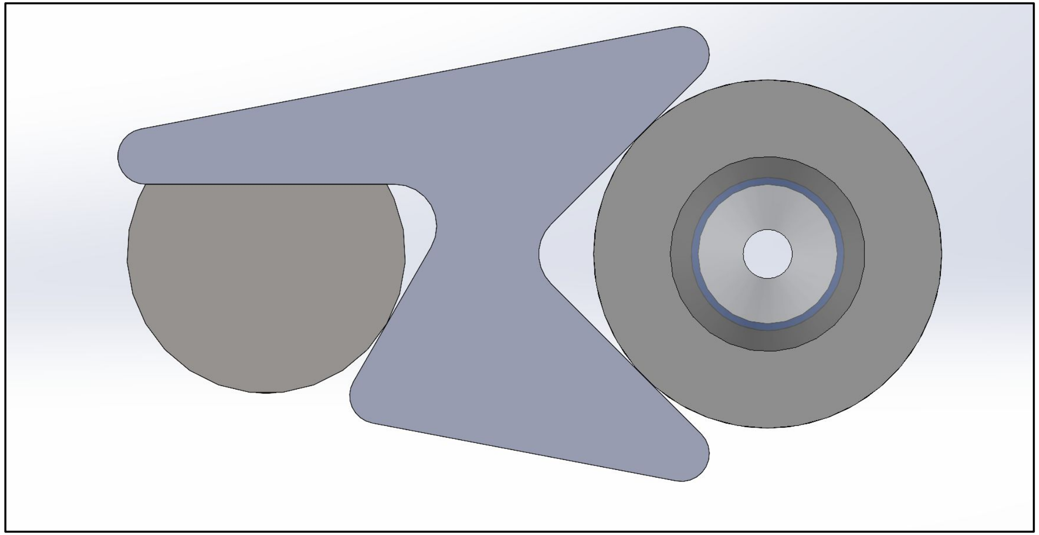
E.g. Cyanoacrylate adhesive
with acetone solvent

Permanent glue

Metal (e.g. wire EDM)

Overconstrained…
Probably better to get rotational alignment with tooling

Z-Block with Adhesives



Metal (e.g. wire EDM)

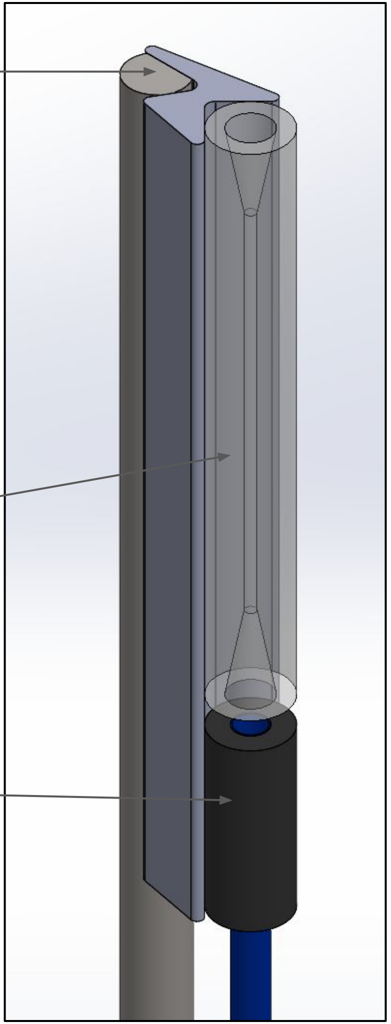
Relies on accuracy of D-groove on shaft…
Probably better to get rotational alignment with tooling

Permanent glue

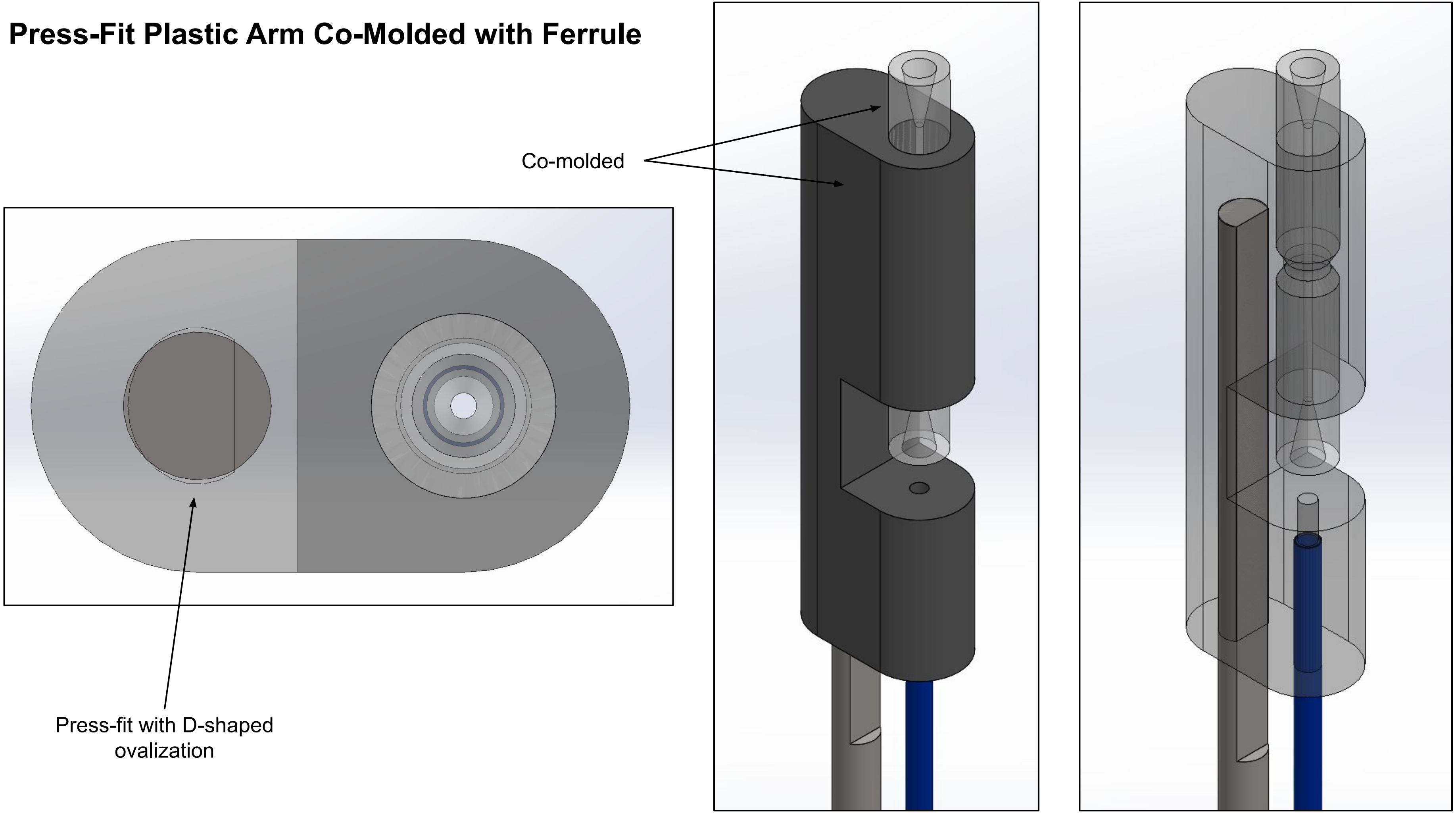
Removable glue

E.g. Cyanoacrylate adhesive
with acetone solvent

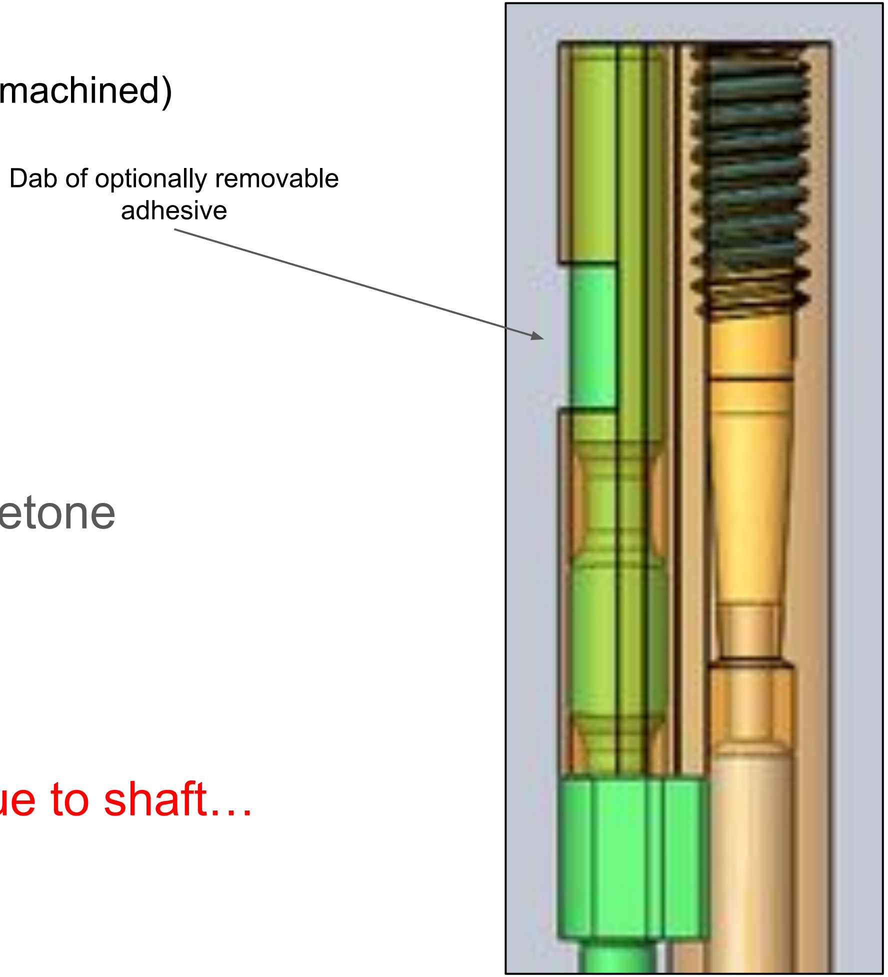
Permanent glue



Press-Fit Plastic Arm Co-Molded with Ferrule



Collet-Lock with Adhesive
Metal (e.g. CNC machined or cast/CNC-machined)



E.g.

Steel / Cyanoacrylate / Acetone

Complicated…
Lots of parts…
Have to apply torque to shaft…
Collet gets stuck…

Collet-Lock with Adhesive

Plastic (e.g. injection molded)

Liquid Crystal Polymer

- Moderate bonding with cyanoacrylate
- Resistant to acetone

ABS/Cyanoacrylate/Acetone wouldn't work because ABS is affected by acetone…

PP/Cyanoacrylate/Acetone wouldn't work because PP doesn't bond well with cyanoacrylate…

Seems like it might be too much trouble to clean and reuse the plastic part. Maybe just throw away the plastic part of the fiber arm and reuse the collet and set screw? Or throw away entire assembly?

Table 4.2.1 · Chemical Resistance

Rating: + Resistant – less than 2% change in weight and dimension, less than 5% change in mechanical properties.
o Limited resistance
– Not resistant

Medium	Conditions (time/temperature)	Vectra® LCP grade	Rating
Acetic acid	(100%) 30 days/118°C	A950	+
	20 days/23°C	A625	+
Acetone	180 days/56°C	A950	+
		A130	+
		A625	+
Acetonitrile	120 days/23°C	A625	+
Brake fluids:			
Castrol® TLX 988C	30 days/121°C	A130	o
		A950	+
		B950	+
	90 days/121°C	A130	–
NAPA® brand DOT-3	90 days/121°C	A130	o
Chlorine gas	180 days/23°C	A950	+
		A130	+
		A625	+
Chlorine/water (saturated solution)	180 days/23°C	A950	+
		A130	+
		A625	+
Chromic acid (50%)	90 days/50°C	A625	+
	180 days/50°C	A950	+
		A130	o
		A625	o
	30 days/70°C	A950	+
		A130	+
	60 days/70°C	A950	+
		A130	o
Chromic acid (70%)	30 days/88°C	A950	+
		A130	o
		A625	o
Dimethyl formamide (DMF)	180 days/66°C	A950	+
		A130	+
		A625	+
Diphenylamine	180 days/66°C	A950	+
		A130	+
		A625	+
Diphenyl carbonate	10 days/250°C	A950	–
Ethanol	30 days/52°C	A950	+
Ethyl acetate 1	80 days/77°C	A950	+
		A130	+
		A625	+
Ethylene diamine	30 days/100°C	A950	–
	180 days/23°C	A950	+
		A130	o
		A625	+

Dab of optionally removable adhesive

- Dissolvable
- Thermoplastic?
  - Wax?
  - Stiff hot glue?
- Mechanical separation?

Table 9.2.2 · Lap Shear Strength

a) Testing Performed at 22°C

Adhesive Type	Range of Values, N/mm^2 As Molded	Range of Values, N/mm^2 Surface Treated*	Average Values, N/mm^2 As Molded	Average Values, N/mm^2 Surface Treated*
2 Part Epoxy	3.1 – 6.9	5.5 – 14.5	4.8	9.0
1 Part Epoxy	4.1 – 9.0	5.5 – 9.7	6.2	10.7
Cyanoacrylate	2.1 – 4.8	3.4 – 6.9	3.4	5.5
2 Part Acrylate	1.7 – 5.5	3.4 – 5.5	3.1	4.8

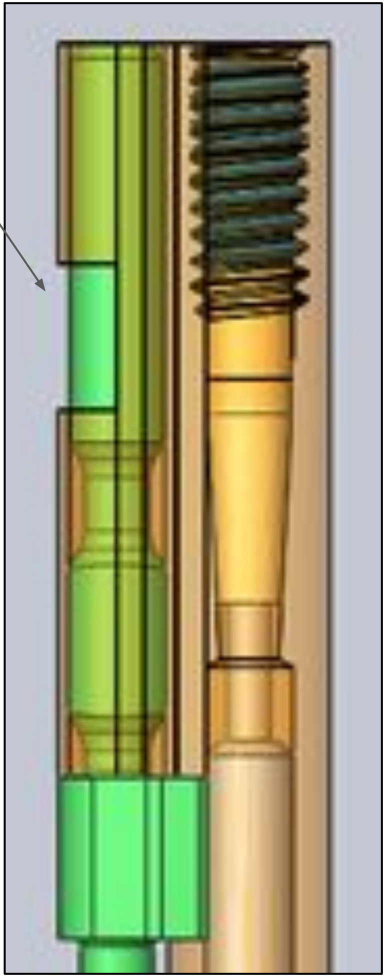
b) Testing Performed at 100°C

Adhesive Type	Range of Values, N/mm^2 As Molded	Range of Values, N/mm^2 Surface Treated*	Average Values, N/mm^2 As Molded	Average Values, N/mm^2 Surface Treated*
2 Part Epoxy	1.0 – 2.1	1.0 – 2.8	1.4	2.1
1 Part Epoxy	1.4 – 4.8	1.7 – 5.5	3.4	4.1
Cyanoacrylate	2.1	2.1 – 3.4	2.1	2.8
2 Part Acrylic	0.7 – 1.4	1.4 – 2.1	1.0	1.7

c) Testing Performed at 150°C

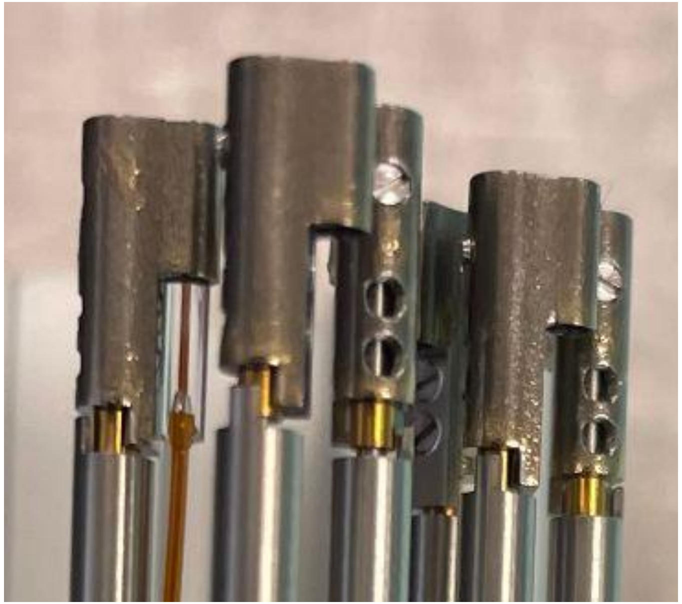
Adhesive Type	Range of Values, N/mm^2 As Molded	Range of Values, N/mm^2 Surface Treated*	Average Values, N/mm^2 As Molded	Average Values, N/mm^2 Surface Treated*
2 Part Epoxy	0.7 – 1.4	0.7 – 1.4	0.7	1.0
1 Part Epoxy	0.7 – 2.1	0.7 – 2.1	1.4	1.4
Cyanoacrylate	0.2 – 0.3	0.3 – 0.7	0.2	0.7
2 Part Acrylic	0.3	0.7	0.3	0.7

** Light sanding or grit blasting and solvent wash*



Complicated features for injection molding…

Set-Screws
Metal (e.g. CNC machined or cast/CNC-machined)



Hard to access set screws…
Slop in both joints…

Orbray Prototype (Jan. 2024)

Set-Screw to Shaft with Adhesive to Ferrule
Metal (e.g. CNC machined or cast/CNC-machined)

Dab of adhesive

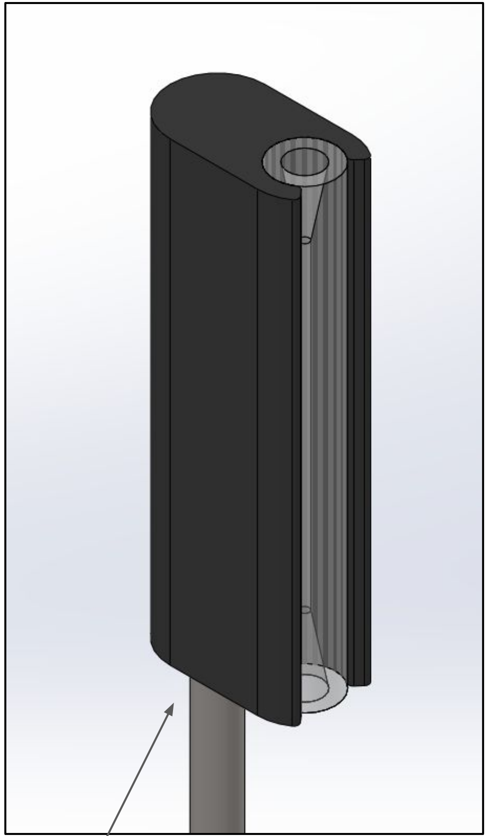
E.g.

Steel / Cyanoacrylate / Acetone

Slop in screw screw joint…
Difficult/expensive to clean/reuse?

Press-Fit to Shaft with Clip to Ferrule

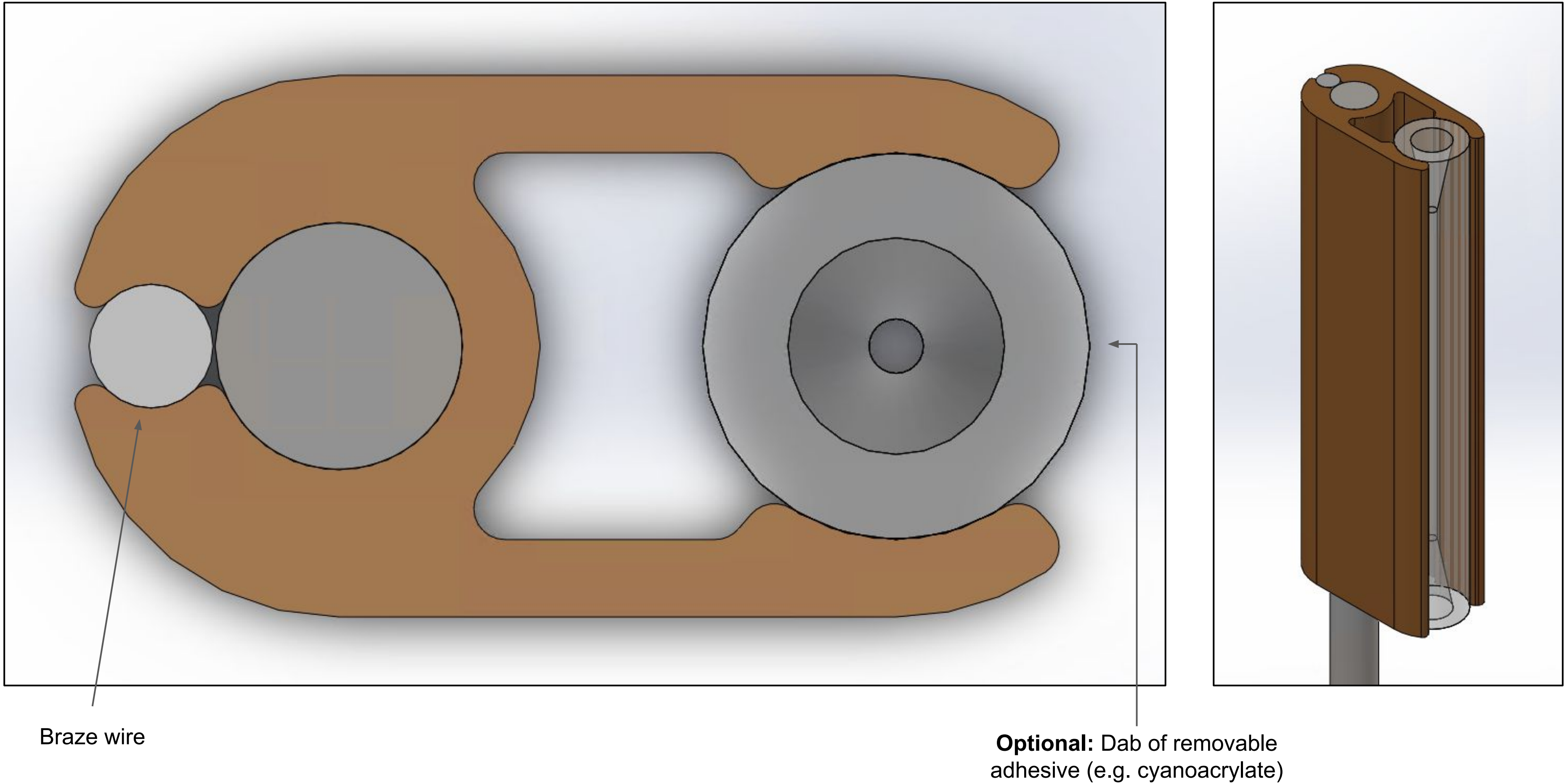
E.g. Injection-molded plastic



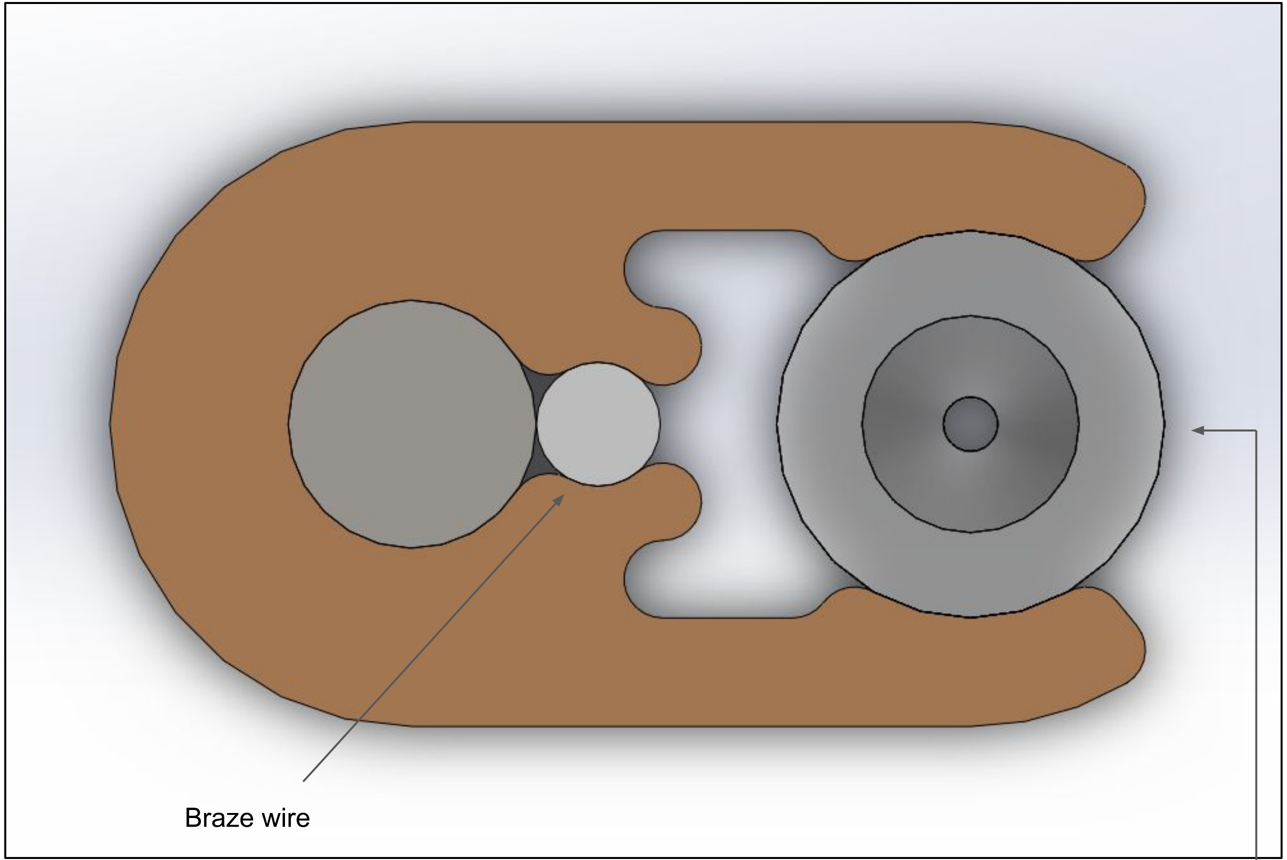
Press-fit shaft (e.g. with D-shaped ovalization)

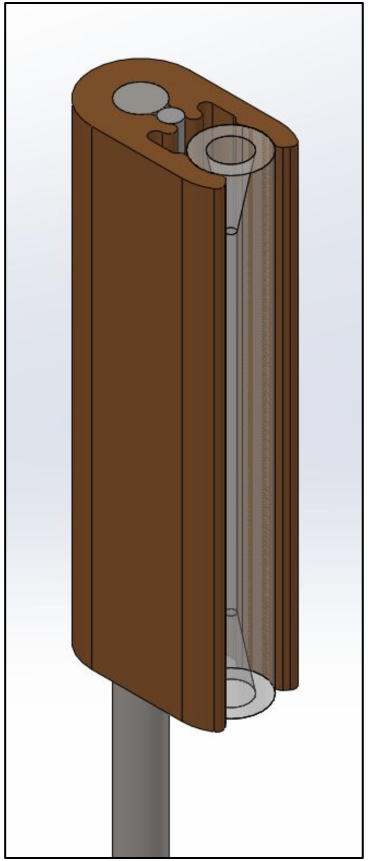
Braze to Shaft and Clip to Ferrule

Metal (e.g. wire EDM)



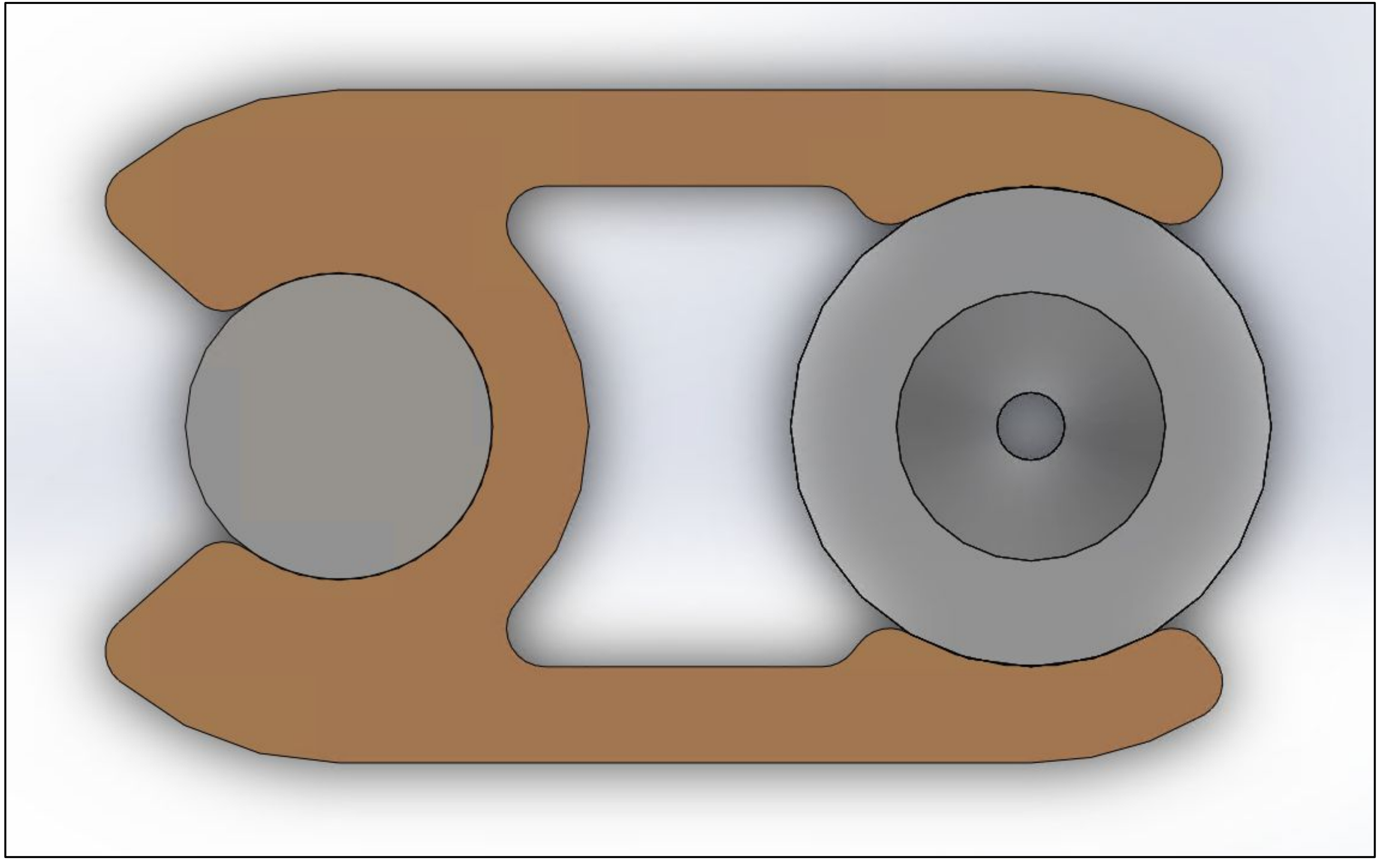
Braze to Shaft and Clip to Ferrule
Metal (e.g. wire EDM)

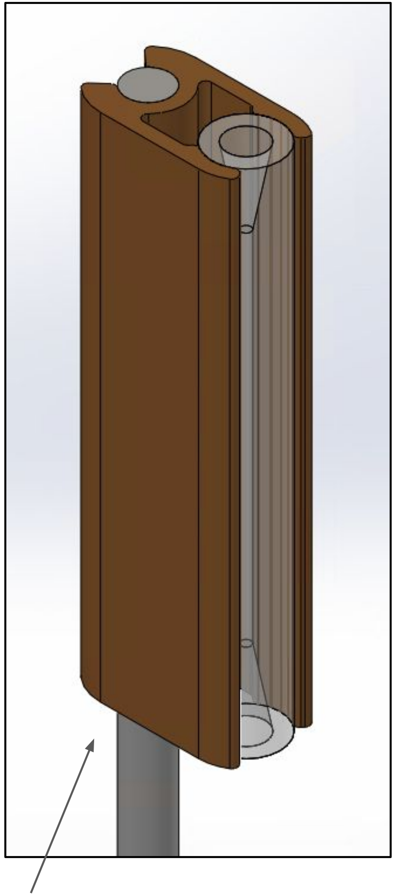




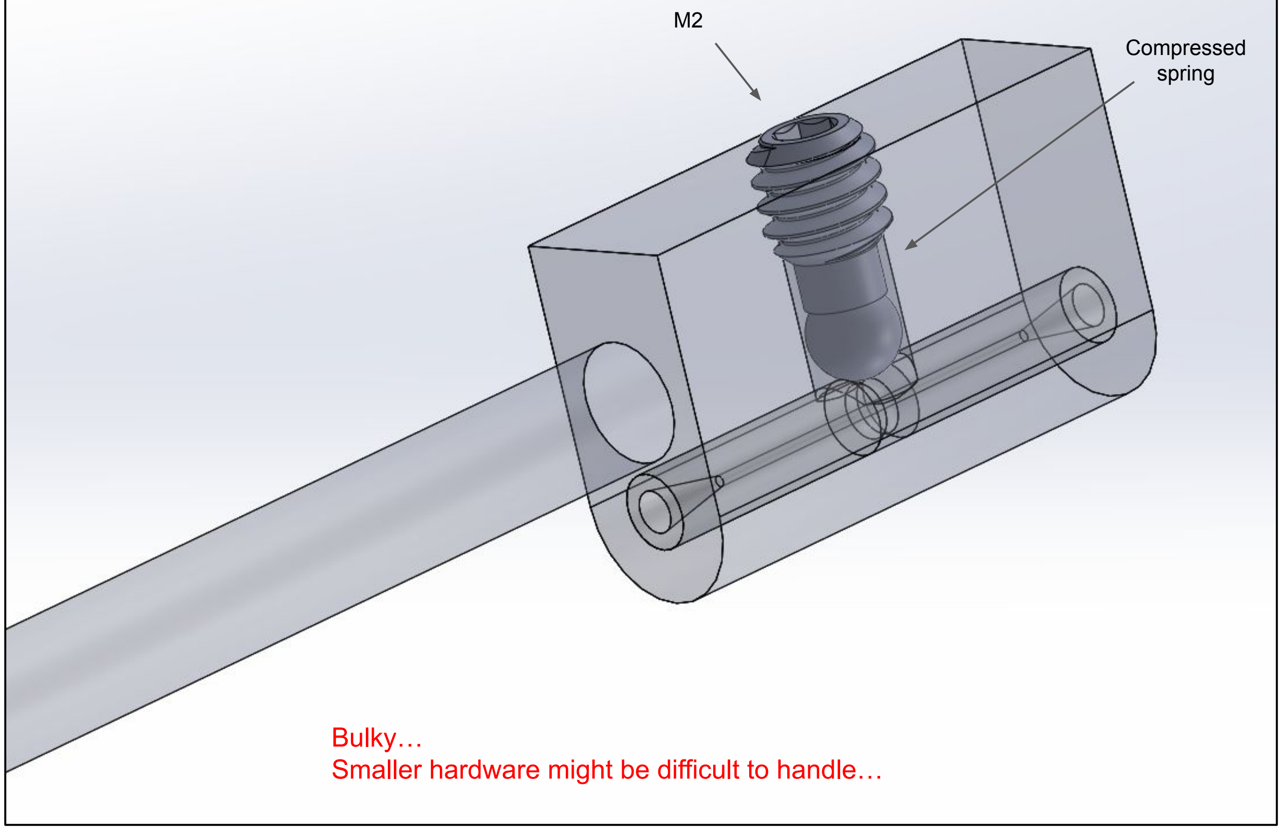
Optional: Dab of removable adhesive (e.g. cyanoacrylate)

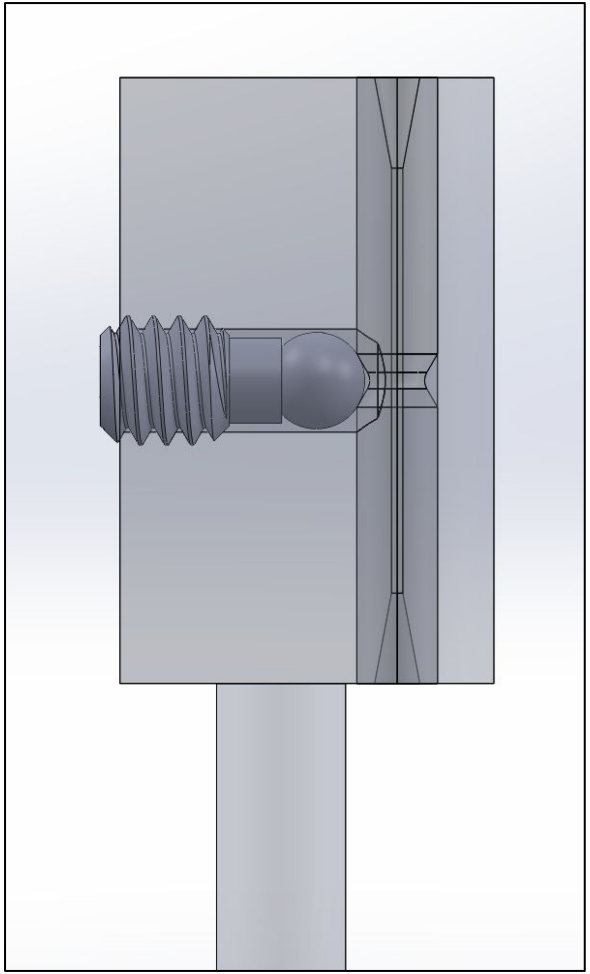
Snap to Shaft and Clip to Ferrule
Metal (e.g. wire EDM)




Snap-on shaft

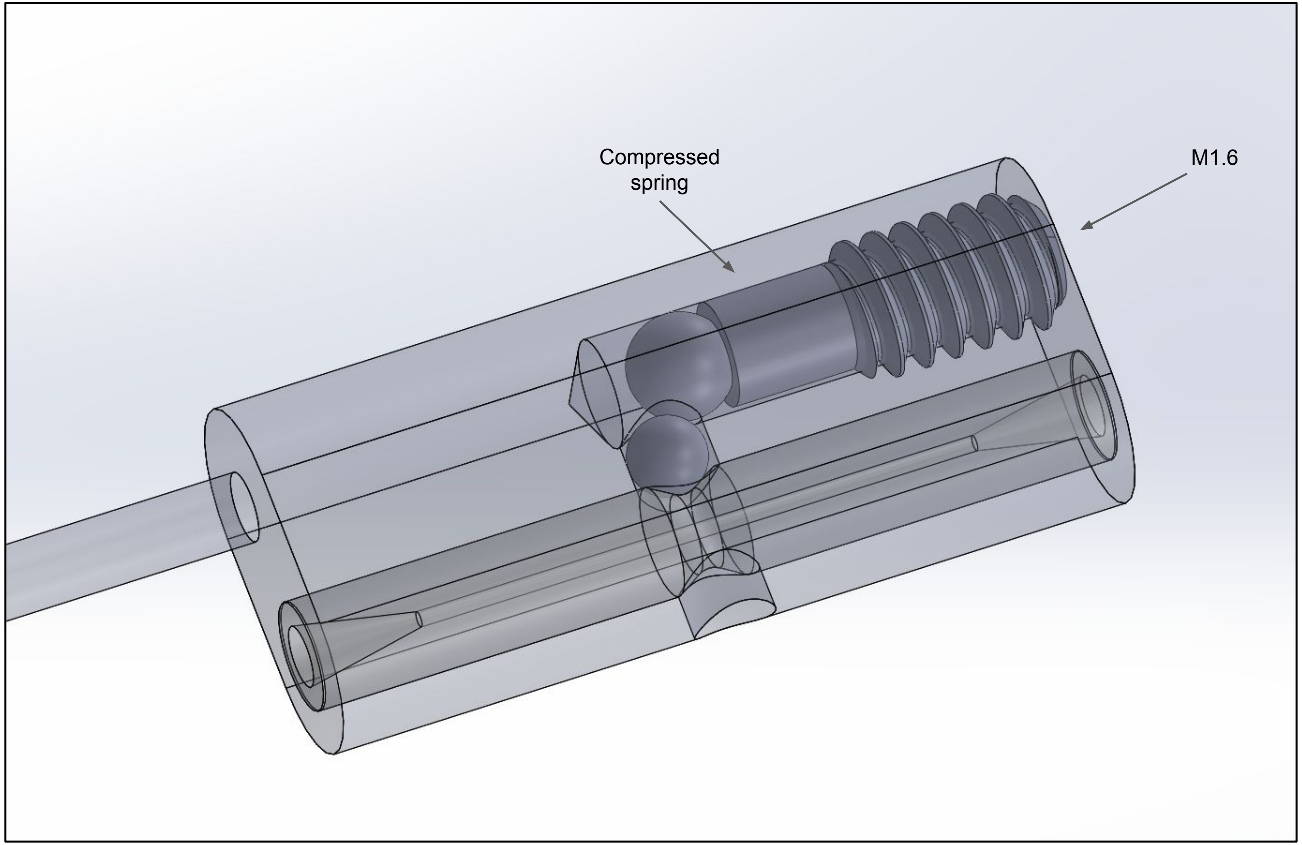
Ball Detent

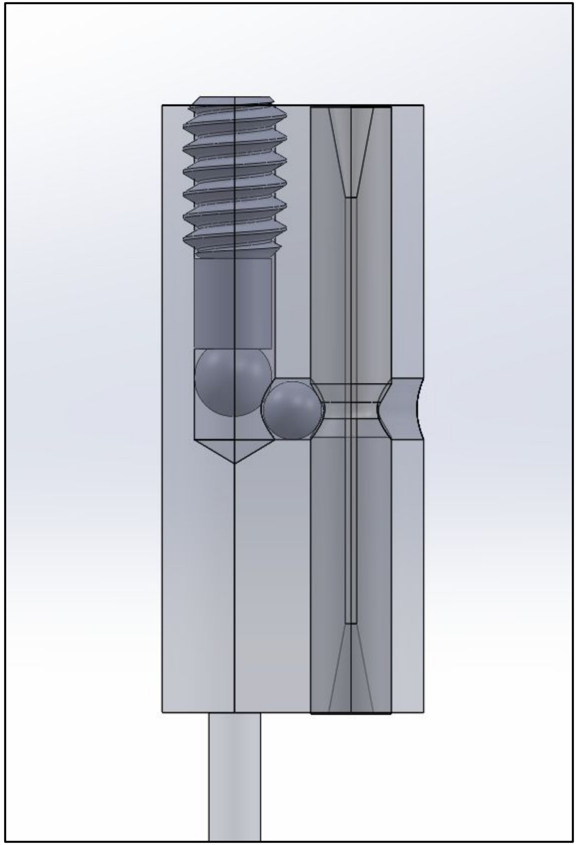




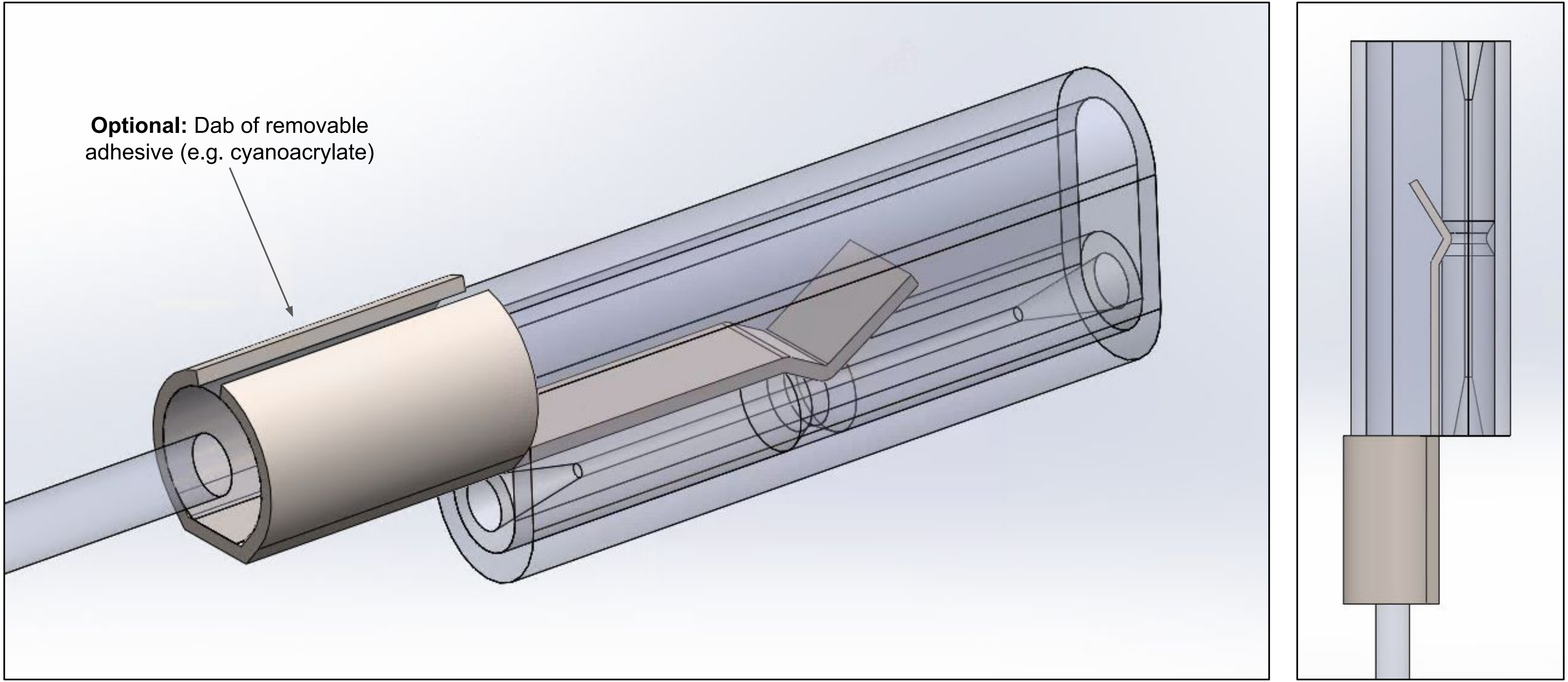
Bulky…
Smaller hardware might be difficult to handle…

Ball Detent with End Entry

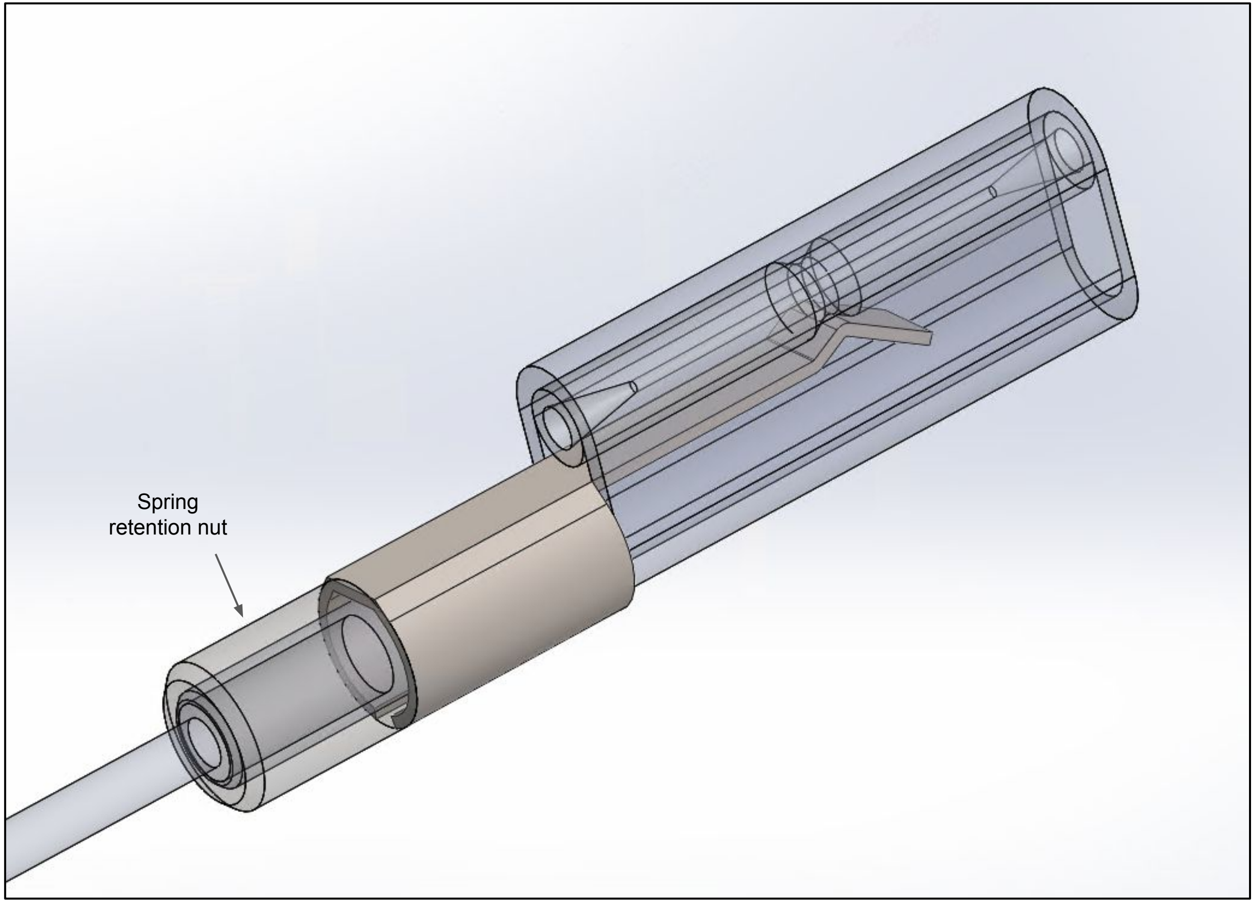


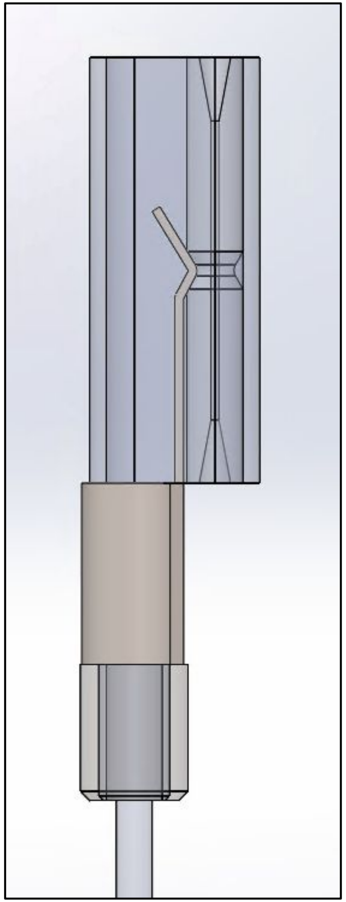


Strap Spring - Friction Fit

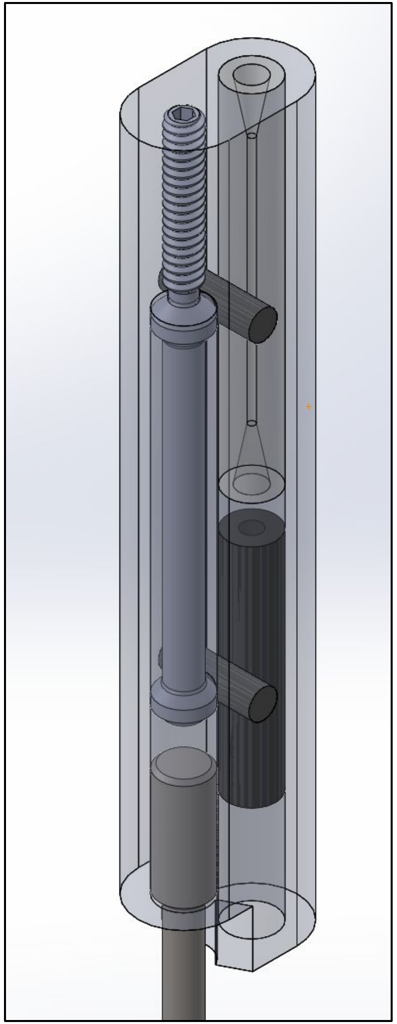


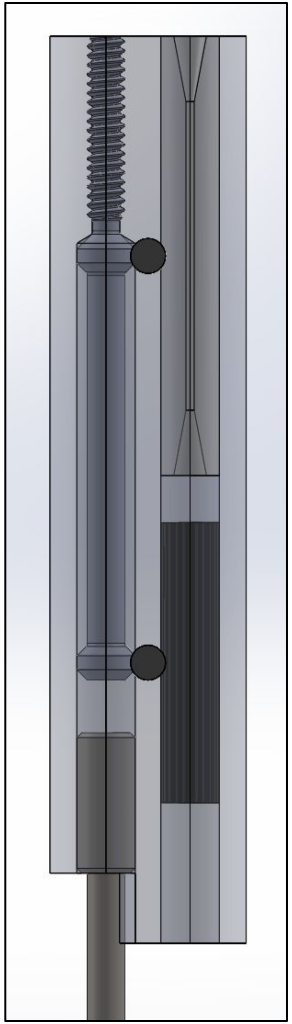
Strap Spring - Retention Nut

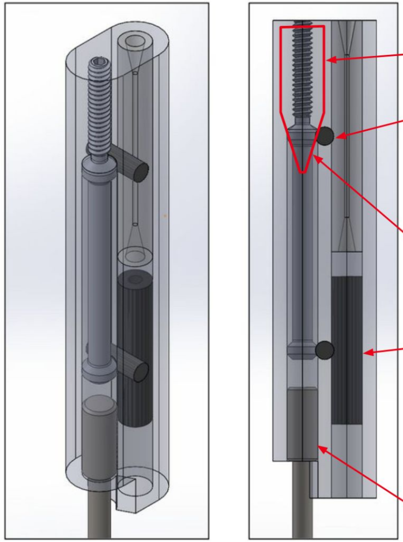




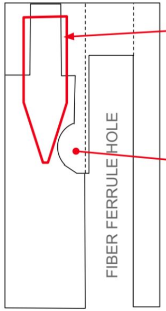
Pinch Fiber Arm 1.0



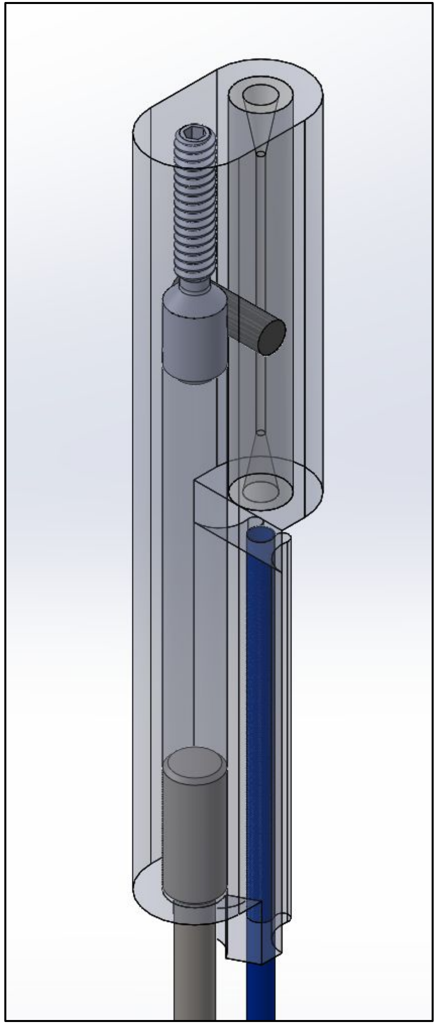


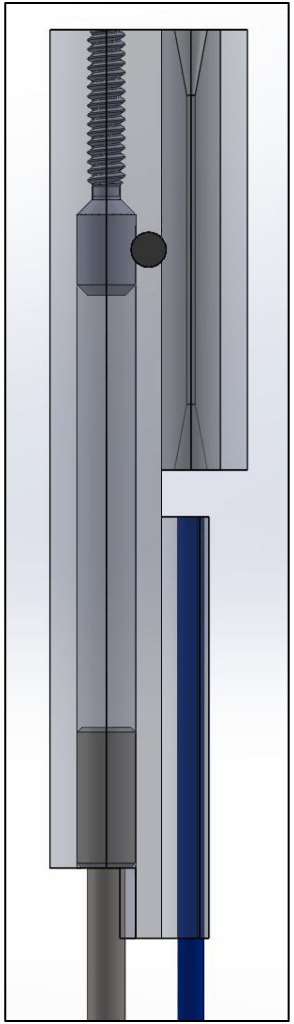


Another question - if this part were a single piece of injection-molded plastic, could it have a sort of built-in flap that does the job of the "rod"? I'm not sure if this works in 3D, but conceptually like:



- The cylindrical faces that touch the rubber rods seem too short to me, I'd want them maybe 4x longer to ensure the rod actually gets compressed without needing fancy tolerances.
- Having the fiber ferrule and sleeve ferrule locked in by the same screw position seems to constrain assembly/repair scenarios. Could the cylinder that presses the fiber ferrule rod be offset for the sleeve ferrule, such that it disengages at a different screw axial position?
- I worry that having orthogonal faces (the cylinders) sliding along the rod in principle isn't good, because then they can rotate the rod, and the rod drives the ferrule up and down like a drive wheel.
- Rod material needs to be selected to minimize risk of creep. (Notching the ferrule for positive engagement would give some fallback safety.)

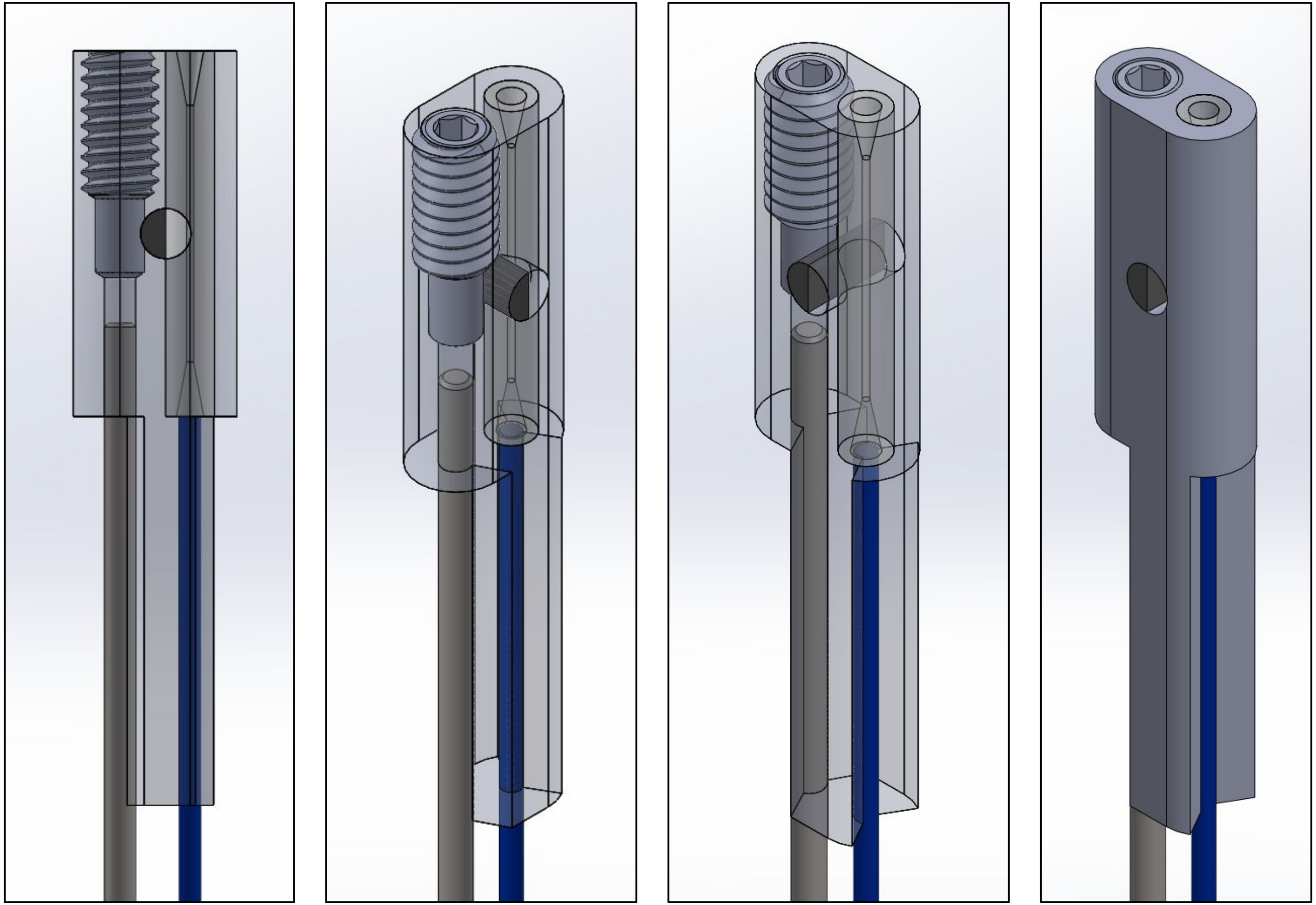




Pinch Fiber Arm 2.0

Better to make the threads on the set screw bigger than the pinching feature

That way you can maintain a small hole for the beta shaft and don't need the expanded diameter on the beta shaft

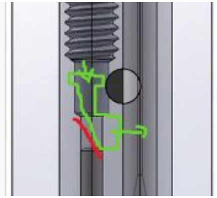


Pinch Fiber Arm 3.0

Probably want to avoid CNC machined metal-metal press-fits at this scale

Ways to capture plug?
How to fabricate plug?
What material?

What about 3D printing or injection molding something and dropping it into the hole, squishing it with set screw?



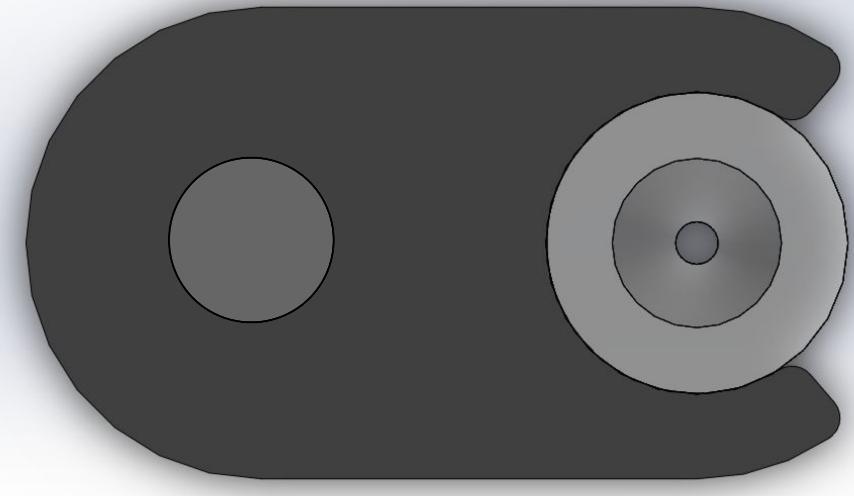
One or both adhesives could be removable

Might be easiest to remove fiber arm from shaft during repairs: Easier to clean and reuse shaft than to clean and reuse fiber arm

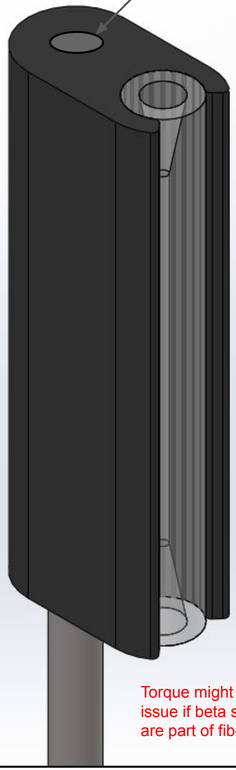
Adhesive Joints

Plastic (e.g. injection-molded)

Need biasing for alignment in holes…

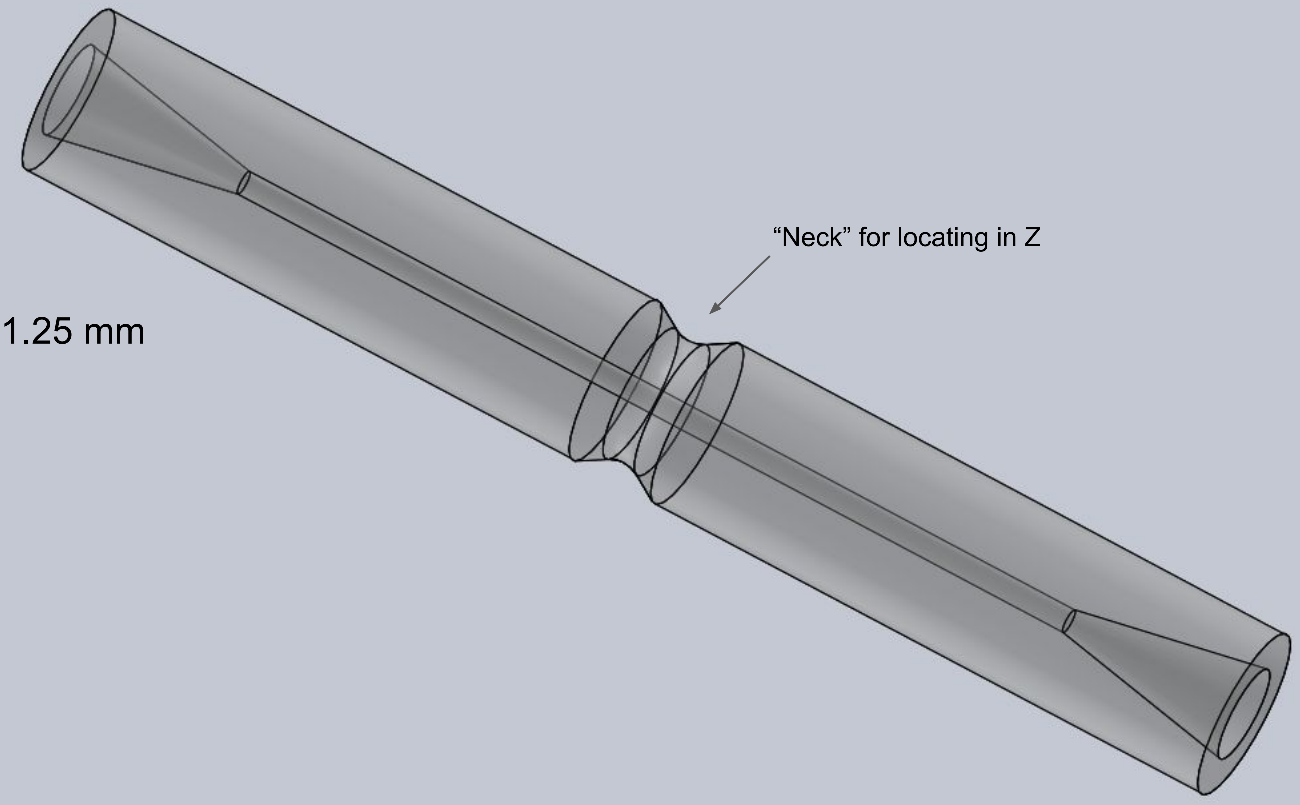


E.g. LCP plastic with cyanoacrylate adhesive and acetone solvent



Torque might be an issue if beta stops are part of fiber arm

“Necked” Glass Ferrule:

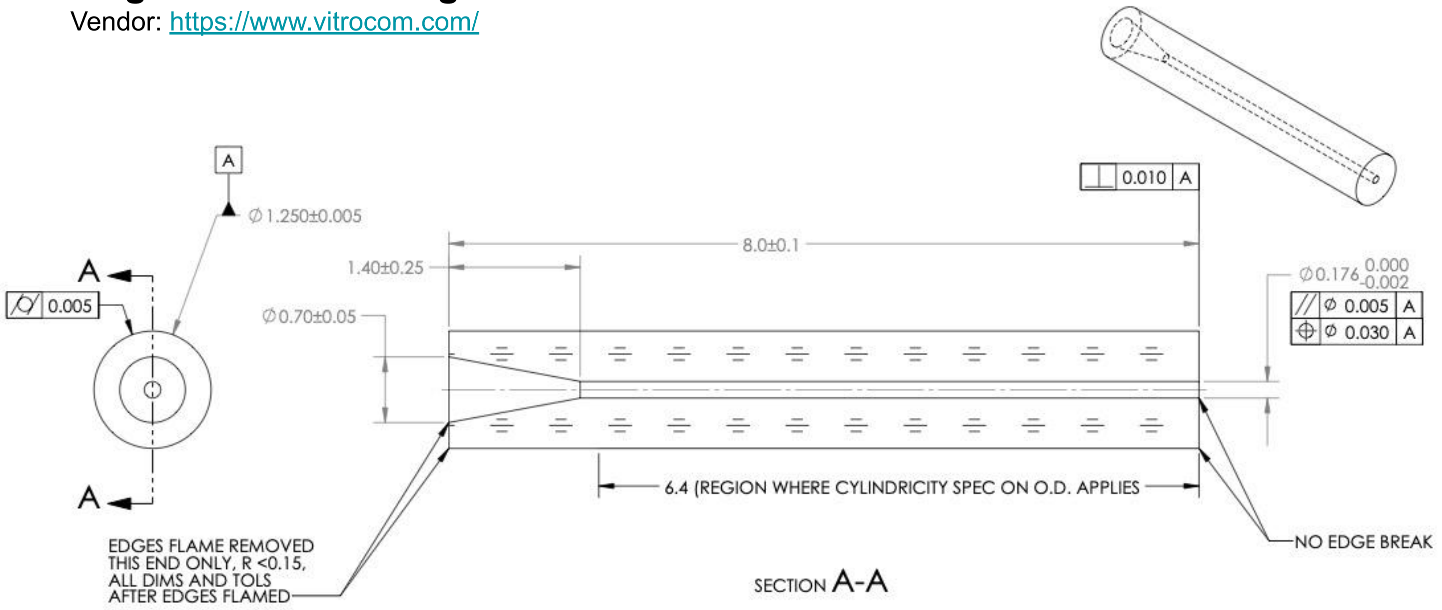


OD: 1.25 mm

REV.	DESCRIPTION	REVISED BY	CHECKED	SYS. E.	CM	DATE
v1	INITIAL RELEASE	RWB	JE	RWB	RWB	5/21/15

Original Ferrule Design:

Vendor: https://www.vitrocom.com/



[Edges in production units were lapped, not flame polished]

NOTES: UNLESS OTHERWISE SPECIFIED

1. MATERIAL: DRAWN BOROSILICATE GLASS, POLISHED FINISH.
2. BAG AND TAG IN GROUPS OF 100.

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS IN MM
TOLERANCES:
ANGULAR ± 0.5°
X ± 0.5
X.X ± 0.1
X.XX ± 0.05
X.XXX ± 0.010
GD&T PER: ASME Y14.5M-2009
MATERIAL SEE NOTES
MACHINING FINISH: SEE NOTES
EDGE BREAK: SEE GRAPHICS
PROJECTION: THIRD ANGLE
DO NOT SCALE DRAWING

Ernest Orlando Lawrence Berkeley National Laboratory

PROJECT: DESI

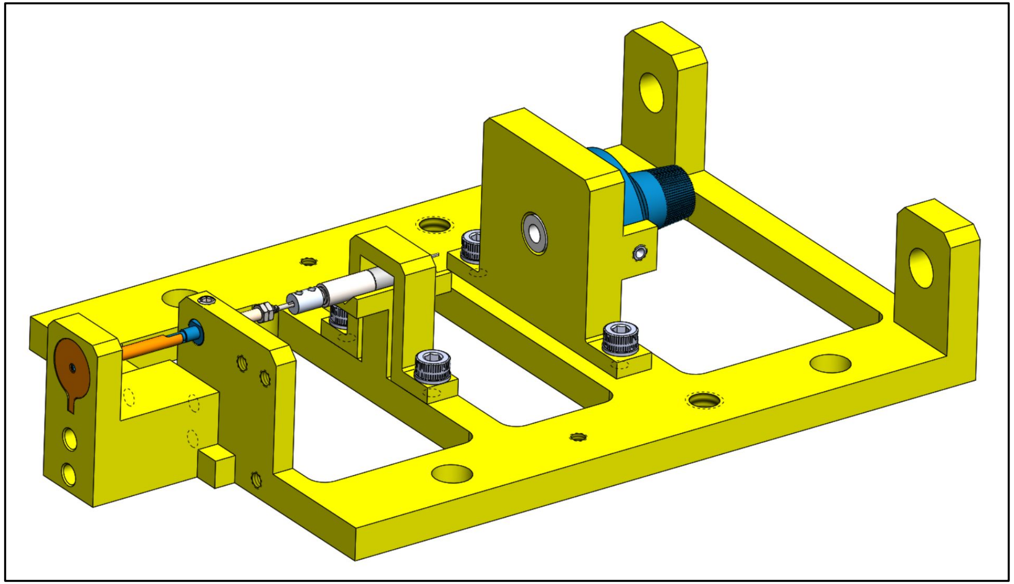
TITLE: TAPERED GLASS FERRULE

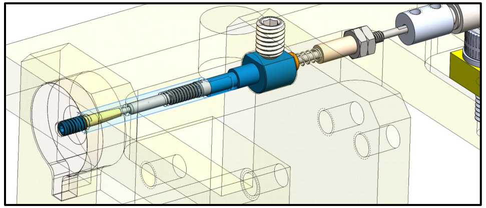
SOLIDWORKS MODEL REVISION AT TIME OF RELEASE: 0004

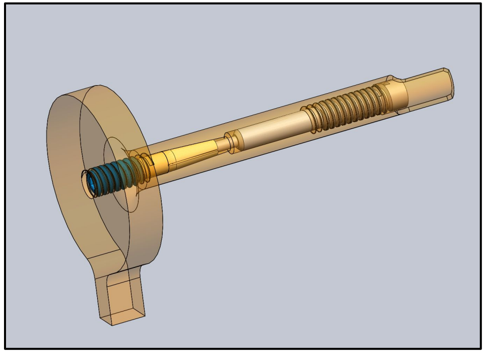
SIZE: B | DWG. NO. DESI-1136 | REV v1

SCALE: 25:1 | WT: Kg | SHEET 1 OF 1

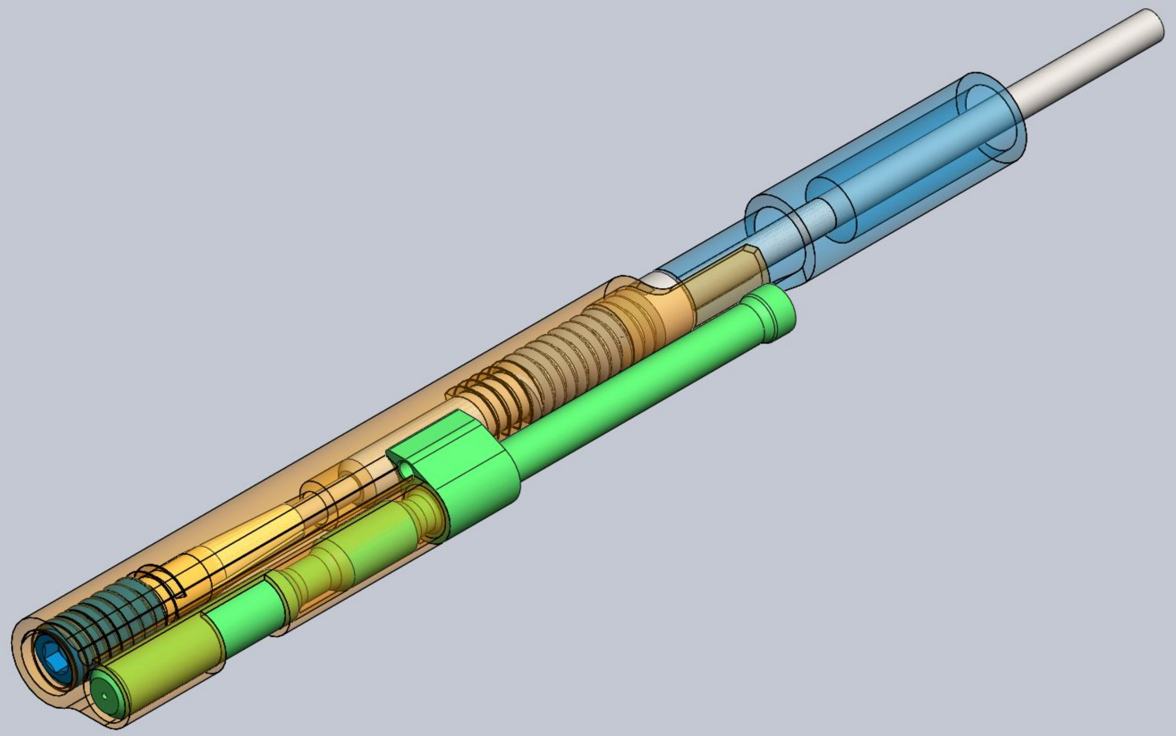
“Auto-Focus” Fiber Arm Prototypes

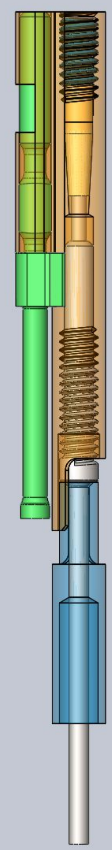






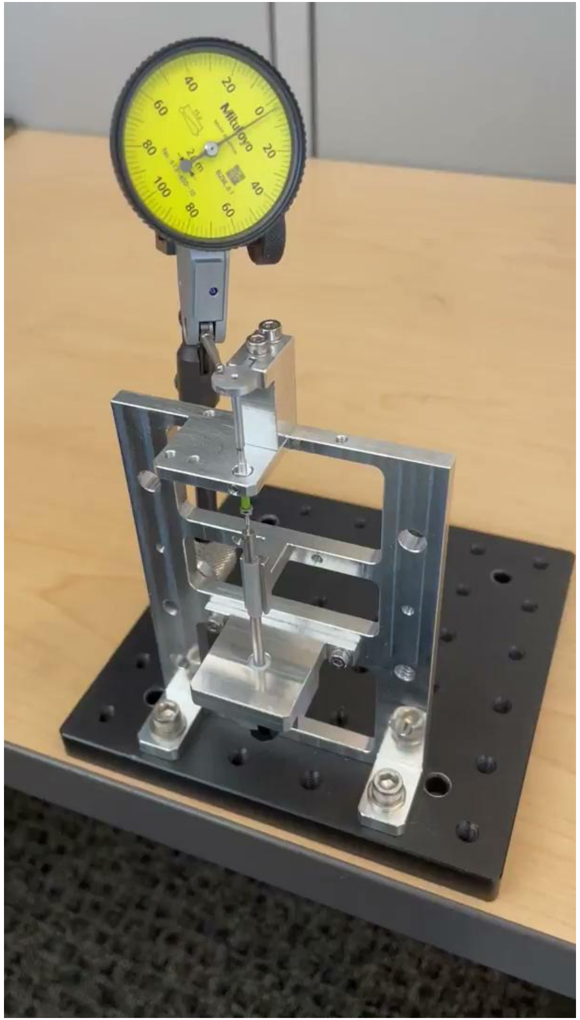
Test assembly is based on MM Fiber Arm Assy concept

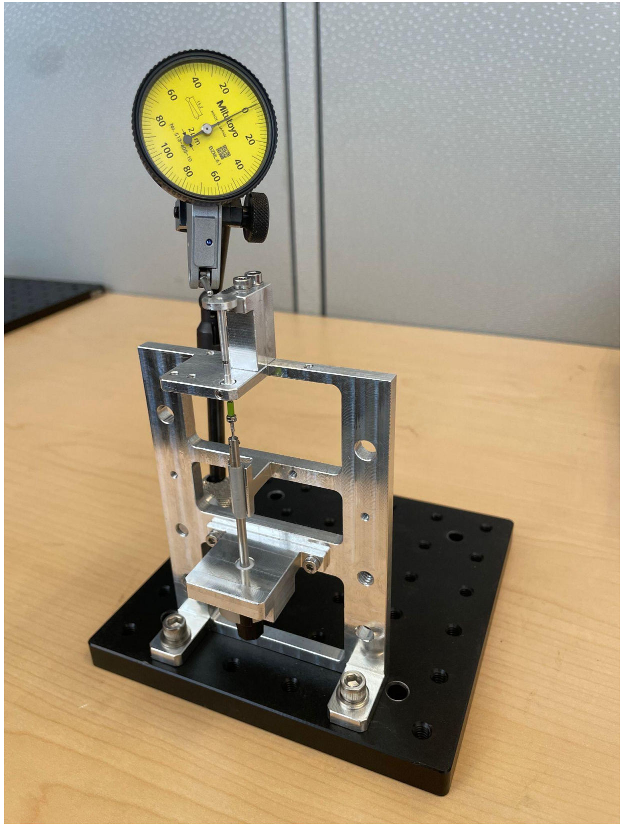




Trial 1:

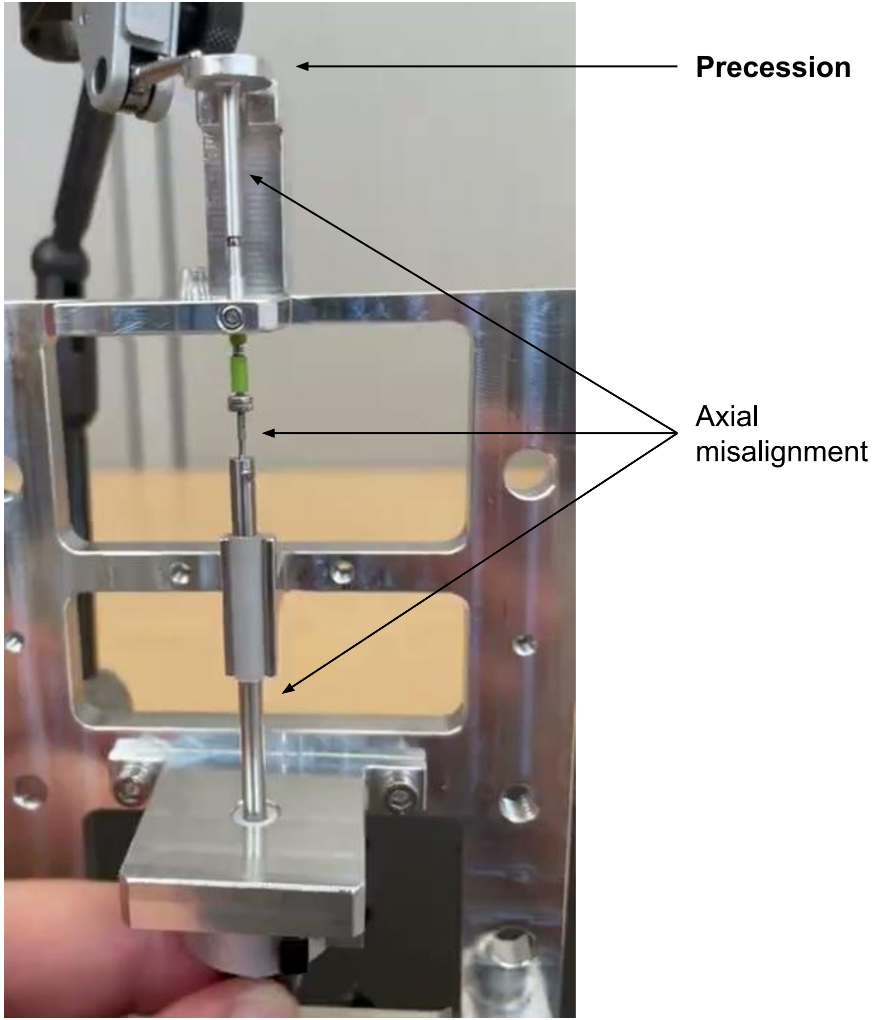
Manual Knob Actuation with Unglued Fiber Arm

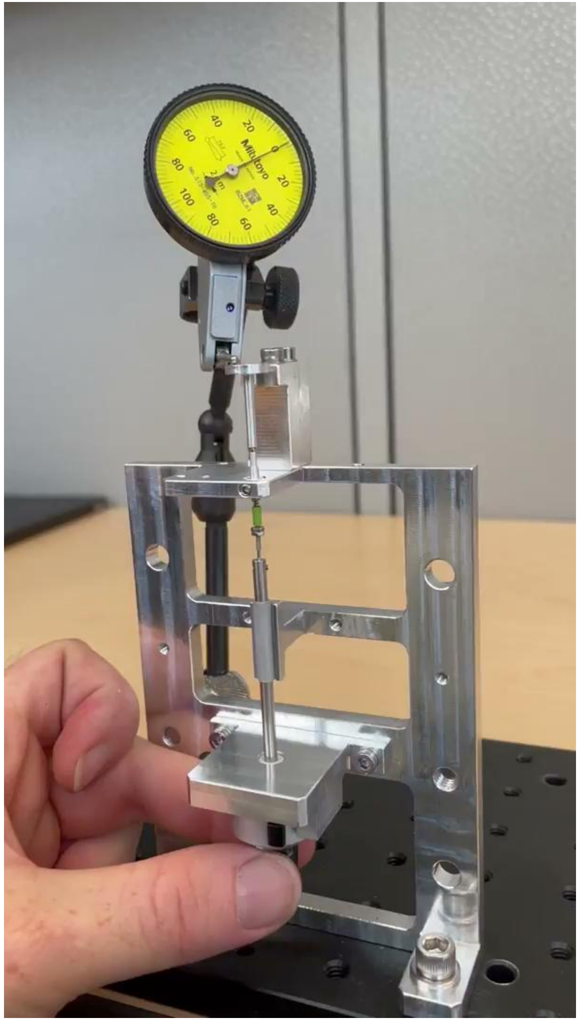




Top Surface of Fiber Arm:

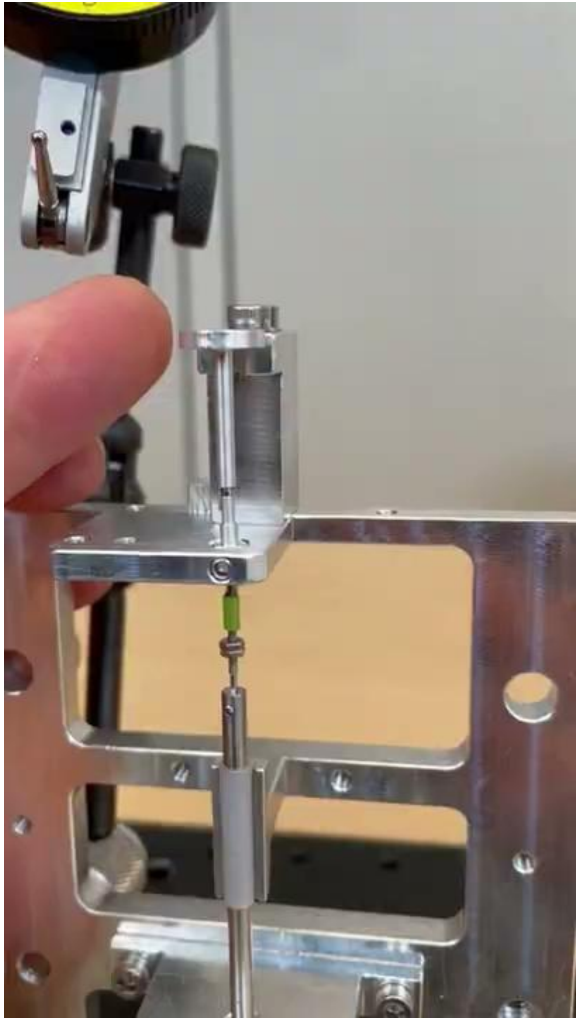
~40 μm max displacement





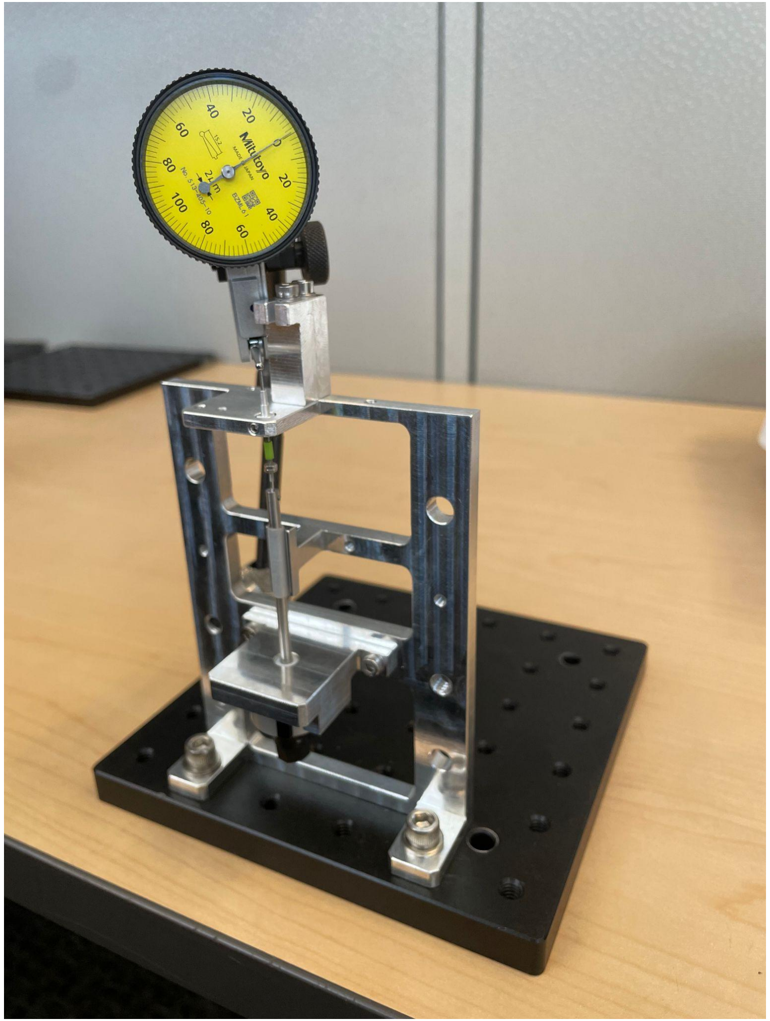
Knob does not fully constrain shaft

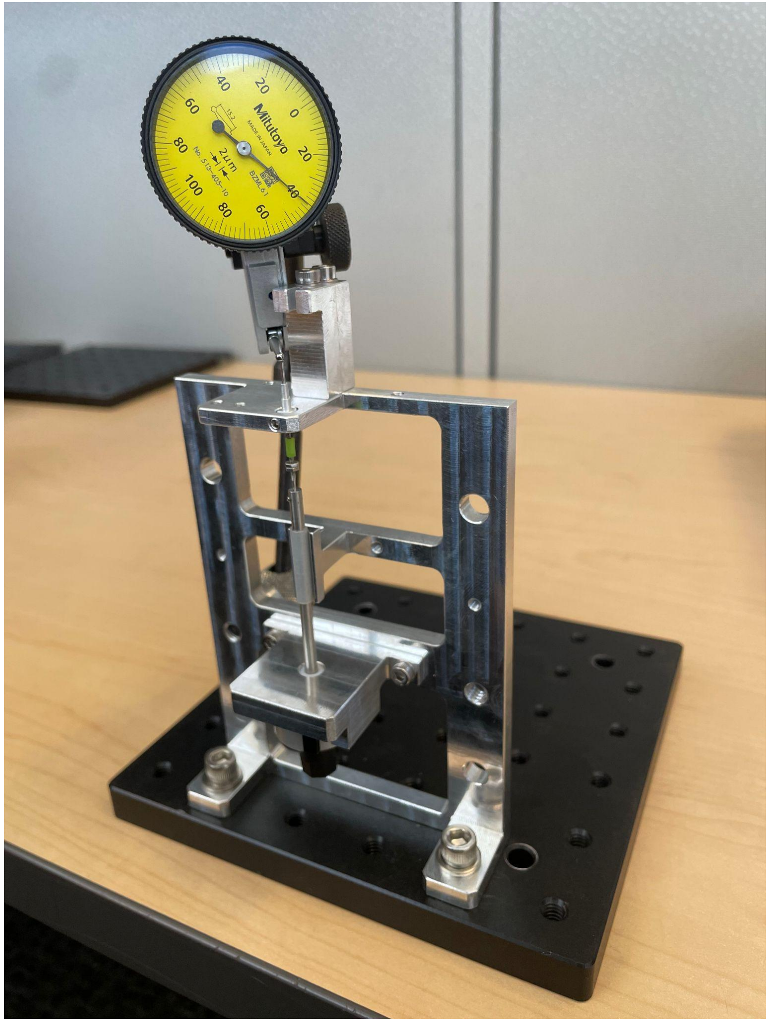
- ~10 µm axial displacement
- Unknown angular displacement



Fiber arm has significant play before glueing

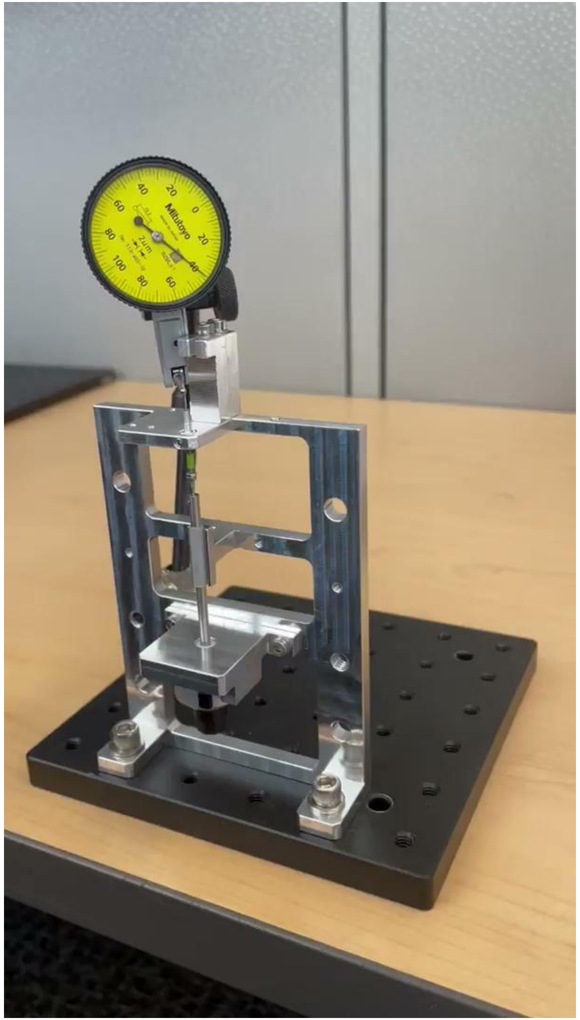
⇒ Axial alignment may be off after glueing

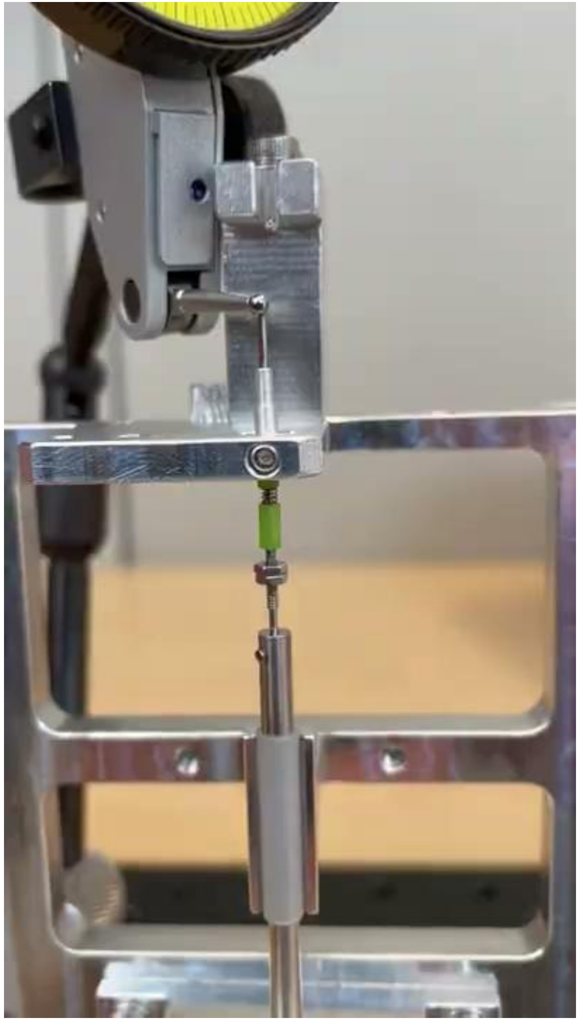




Top Surface of Beta Motor Shaft:

~40 µm max displacement

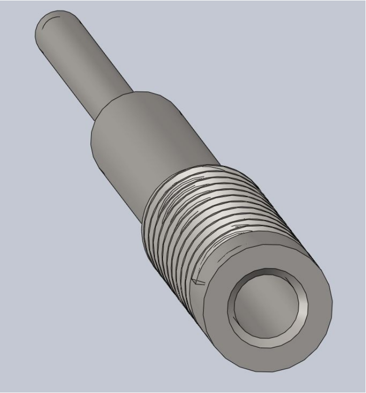




Top Surface of
Beta Motor Shaft:

~40 µm max
displacement

Axial displacement
may originate in
turn-indicating knob



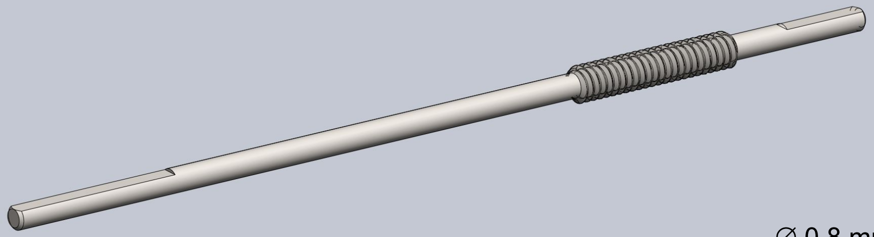
Difficult to thread MM Threaded Beta Shaft End into MMAF Fiber Arm

Required re-tapping and cleaning fiber arm a few times and gripping circular faces with sharp-nosed tweezers

Issue may be resolved when components are glued and threading can be driven by manual knob or motor

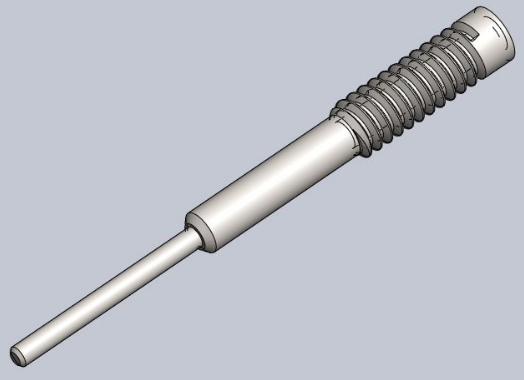
One fiber arm was ruined by inadvertent cross threading with the tap

MMAF Beta Motor Shaft



∅ 0.8 mm

MMAF Threaded Beta Shaft End

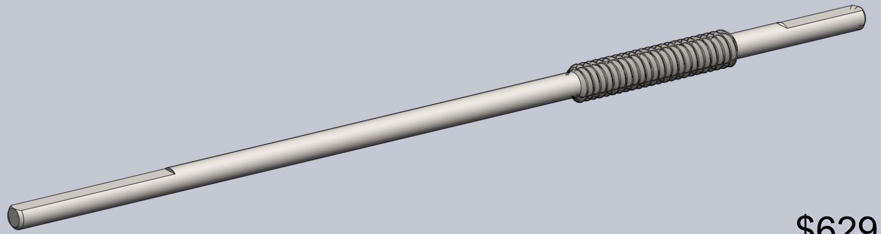


∅ 0.6 mm

Small diameter parts risk getting bent

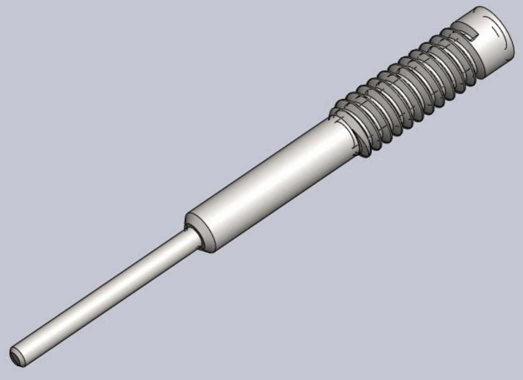
Small, high precision parts with multiple features can be costly

MMAF Beta Motor Shaft

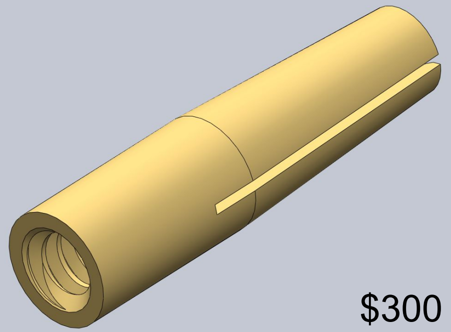


$629

MMAF Threaded Beta Shaft End



$629



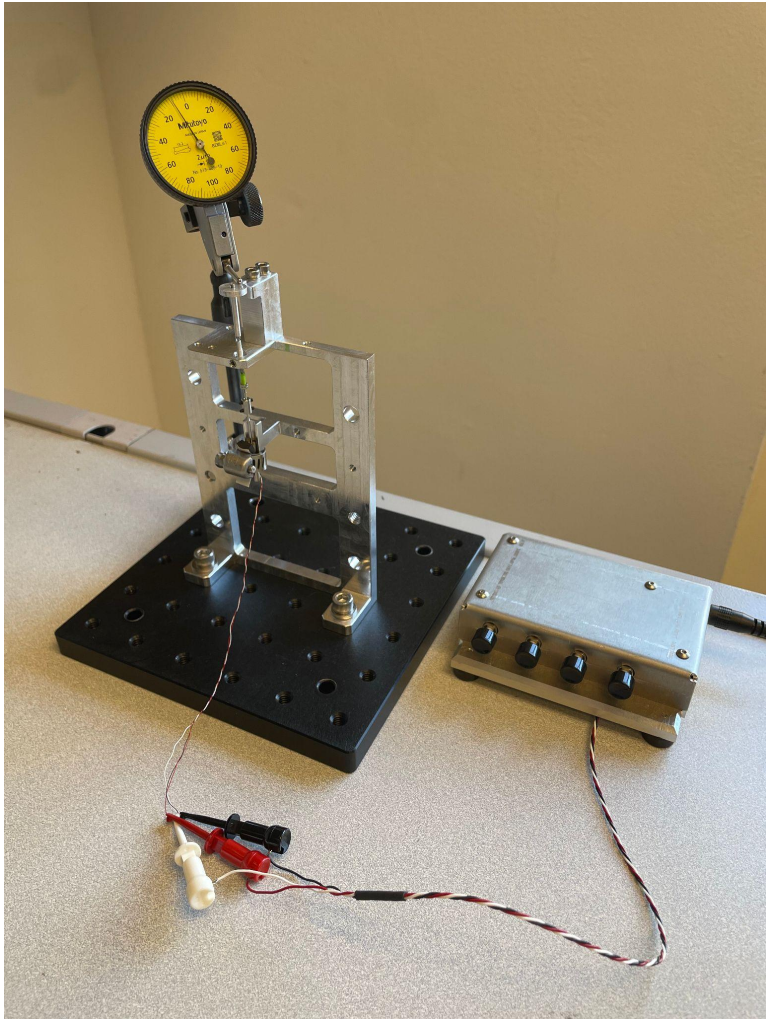
$300

Conclusions

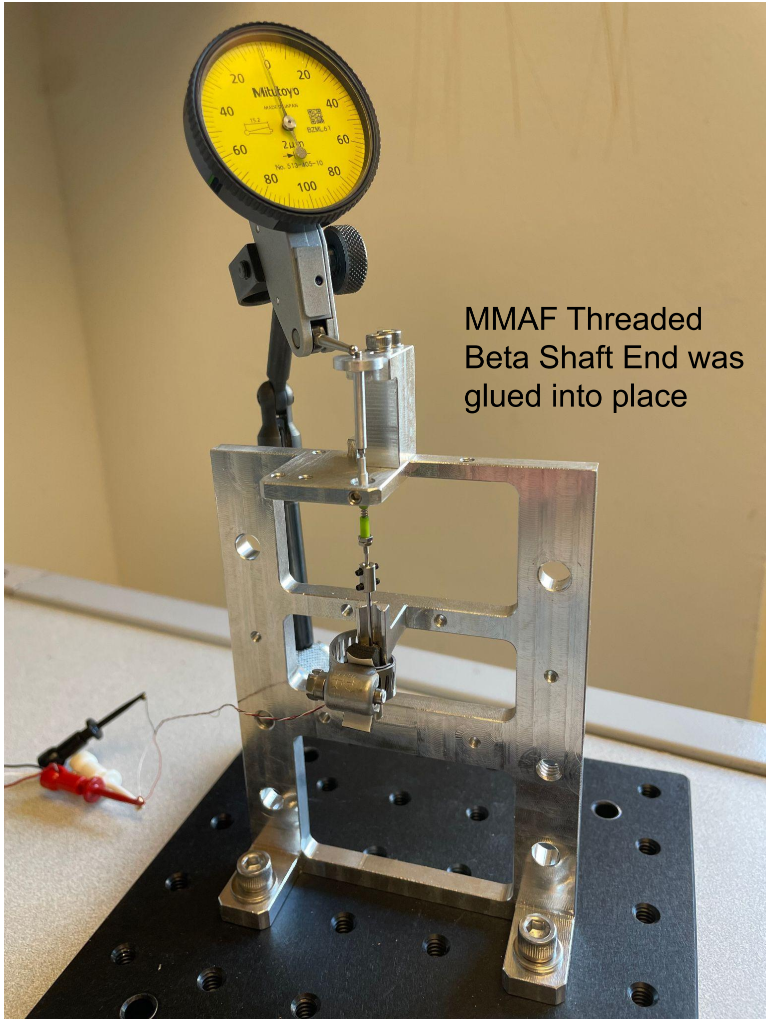
- Challenges
  - Non-alignment between part axes ⇒ precession
  - Main shaft is underconstrained
  - Small diameter parts risk getting bent
  - Large number of small, high tolerance parts with multiple features
  - Potentially high cost
- Potential Solutions
  - Constrain main shaft
  - Improve axial alignments
  - Ensure temper/material of small diameter parts prevents plastic deformation

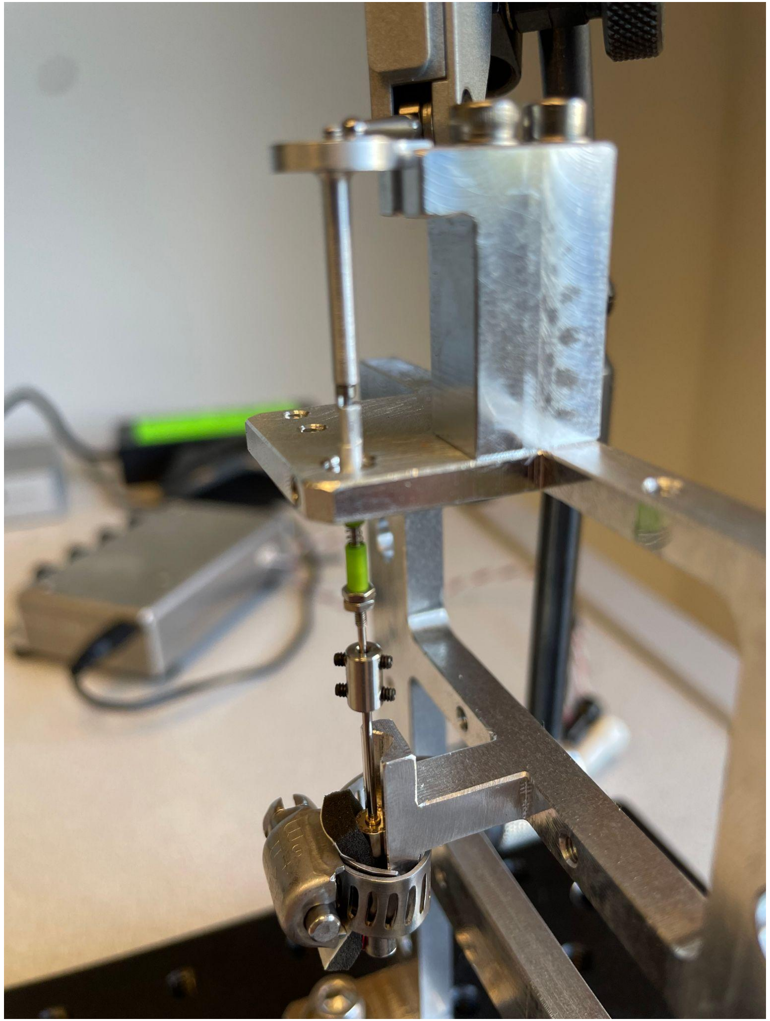
Trial 2:

Motor Actuation

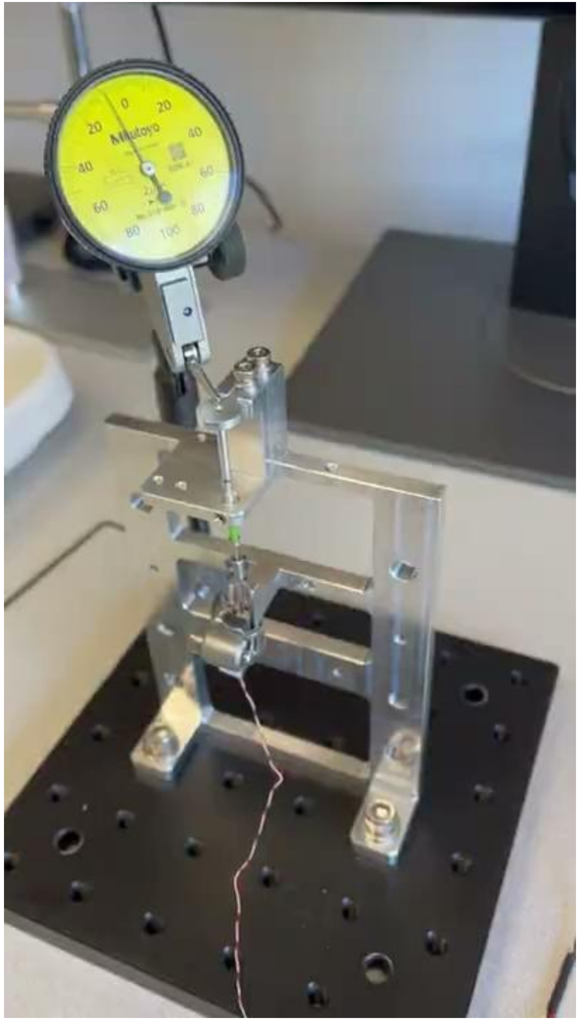


Motor and driver were installed


Mitutoyo
MMAF Threaded
Beta Shaft End was
glued into place



With the set screw loose (and having never been tightened against the collet) the motor successfully raised and lowered the fiber arm

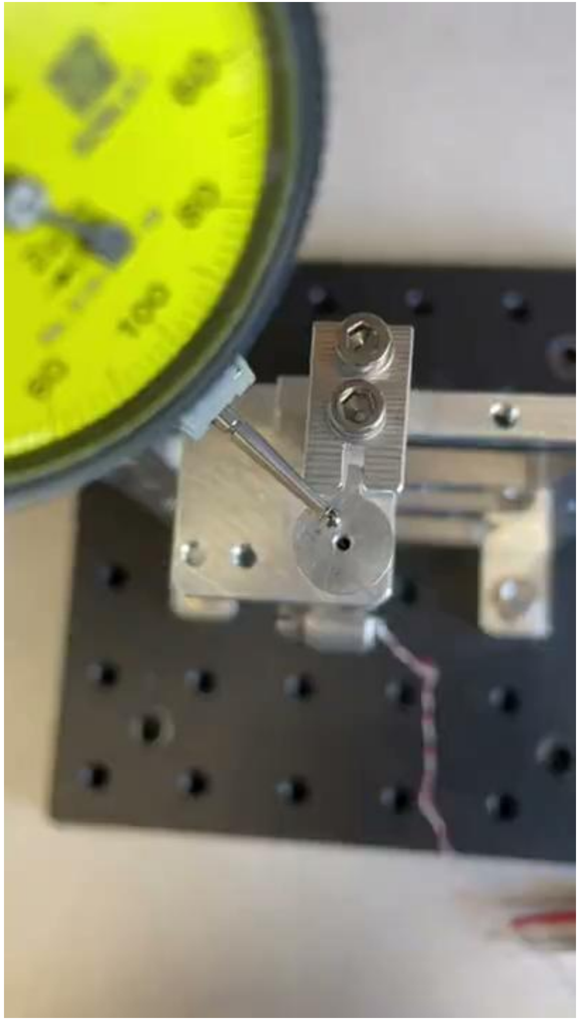


The set screw in the fiber arm was tightened

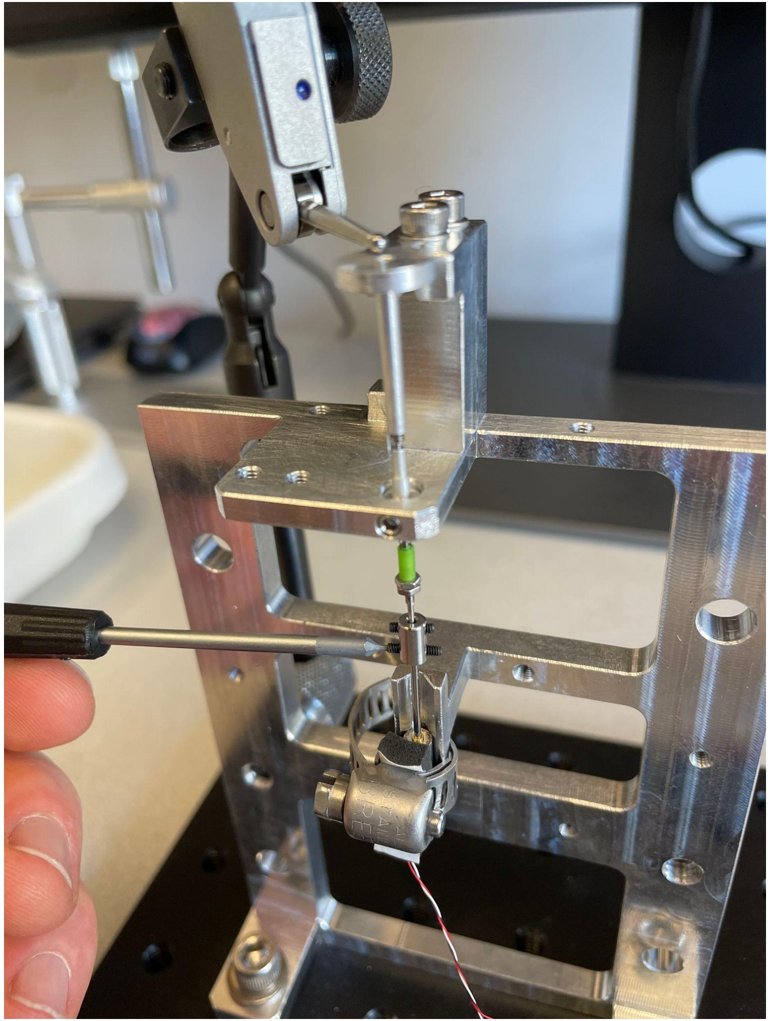
Tightening torque was not measured, but the set screw was tightened “lightly”, anticipating the risk of jamming the collet

As expected, the fiber arm was locked in place and the motor could not advance the screw

When the set screw was loosened, the fiber arm was still locked in place



Even with the set screw fully removed, the motor was unable to overcome friction



The shaft was decoupled from the motor and advanced manually, raising and lowering the fiber arm several times

Significant friction was present

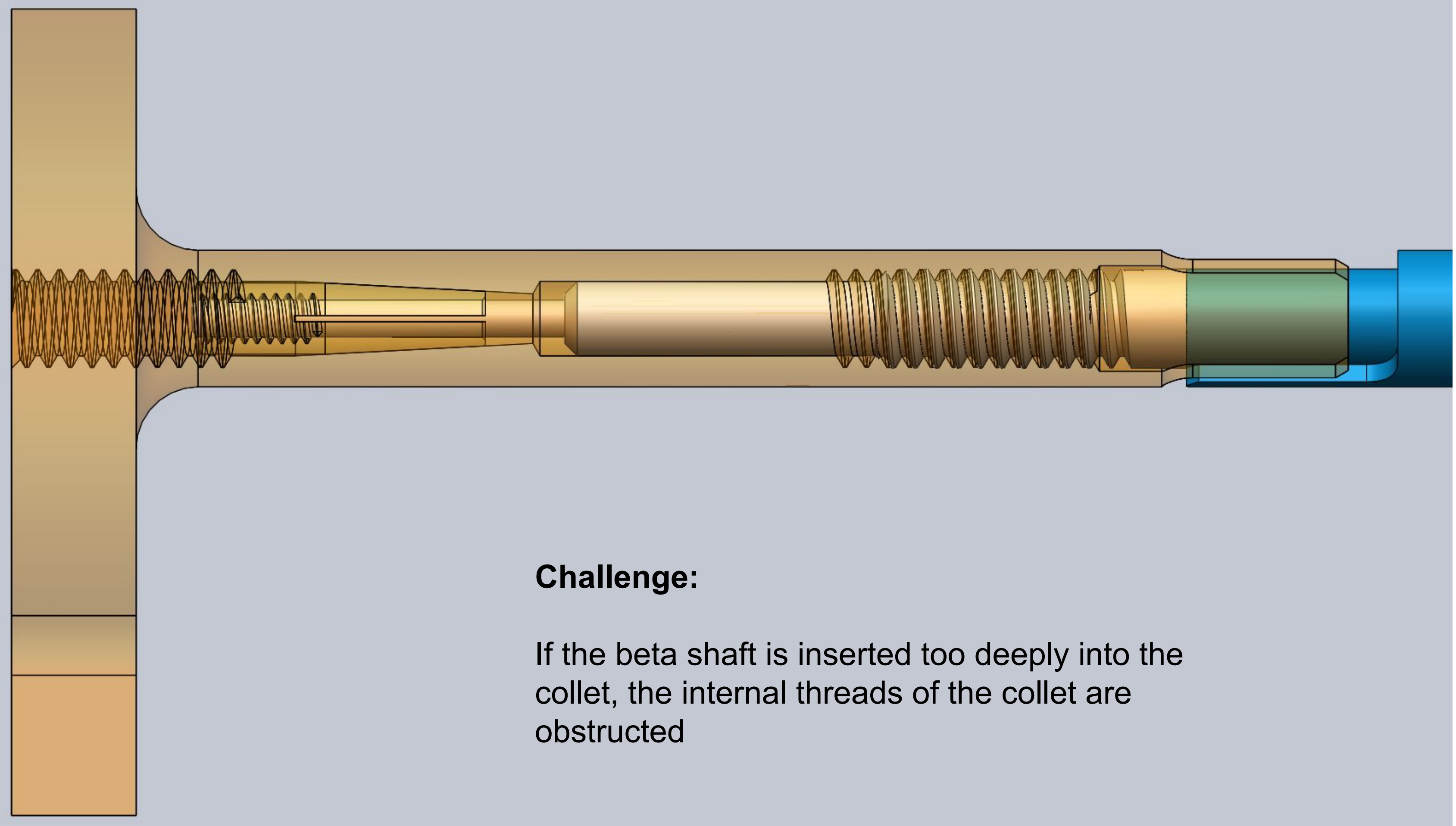
The shaft was recoupled to the motor and the set screw was left removed

The motor was still unable to overcome friction and advance the screw

⇒ After being tightened, the collet appears to get jammed into place such that the motor cannot overcome the resulting friction

Conclusions

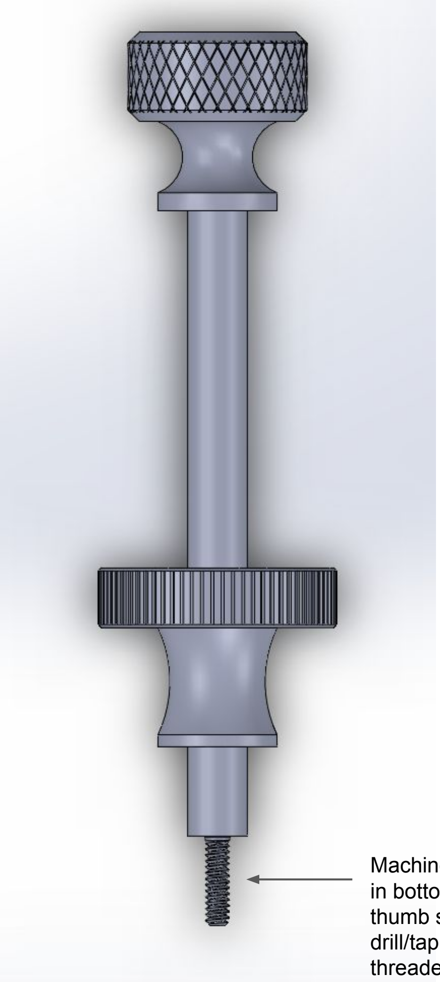
- Challenges
  - The collet appears to get jammed such that the motor cannot overcome the resulting friction
- Potential Solutions
  - Manually unjam the collet each time the fiber arm is adjusted by pulling it out with a tool threaded into the collet’s internal threads



Challenge:

If the beta shaft is inserted too deeply into the collet, the internal threads of the collet are obstructed

Collet Removal Tool



Machine M0.8 threads in bottom section of thumb screw (or drill/tap and insert a threaded post)

Stainless Steel Flared-Collar Knurled-Head Thumb Screw
M2 x 0.40 mm Thread Size, 24 mm Long

Flanged Knurled-Head Thumb Nut
18-8 Stainless Steel, M2 x 0.40 mm Thread Size, 8 mm Head Diameter