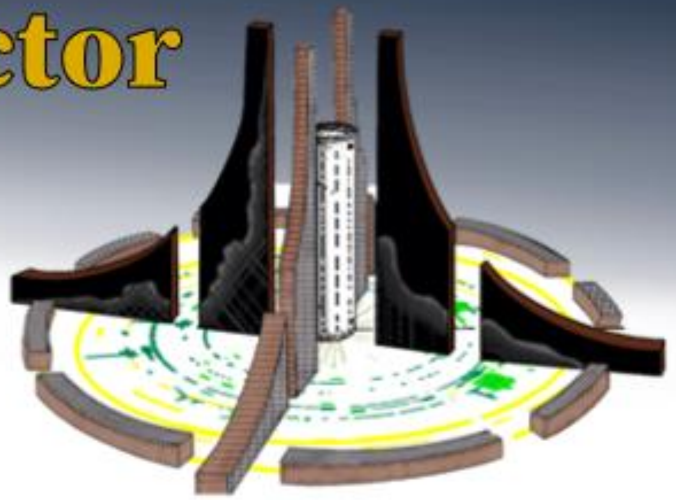
12th Forum on Tracking Detector Mechanics

Purdue University, West Lafayette, USA
29-31 May 2024



Assembly and installation of the MVTX silicon vertex detector into the sPHENIX experiment

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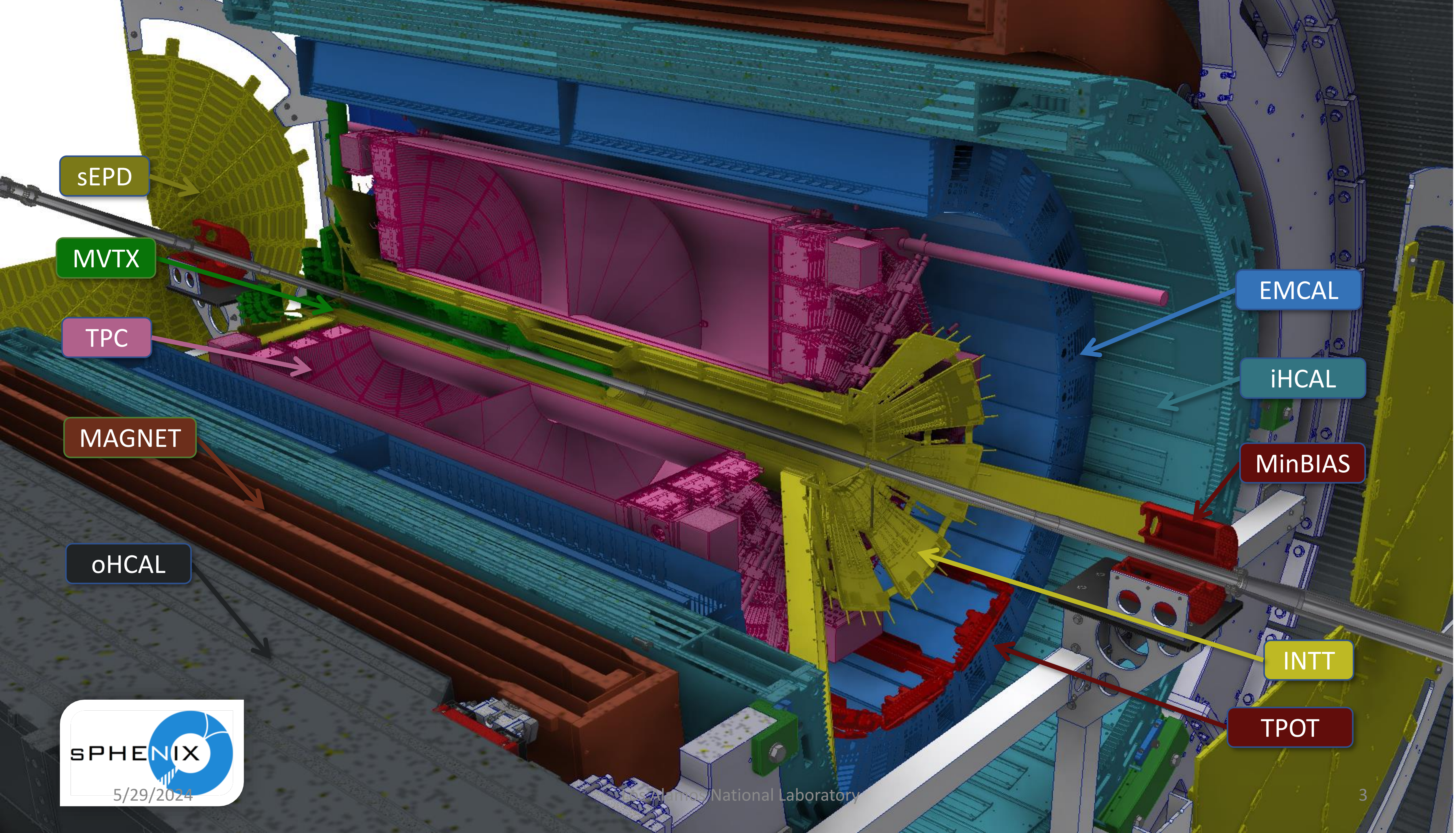
Los Alamos National Laboratory
May 29th, 2025

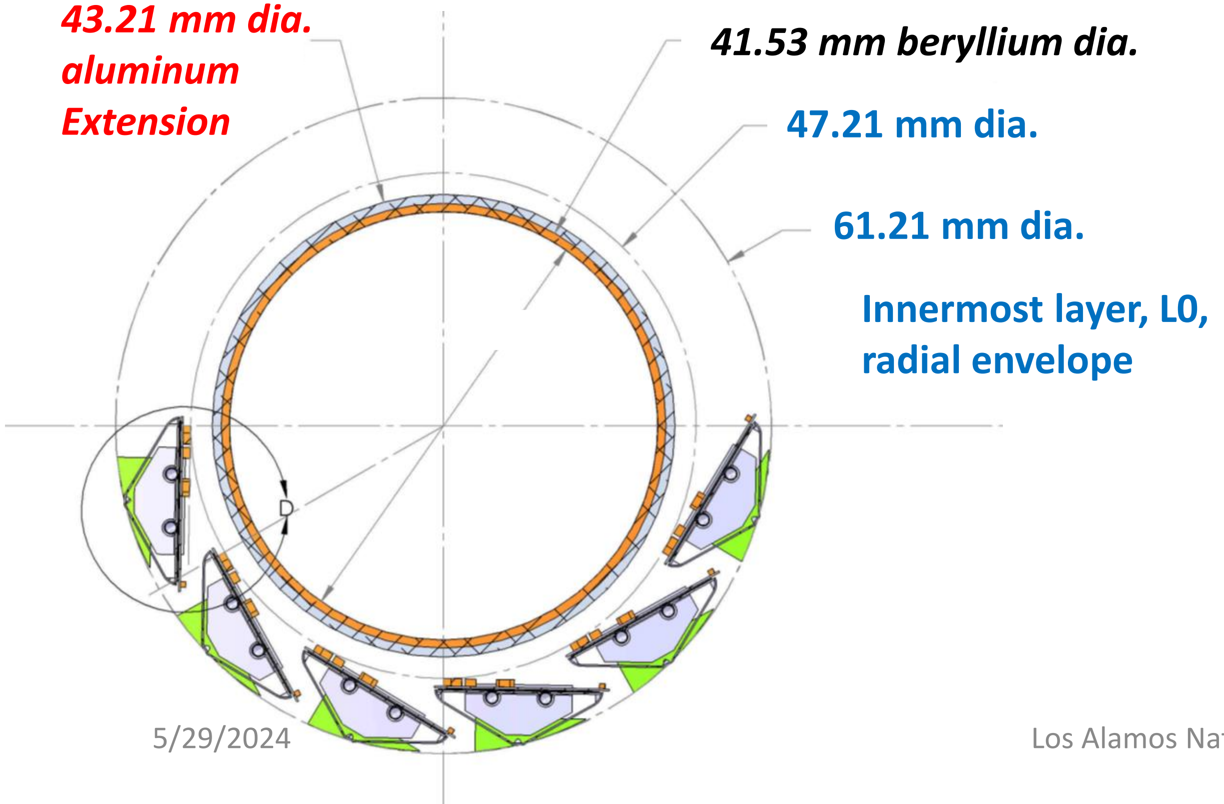
sPHENIX experiment at RHIC

- Collider physics experiment using the RHIC accelerator at BNL, major facility hall;
  - Physics goal take data with P-P and Au-Au collisions at 200 GeV
  - Overall size: length 7556.5 mm, width 7620.0 mm height 7473.0 mm
  - Solenoid magnet coil – BABAR experiment, SLAC, 1.4 tesla magnetic field


sEPD
MVTX
TPC
MAGNET
oHCAL
EMCAL
iHCAL
MinBIAS
INTT
TPOT
sPHENIX

Engineering challenge; to construct a silicon vertex detector as close as possible to the installed collider Beryllium beampipe and be able to install this detector with the other two tracking detectors in place – the INTT and the TPC

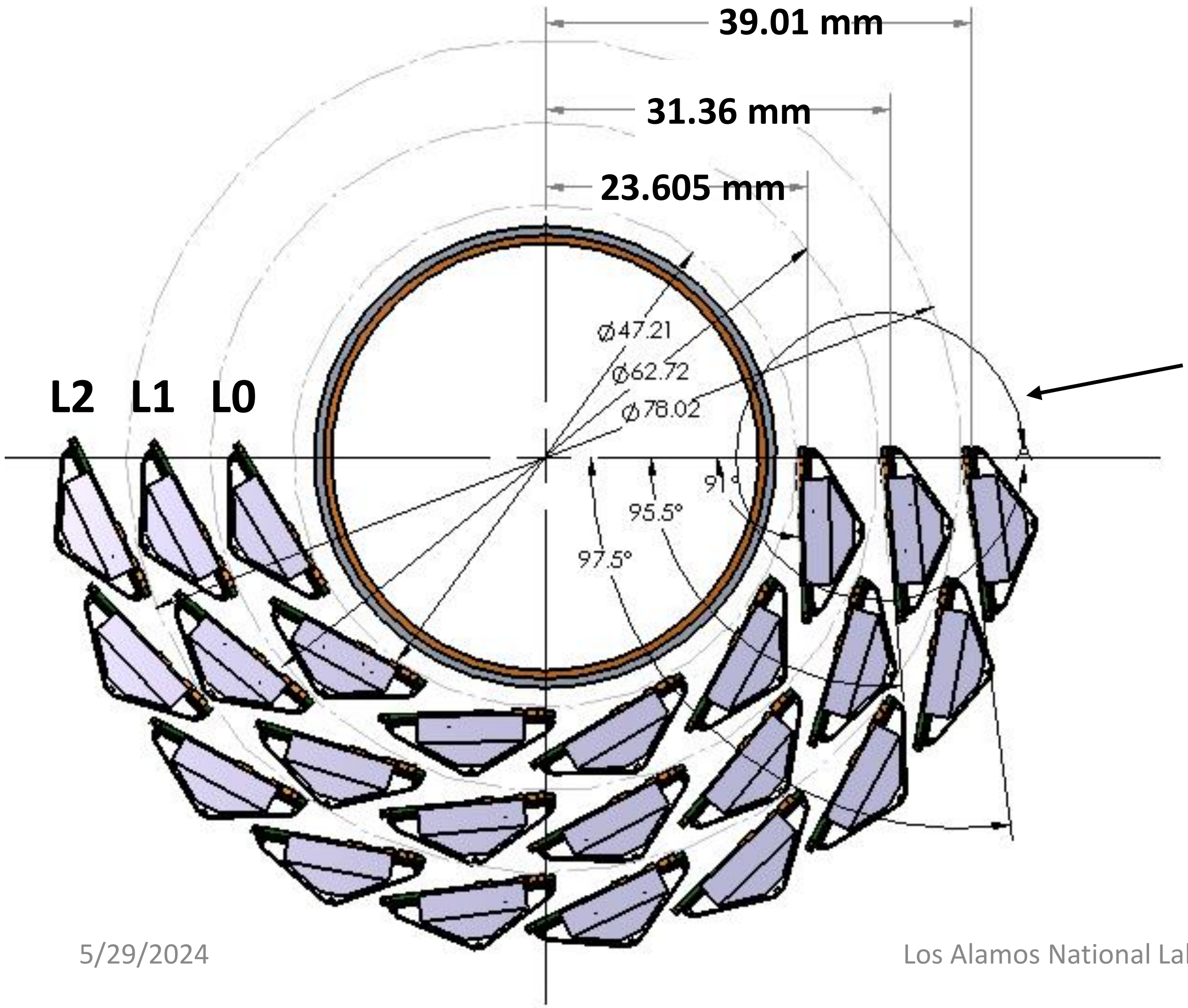
- The MVTX detector will be designed to make use of the same stave/ladders used in the ALICE ITS2 vertex detector.
- Different geometric constraint:



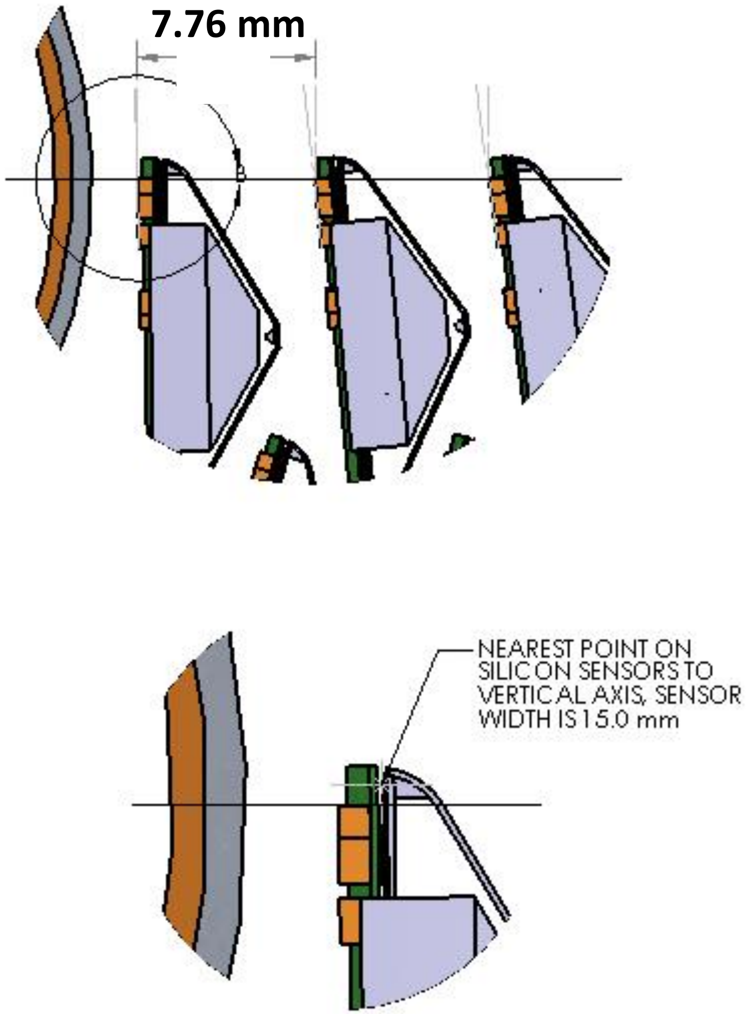
ELEMENTS	ALICE ITS2	sPHENIX MVTX
# Staves, 3 radial layers	48 (inner barrels)	48
Cantilevered Length (support-to- IP)	~1.0 m	~1.8 m
Beampipe radius	19.0 mm	20.76 mm (Be) / 21.7 mm (Al)
Inner Layer L0 sensors radius	22.38 mm	23.61 mm
Beampipe clearance (to sensors)	3.38 mm	3.85 mm (Be) / 2.91 mm (Al)
Beampipe clearance (to nose flange)	3.38 mm	2.07 mm (Be) / 1.125 mm (Al)
Primary structural construction	Foam core carbon fiber	Carbon fiber
Detector split configuration	Top / Bottom	Left / Right
Expected total radiation dose	2700 kRad	< 100 kRad

New radial configuration for three layers of staves for the MVTX detector in sPHENIX

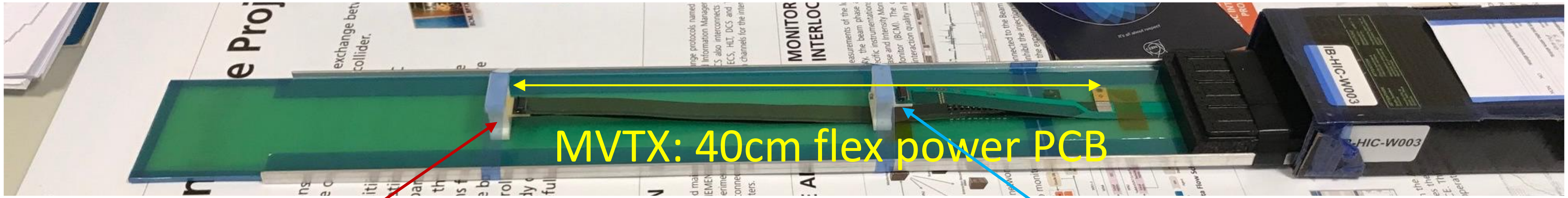
Radial distance to closest point on silicon sensors:



Detail view



Modification to ITS2 stave assembly, extended power cable by 40.0 cm, needed because of radial space restriction – INTT for patch panels



Location for patch panel for power cables in ***service cylinder*** down stream of CYSS

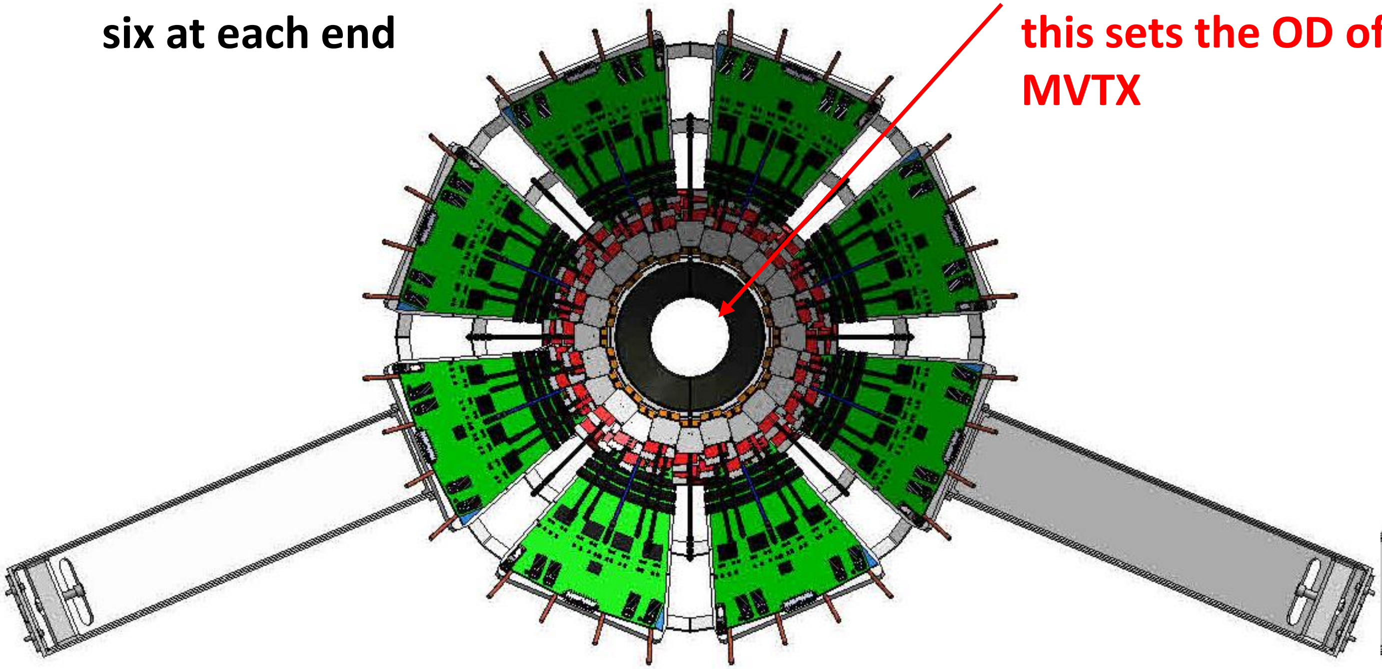
Location for patch panel at CYSS, signal cables

With the ***tested*** extended length of the power cables from the stave we now have a path forward to reduce the diameter of the ***patch panels*** in the conical region of the MVTX detector

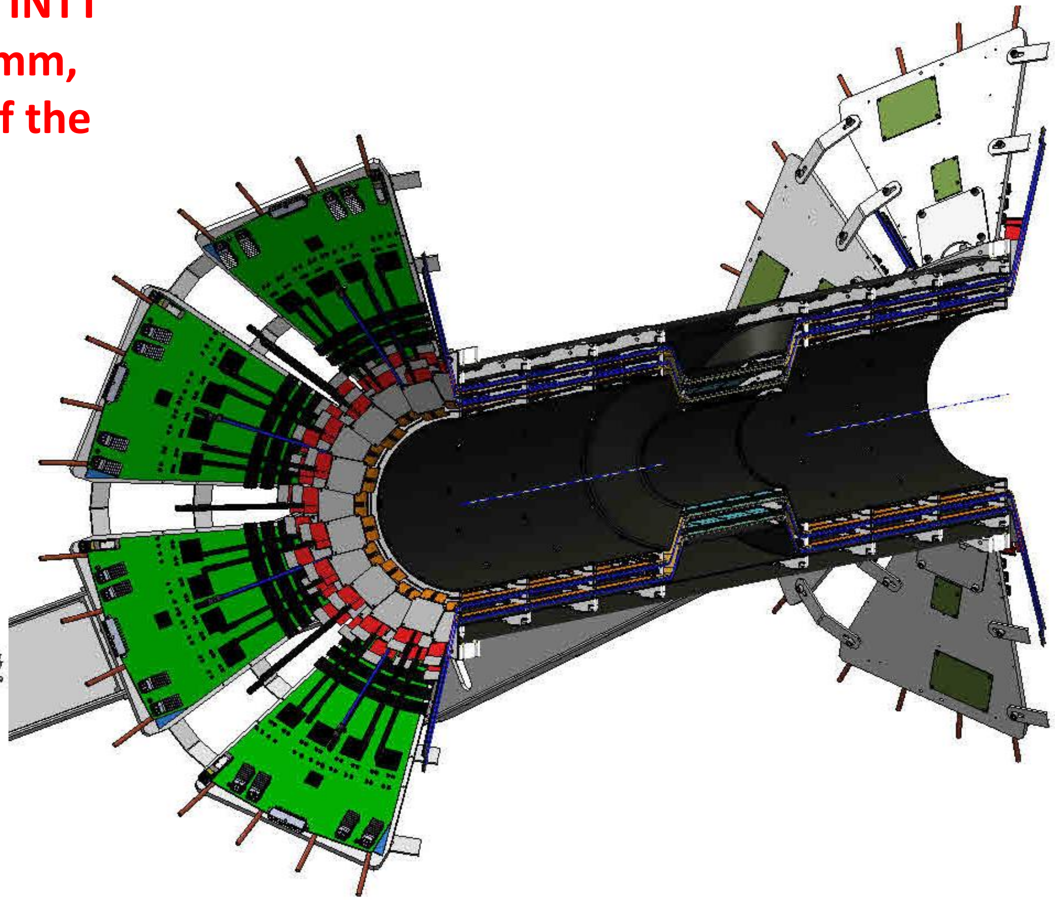
INTT sets the maximum outer diameter for the MVTX

INTT read-out cards, six at each end

Inner diameter of INTT inner shell 129.7 mm, this sets the OD of the MVTX

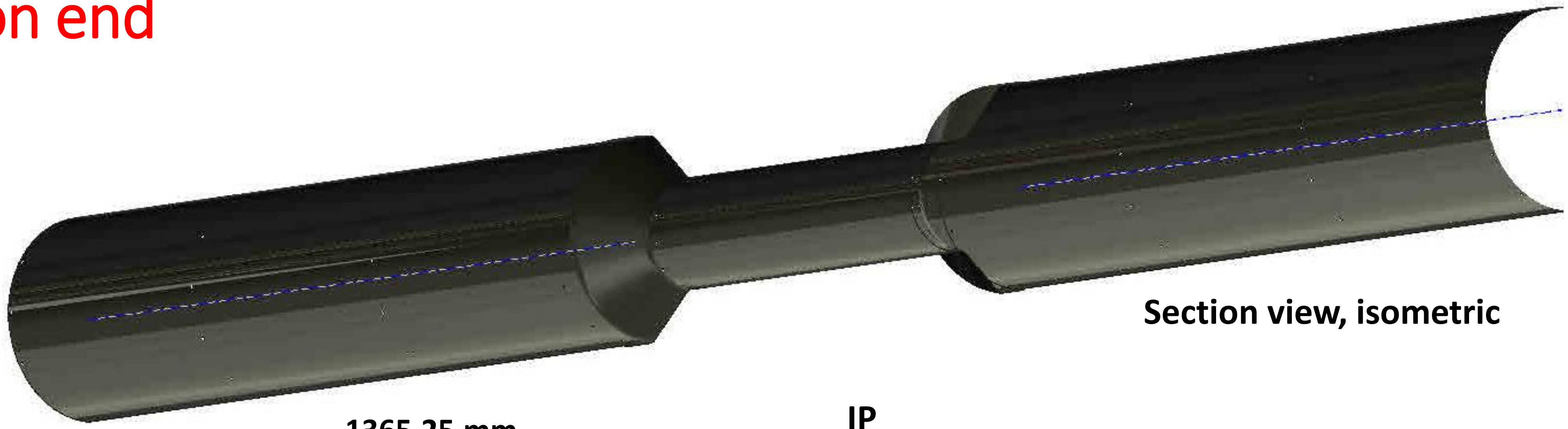


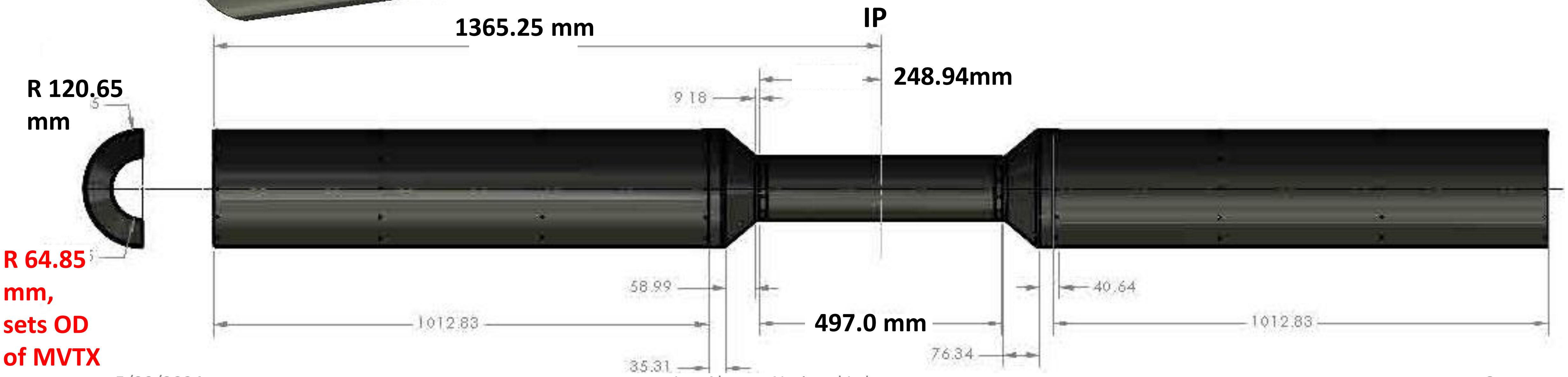
End view with support structure



Section view, lengthwise, inner carbon shell defines outer MVTX envelope

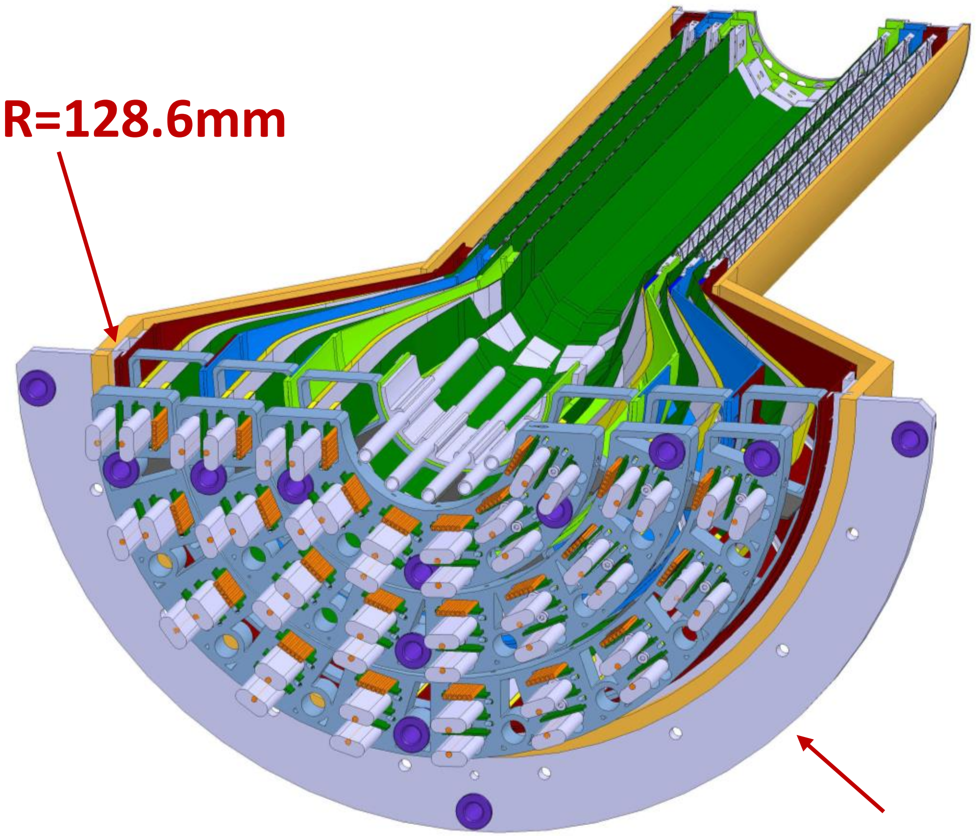
INTT inner carbon tube, the MVTX vertex detector will be designed that the staves center about the IP, 1365.25 mm at a minimum from the insertion end

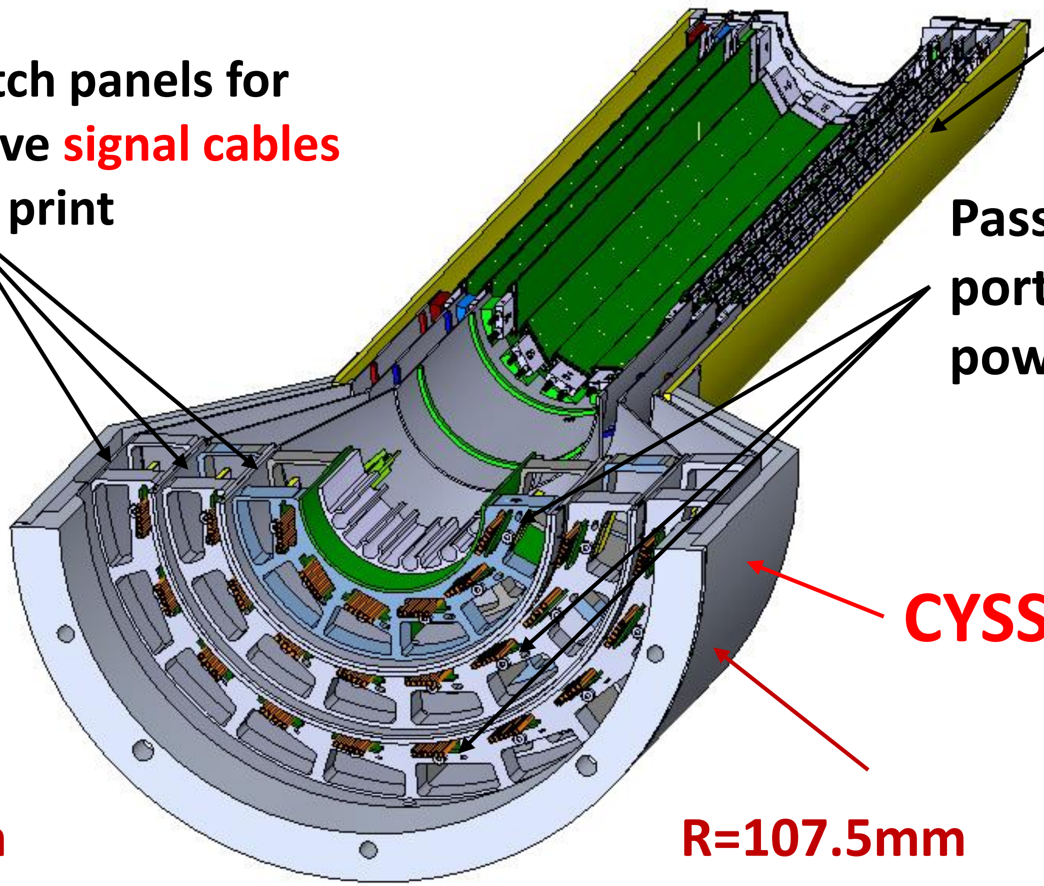




Conical sections of MVTX needs to have smaller diameter from ALICE ITS2 design

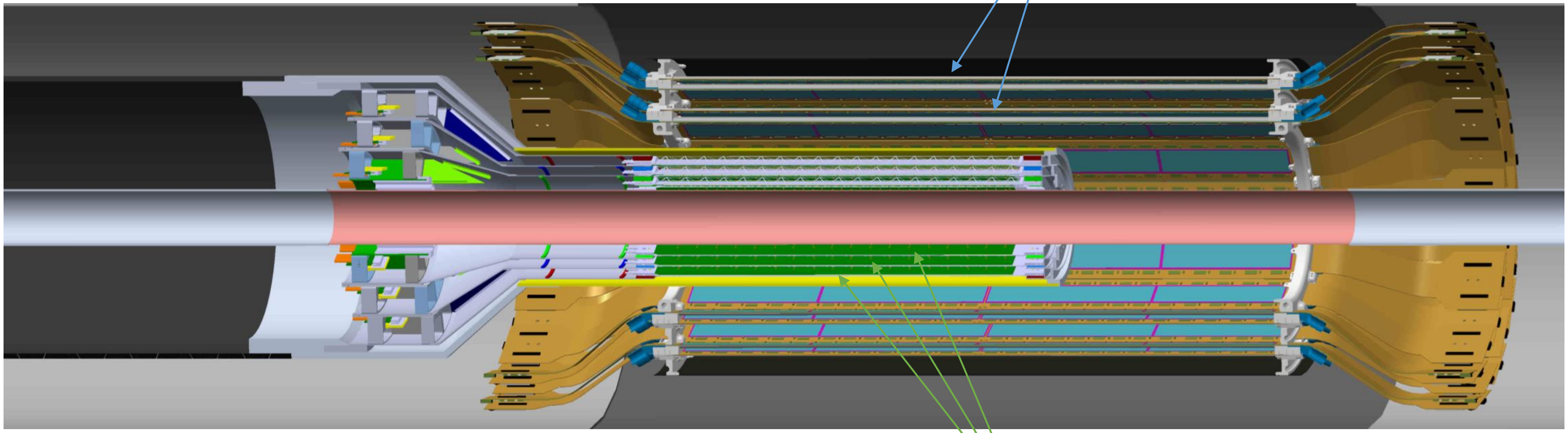
Integration with **INTT** detector prohibited by original larger diameter of conical region:





Thread the needle, integrate the MVTX with the INTT and the beam-pipe

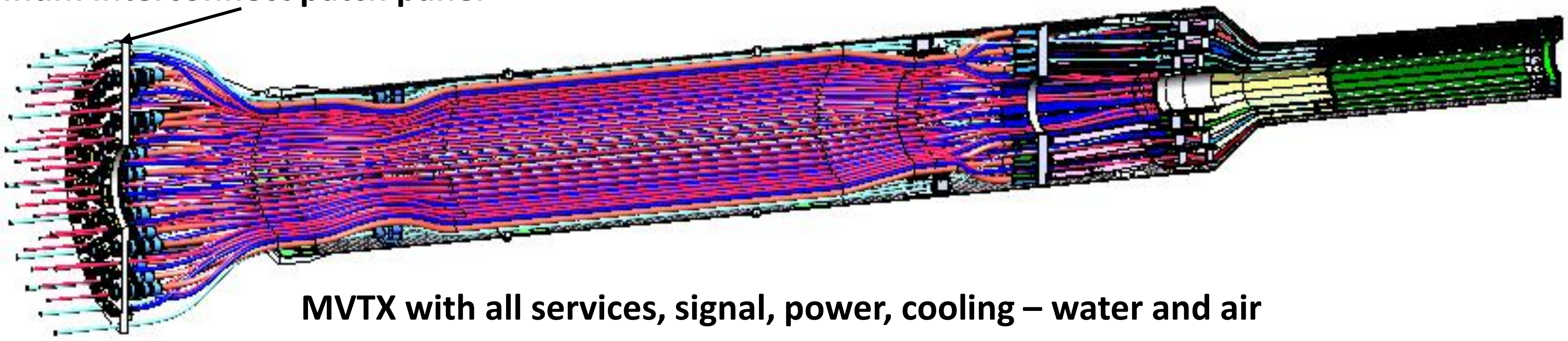
Two layer silicon strip ***INTT*** detector,,
Extension cables go out each end



Three layer ***MVTX*** detector
Extension cables only in ***service cylinder***

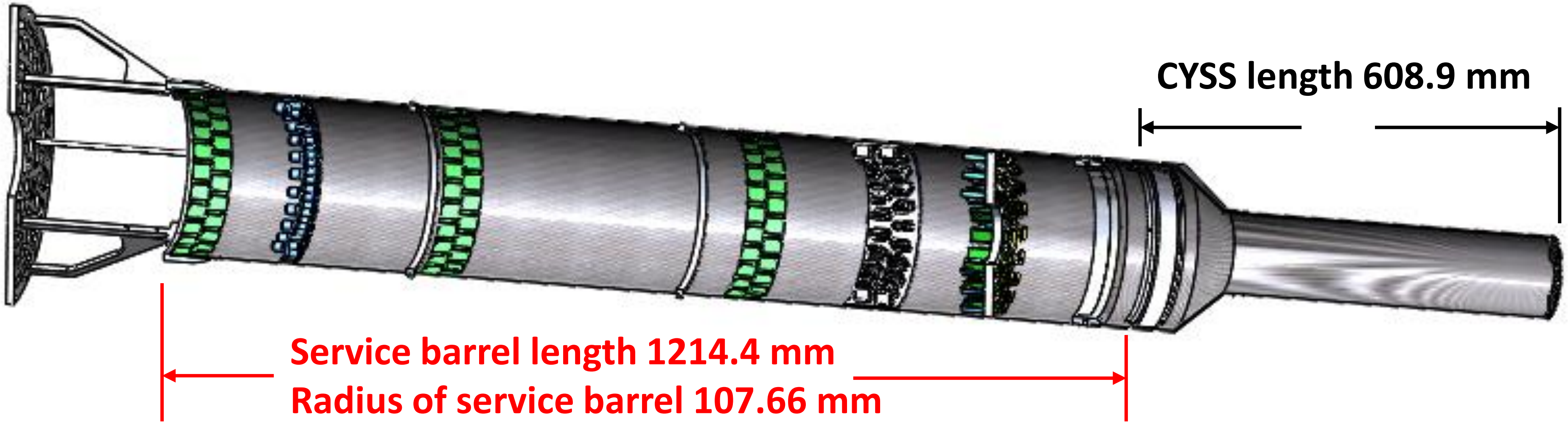
Initial CAD model for a half MVTX assembly

Aluminum interconnect patch panel



MVTX with all services, signal, power, cooling – water and air

CYSS length 608.9 mm

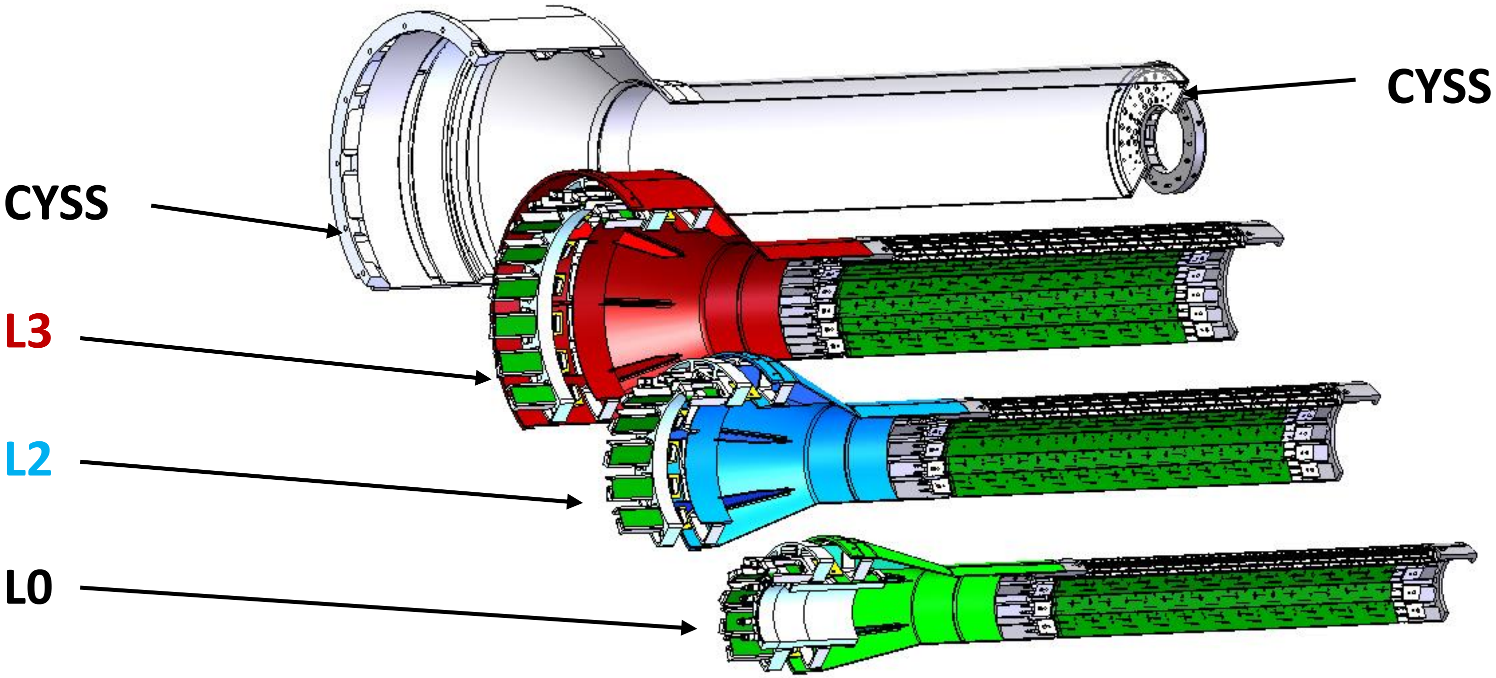


Service barrel length 1214.4 mm
Radius of service barrel 107.66 mm

Proposed MVTX exterior carbon composite structure

Composite fabrication: *Work-shape*, La Roche-de-Glum, France

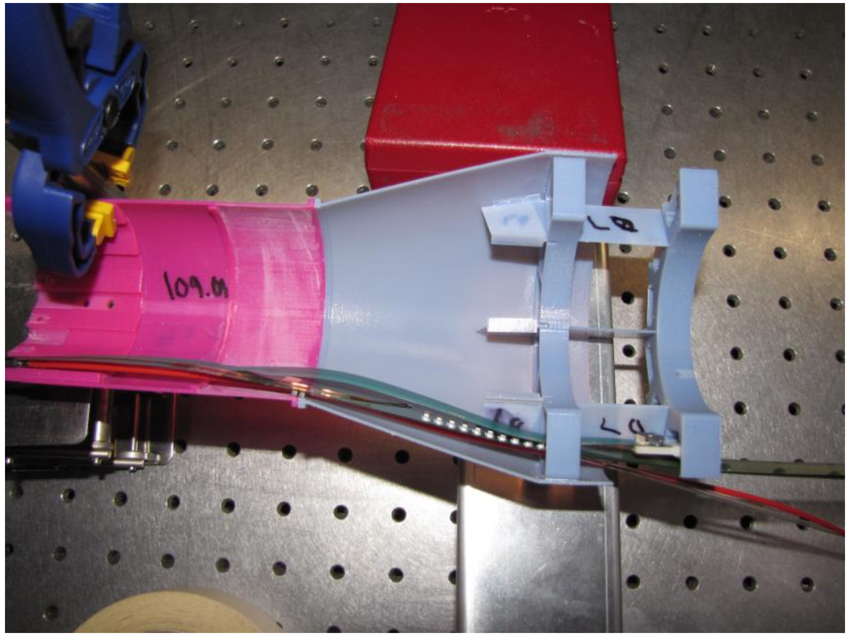
- Fabricated composite pieces for ALICE ITS2 assembly
- Owner Simon Rubet
- Contract to fabricate all composite pieces and pre-assemblies for the MVTX detector, 26 individual pieces; including end wheels for each of the three layers, CYSS outer shell for the stave assembly, long half service barrel assy.
- Material choice: NGF Granoc; F8A03-1437 fiber with NM31 resin



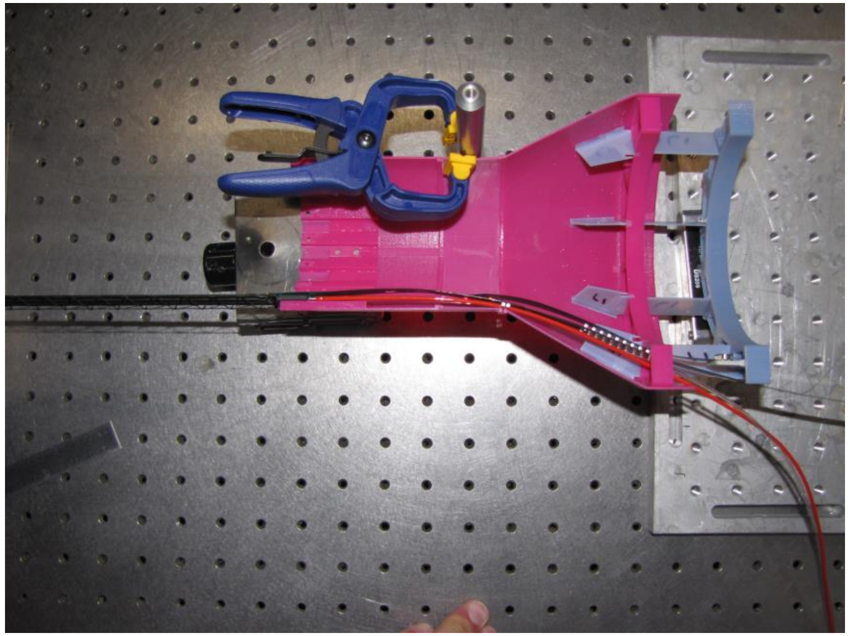
All three layers nestle with in each other using alignment pins and an indexed end flange as a part of the CYSS shell

3D print prototype pieces to verify design will function with routing of service, before finalizing design for fabrication

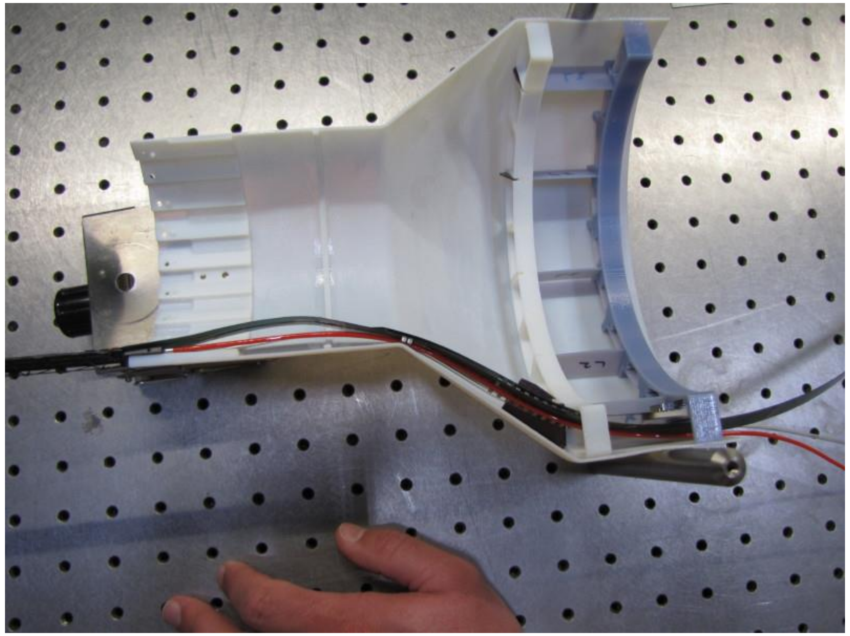
Layer 0, stave services side



Layer 1, stave services side



Layer 2, stave services side



Work-Shape designs fixtures for composite layups, example L0

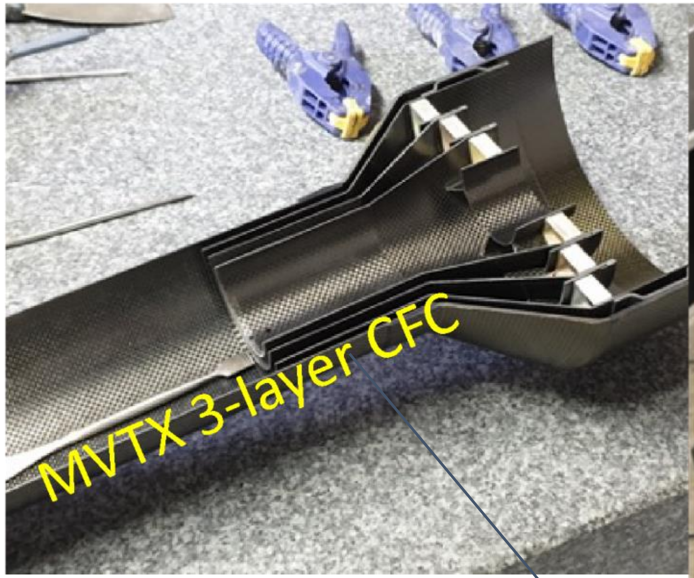
Work-Shape aluminum and 3D printed parts for L0 stave pass-through and stave signal cable termination interface

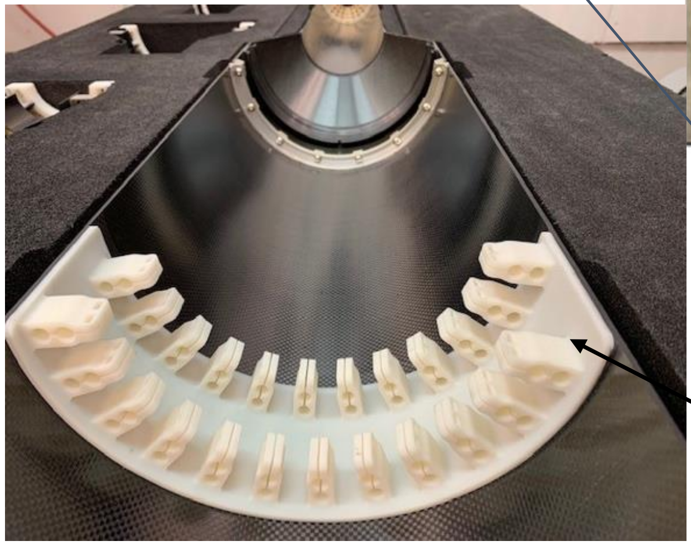
7075 aluminum pass-through and divider mount

Accura25 PP1

Delivery of composite pieces at LBNL from *Work-Shape* for layer assembly

1) **Carbon fiber components:**
   - in hand & meet design specifications/tolerances, verify with CMM.
   - Pre-assembled sections bonded using Scotch DP490 epoxy, this includes services supports, patch-panel and support ribs in interior of service barrel.
   - Similar bonding of detector layer end assemblies, like the one shown in the upper left picture.
   - All bonding was performed at Work-Shape prior to shipping.



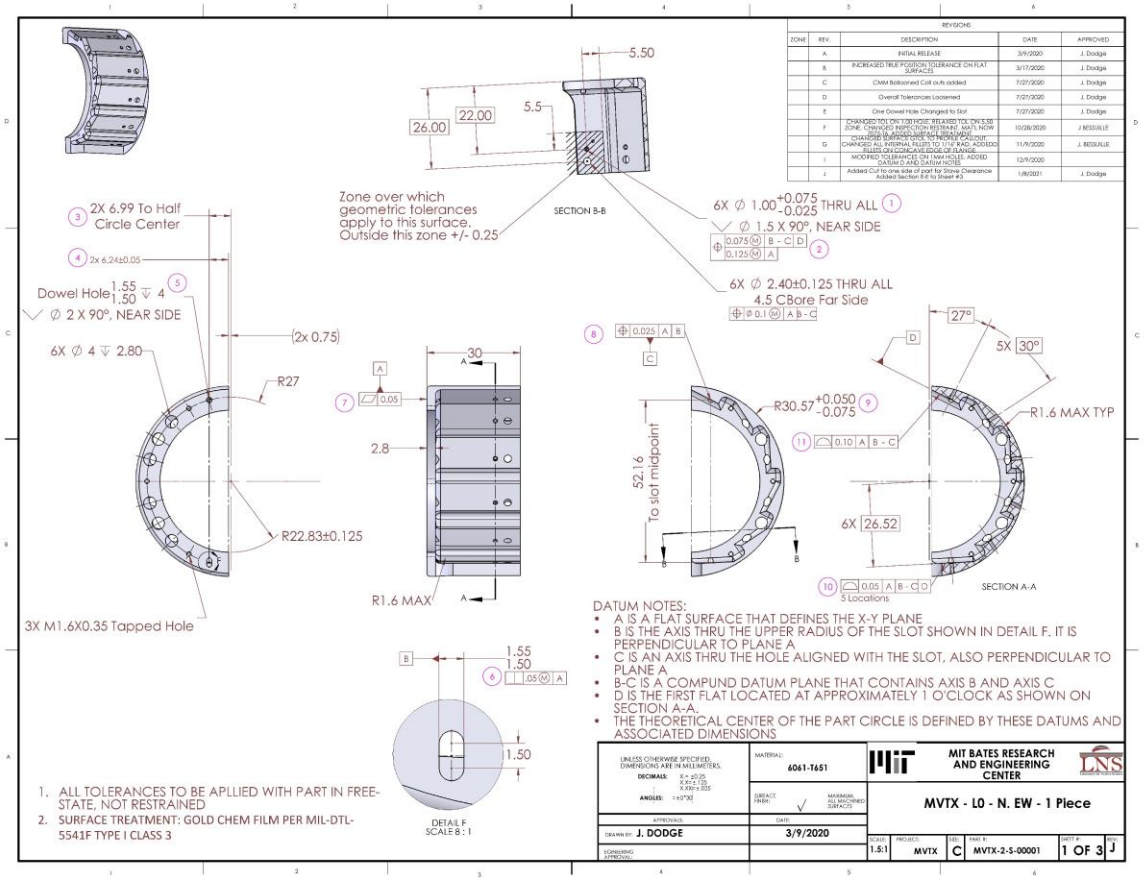


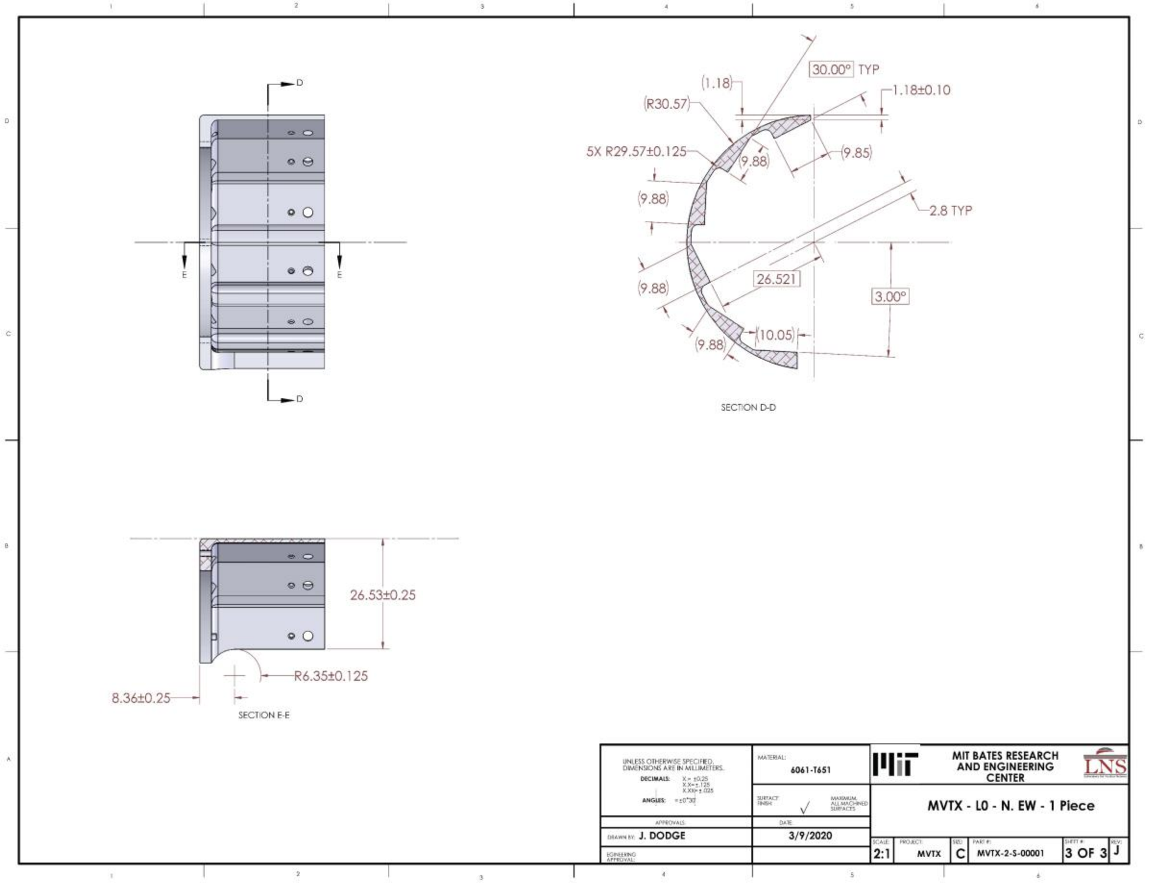
3D print services support, Accura Bluestone

Precision machined end wheels to locate staves in each layer

- To simplify each layer assembly a single machined piece was chosen
  - Material 6061 T651 aluminum, anodized, five axis machined, Layer 0 drawings:
    - Staves located using ruby ball in end wheels that aligns with hole and a slot in stave assembly
    - End wheels machined to very tight tolerances

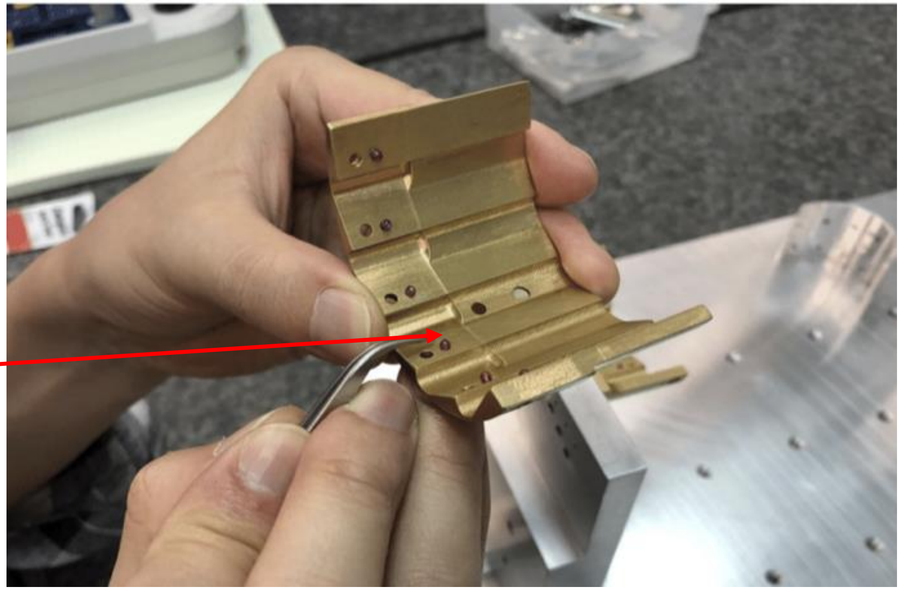
L0 South end wheel, sheets 1 & 3





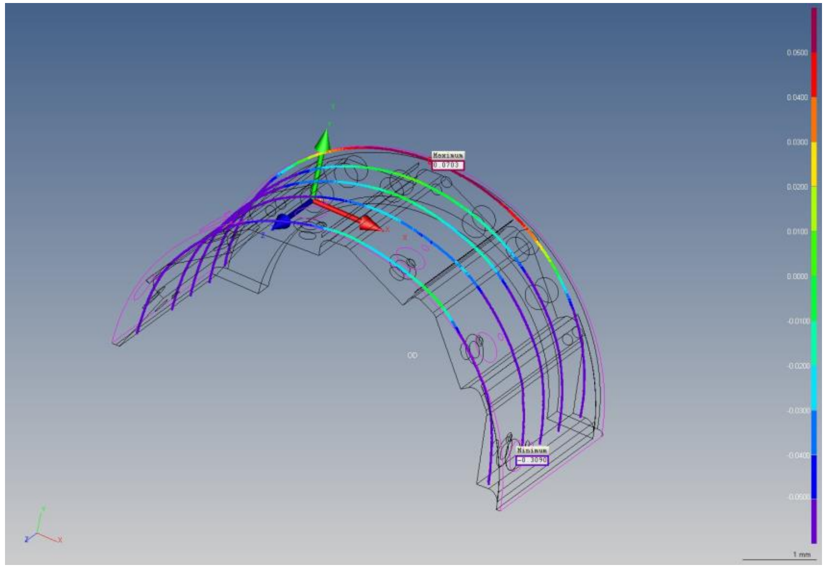
Fabricated aluminum end wheels prior to final assembly

Locate stave to end wheels;



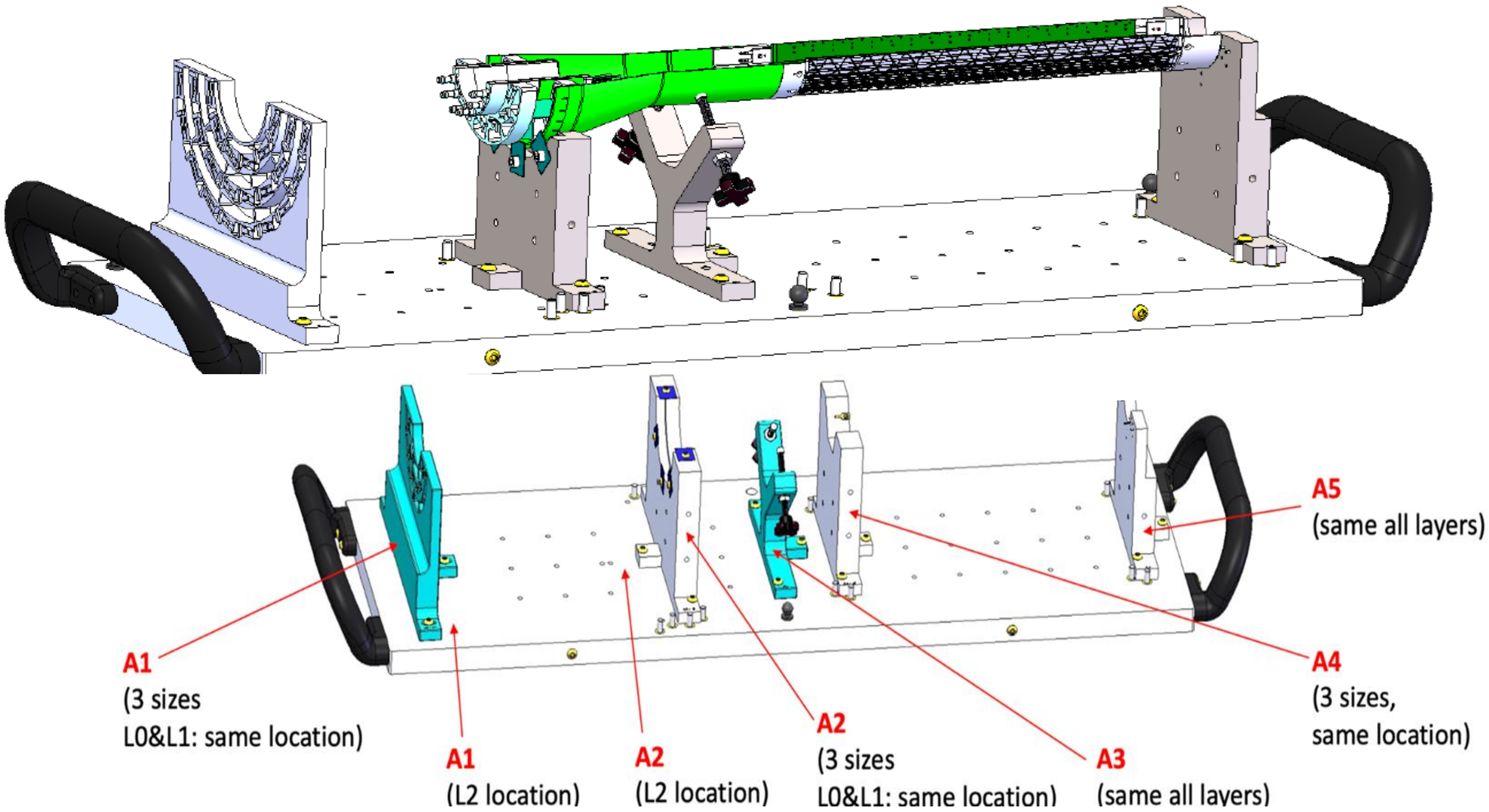
1.0 mm dia. pin,
3.1 mm dia. ball.
Key match pin to hole in end wheel

CMM Study end wheel



Fixtures; critical to the assembly of the three inner layers

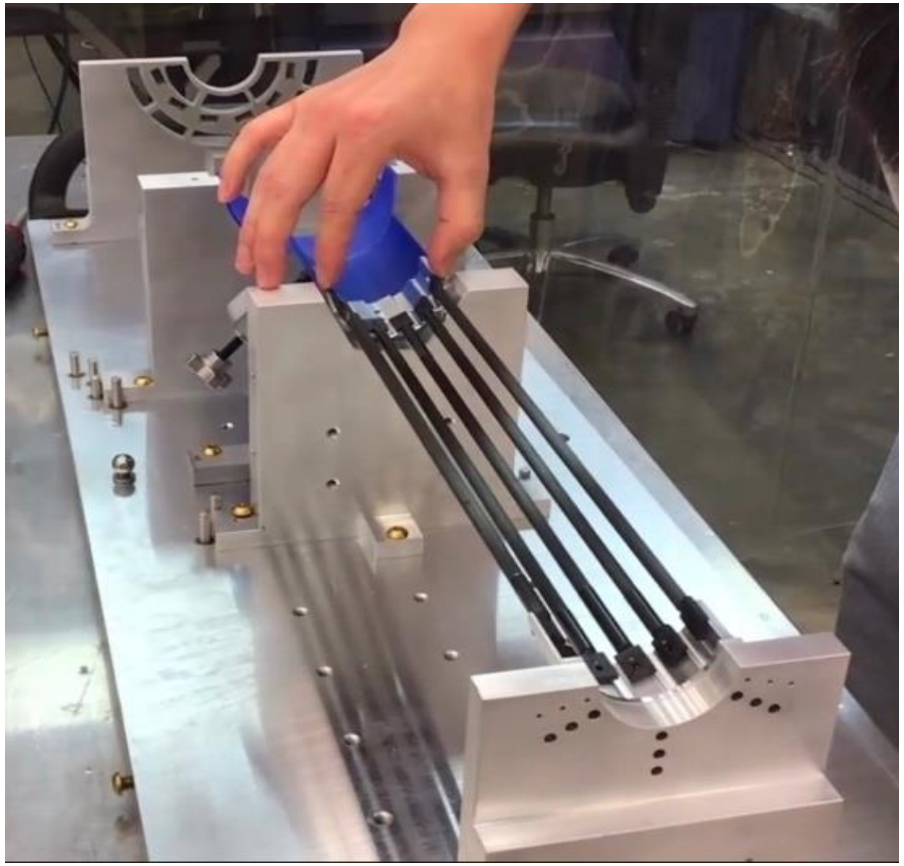
- Precision fixtures necessary so the two half detector assemblies come together around the beam-pipe to make 2π coverage.



L0 assembly fixture, used in one of 35 step assembly procedure for just this layer!
Using CMM is necessary to verify the dimensional tolerance of a fixture.

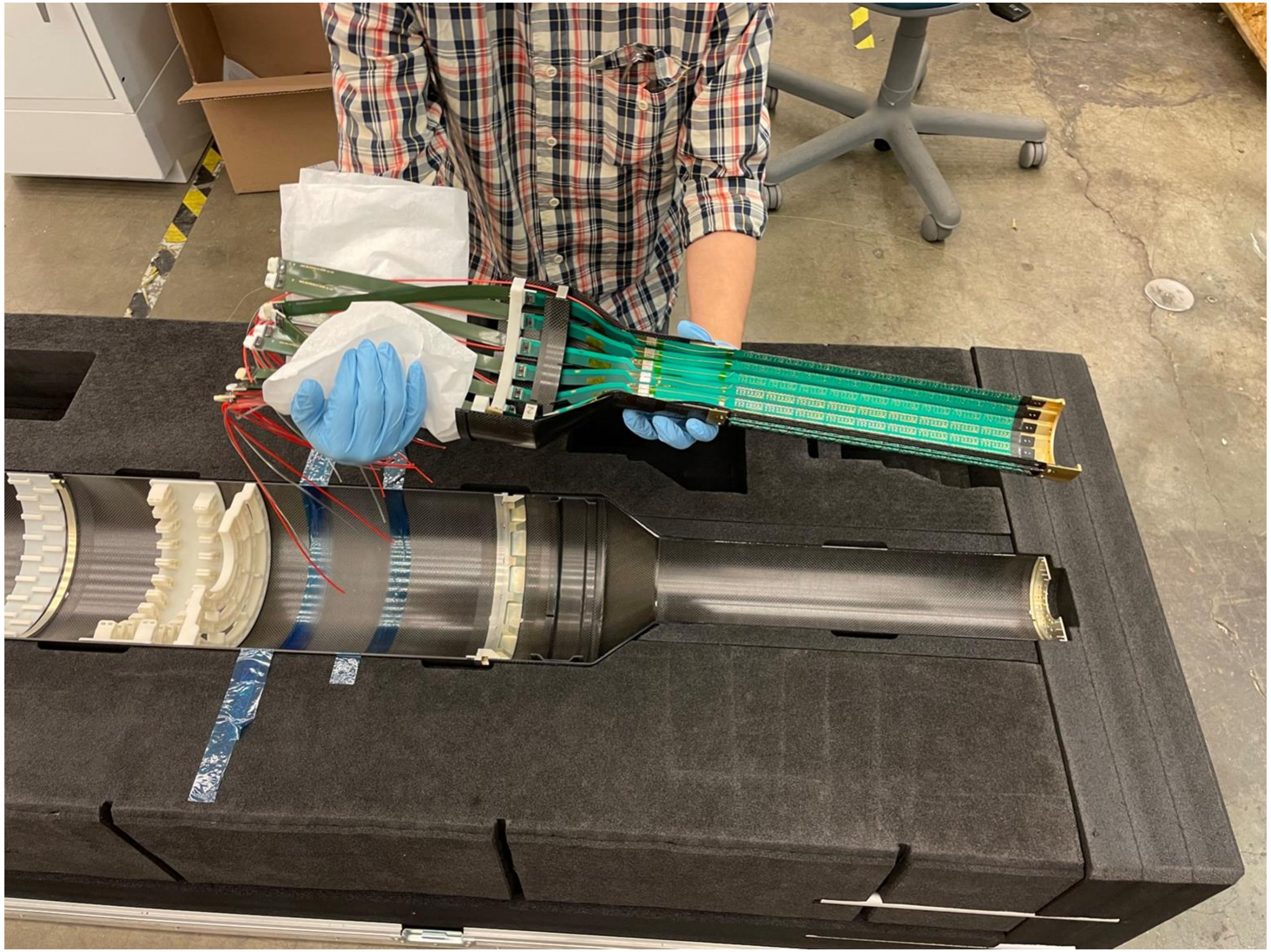
Layers L0 and L2 in assembly fixture with dummy staves

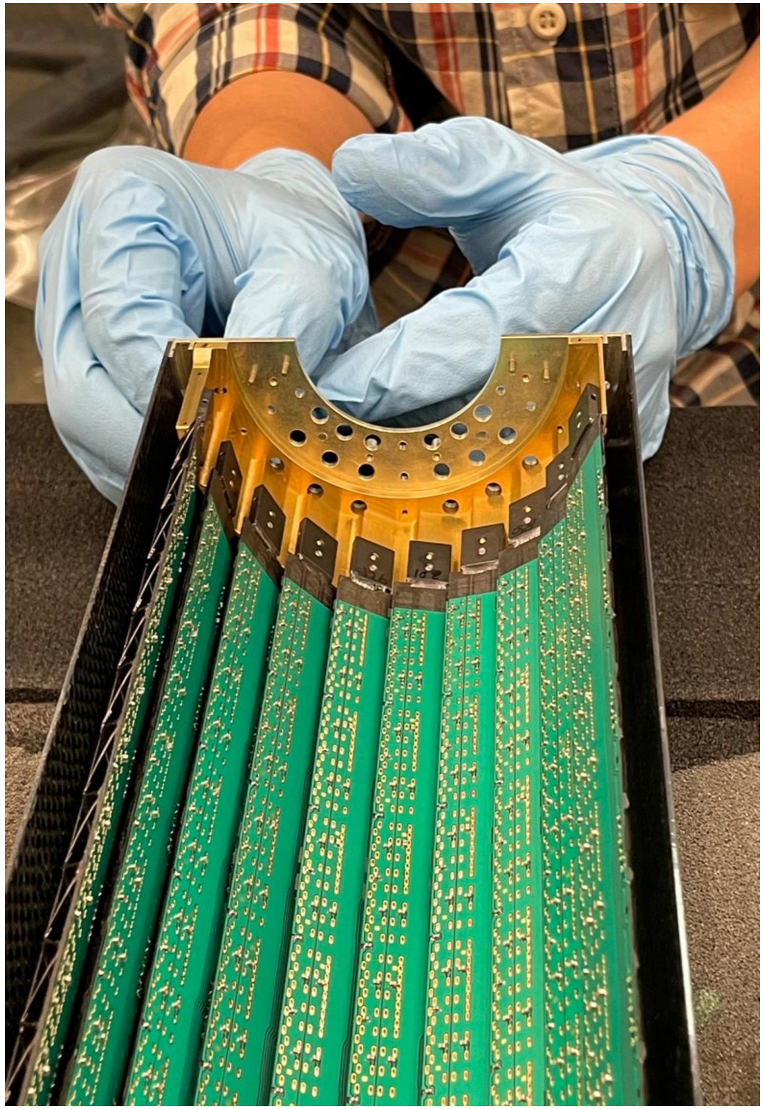
L0



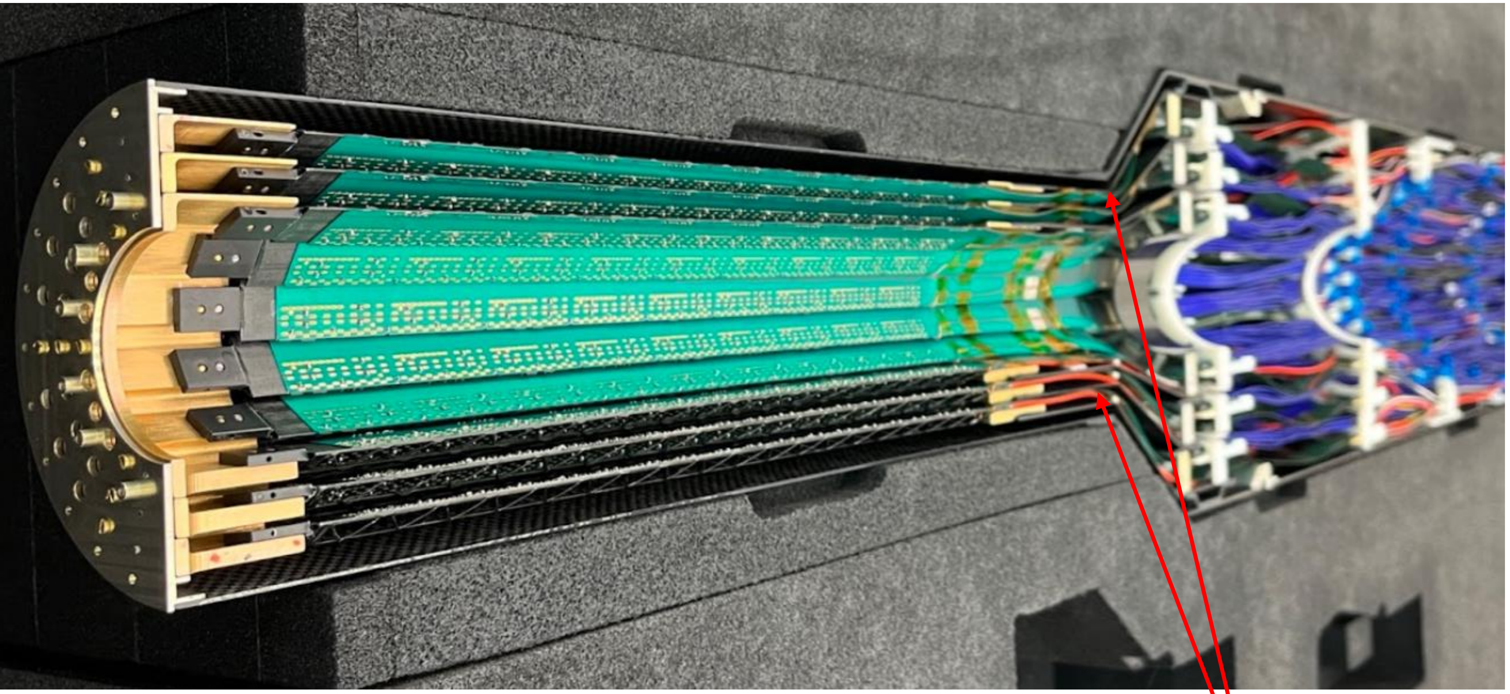
L2

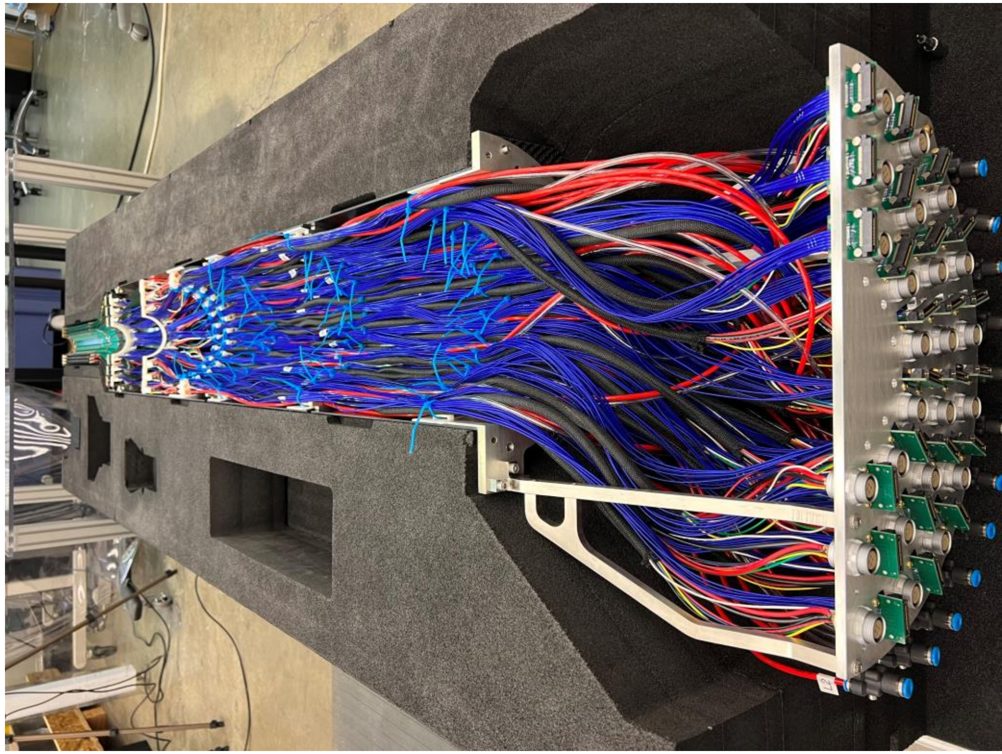
Mating assembledL2 with service barrel





Half MVTX assembly, three layers with attached services

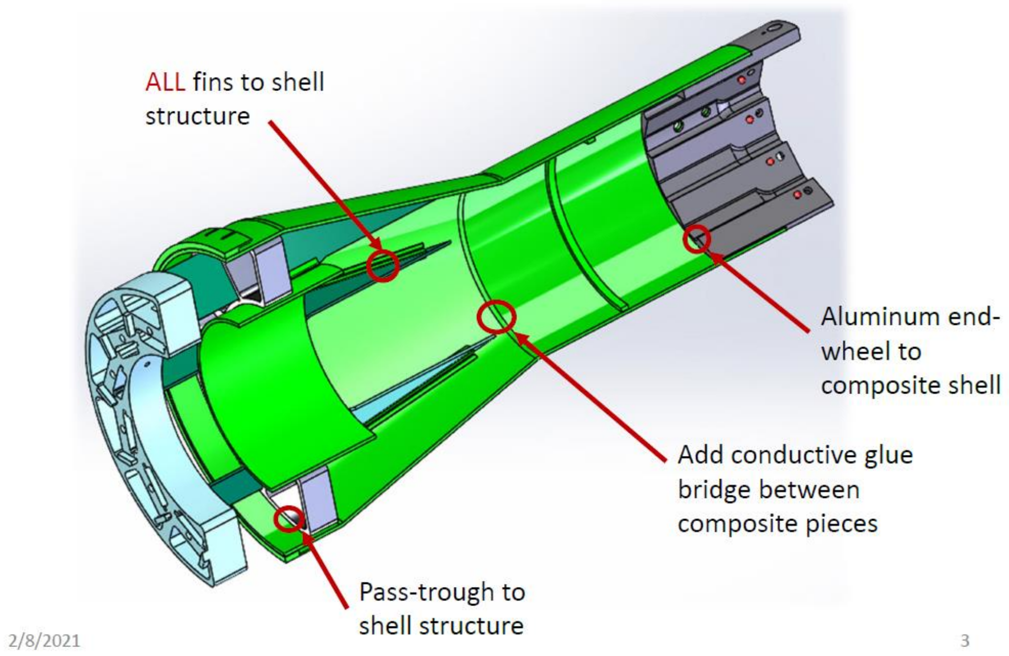


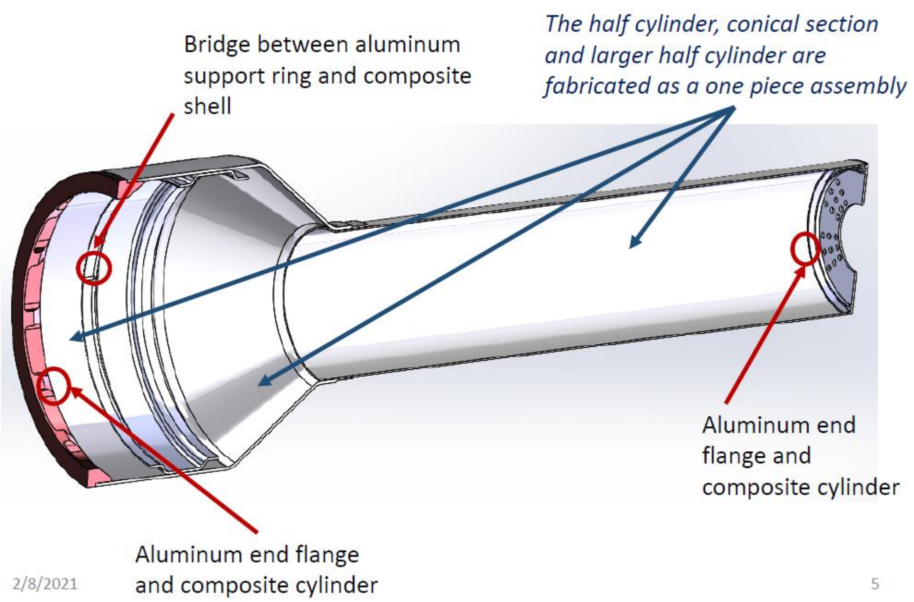


When you bring the two half detectors, there is the possibility that the FPC extension may come in contact between the two halves instead of leafing between them. We used 3D scans to see if there may be an interference – and if, place strategic spacers to help create adequate gaps so they would not interfere; one half with the other.

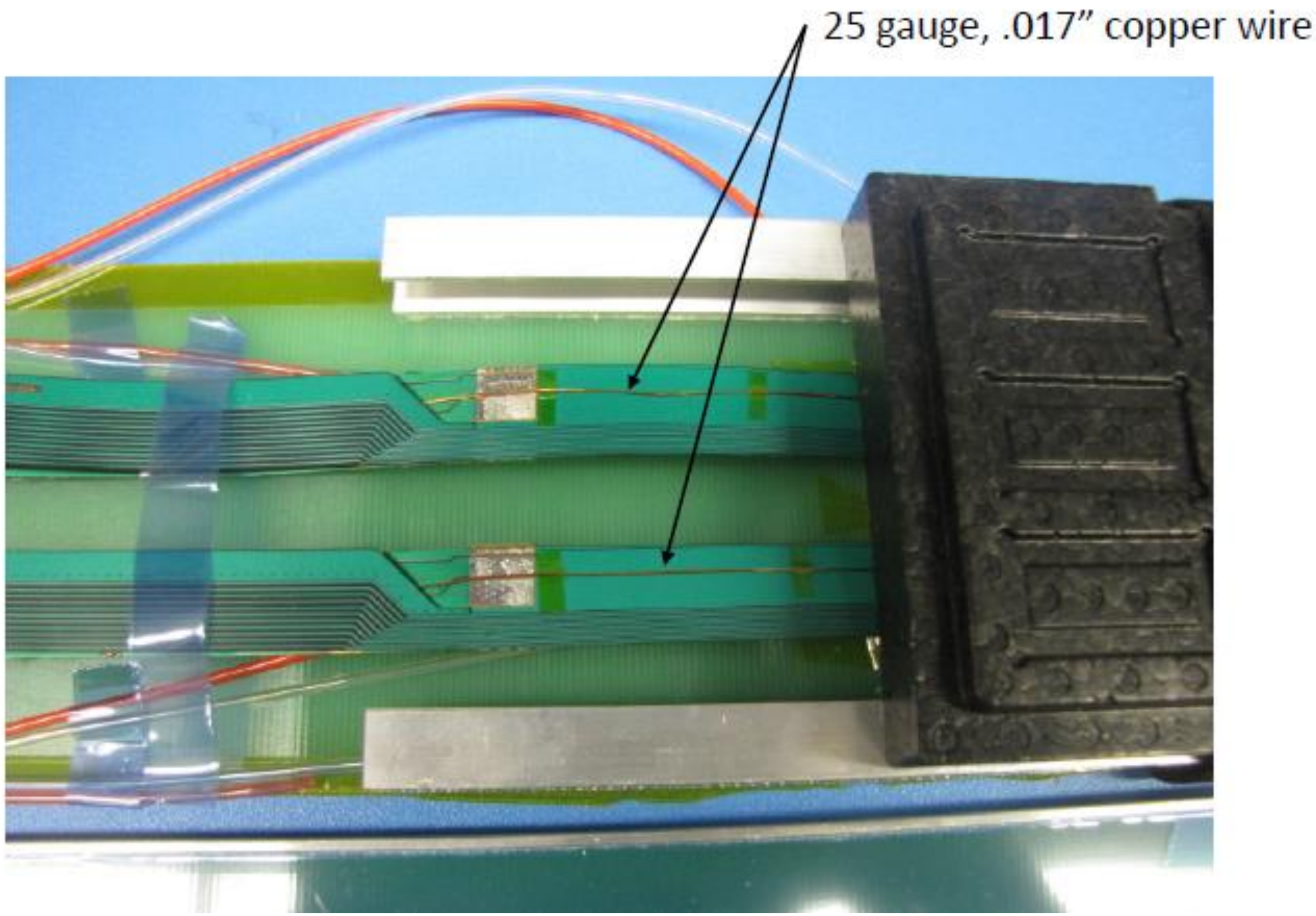
Grounding composite and aluminum pieces in half assembly

- **Use POLYTEC, PU1000 conductive glue as an interconnection between all the composite and aluminum pieces, scratch a patch 1 X 2 mm in composite surface**
- **After application is cured check for continuity –**
- **The aluminum anodized pieces have a gold chem film applied per MIL DTL 5541F**



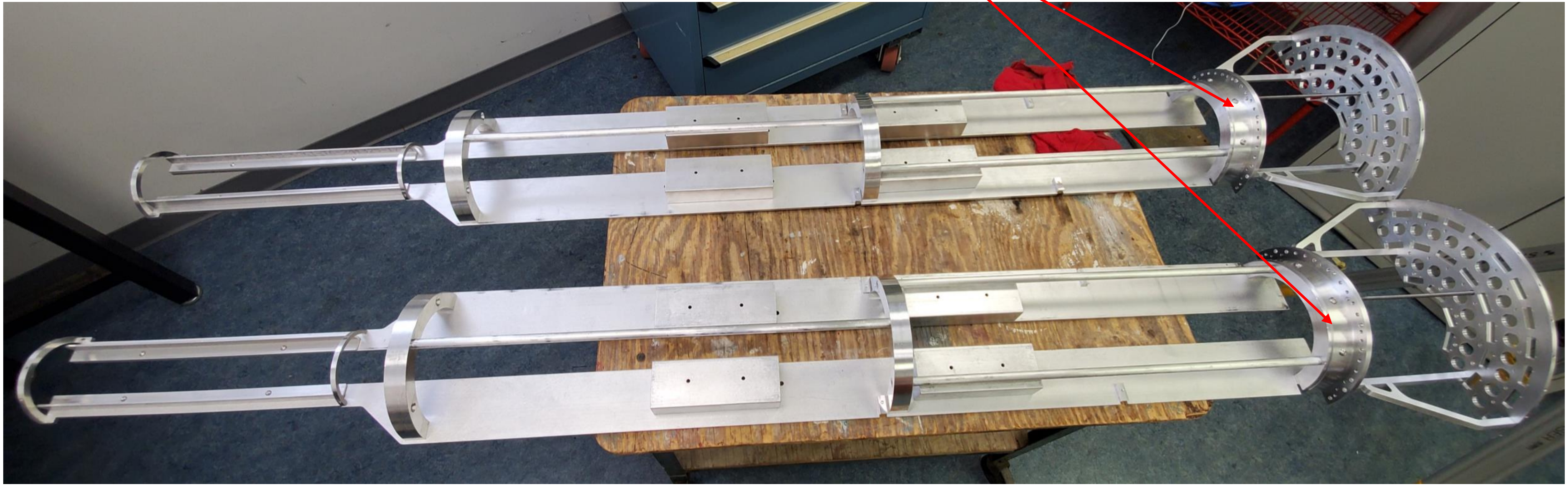


Stave assemblies have a ground wire incorporated in their assembly, it is brought out through the power connector

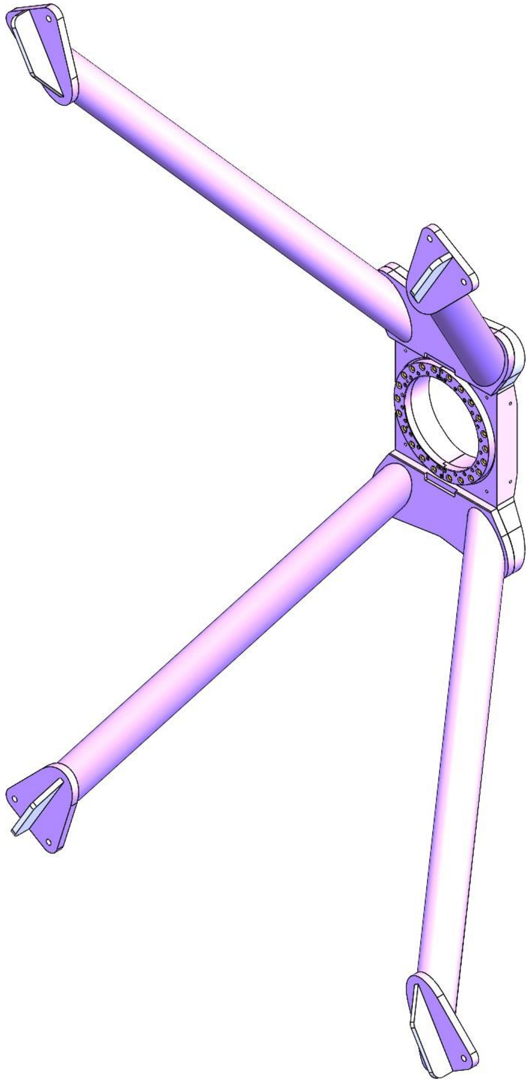


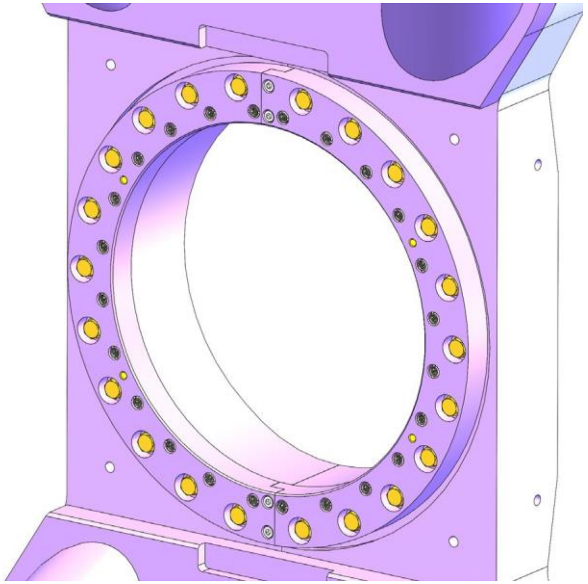
MVTX mechanical mock-up, same mass, staves and services

This mechanical mock-up is critical to test installation scenarios, it too would be mounted so the detector is cantilevered from the end flanges of the service barrels. Each half same mass as the MVTX detector – uses ballast blocks:



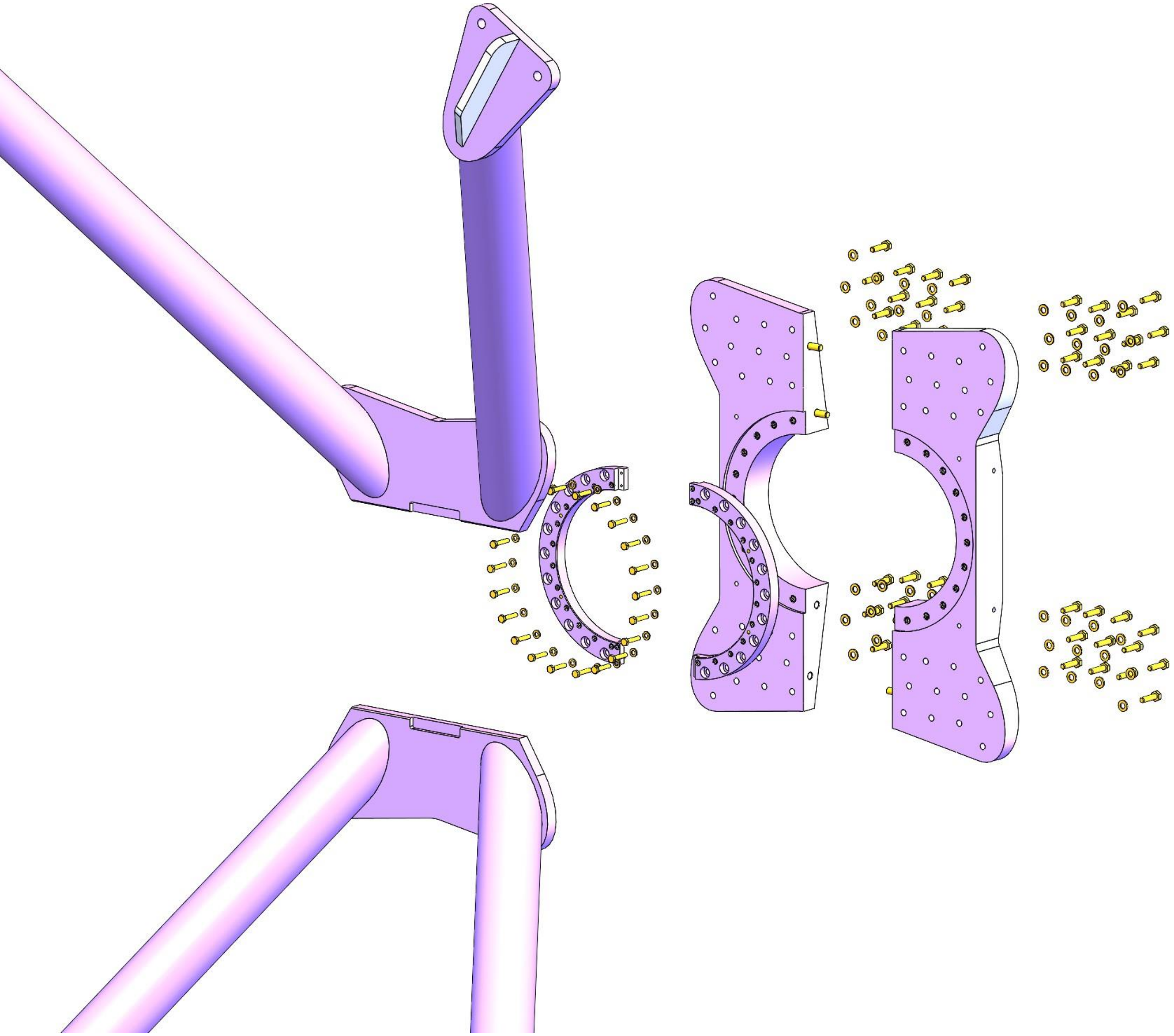
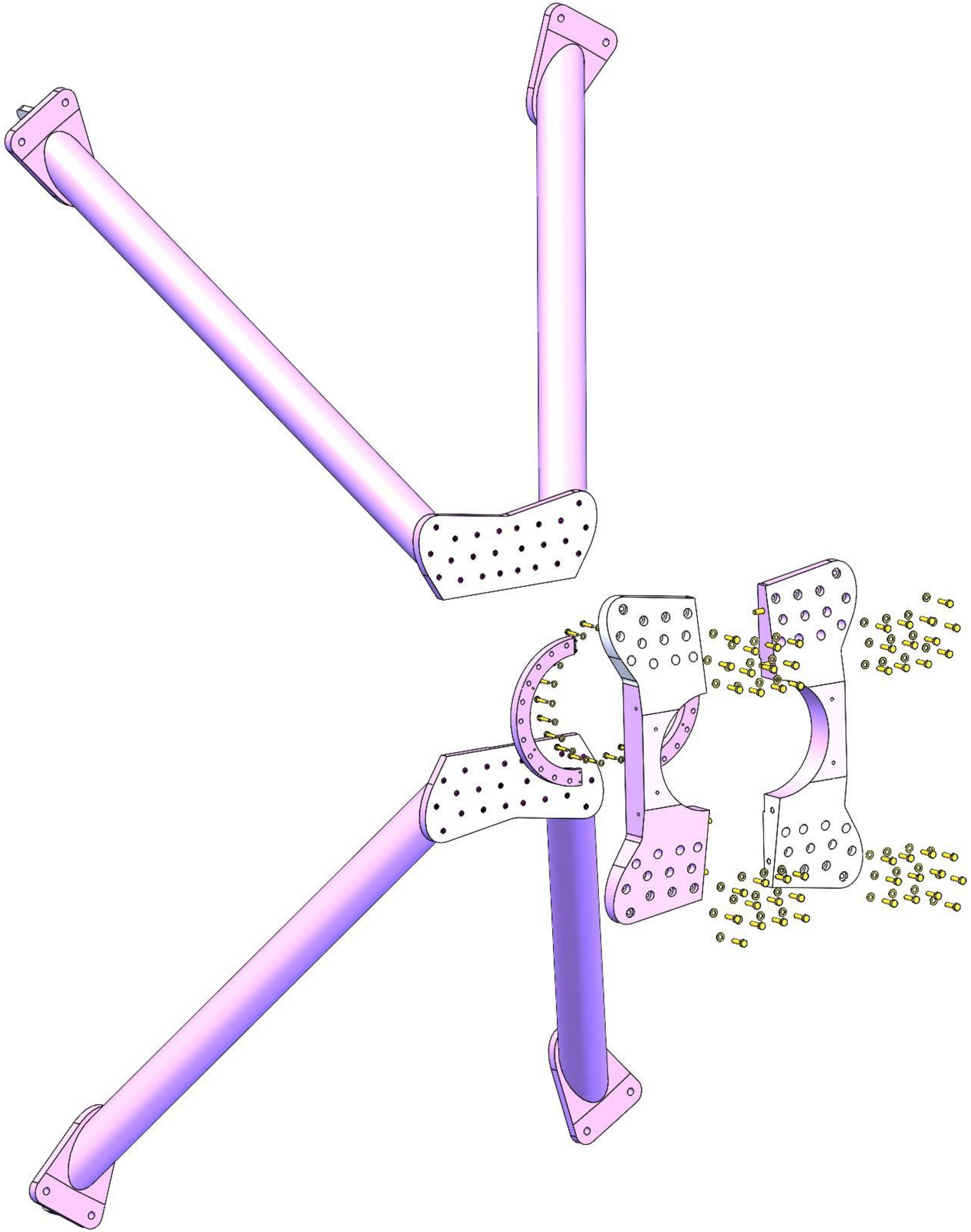
Integrate the MVTX detector with sPHENIX – *X wing*



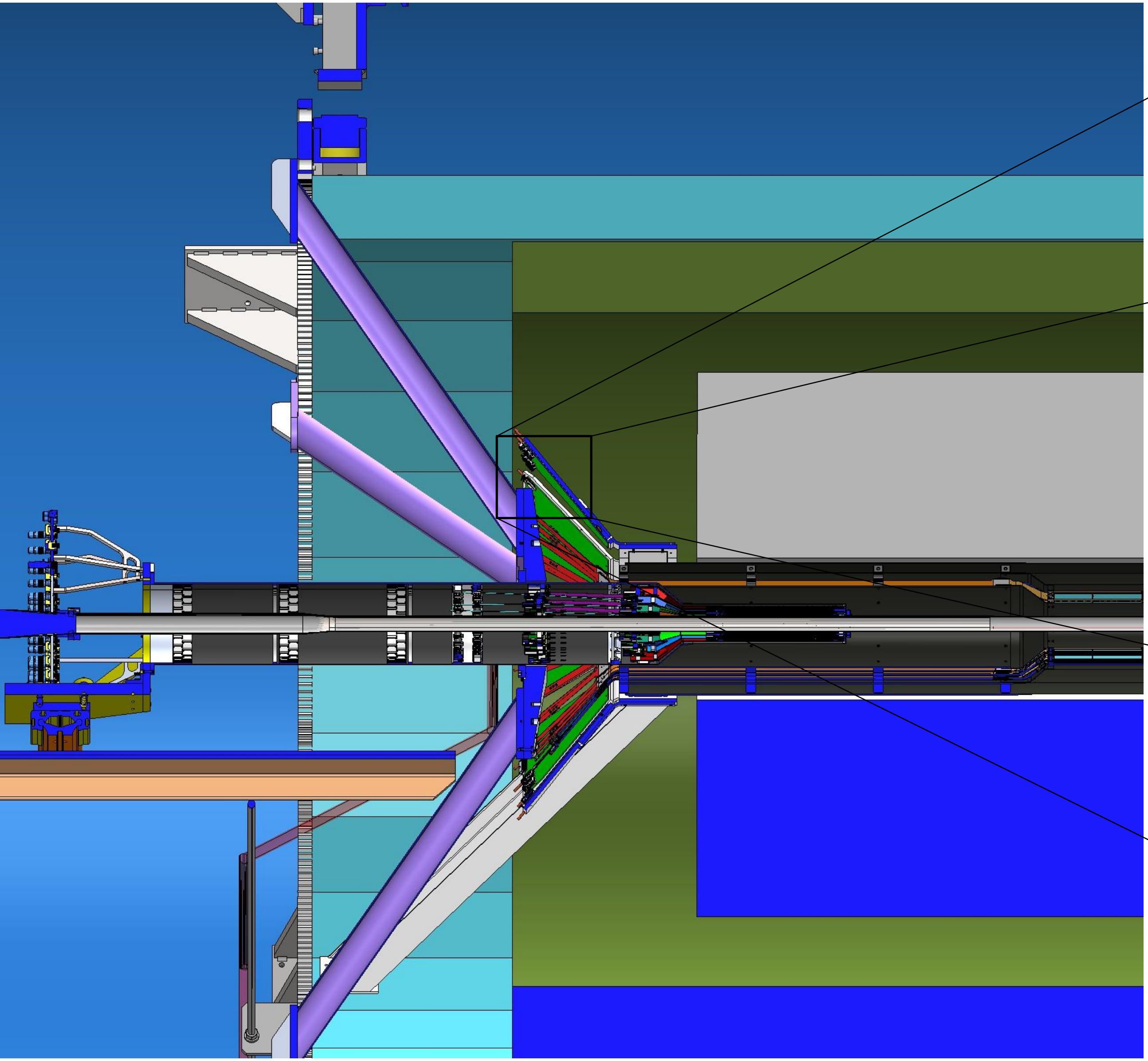


Once mounted to inner HCAL support ring, surveyed to +- .5 mm In X and Y.

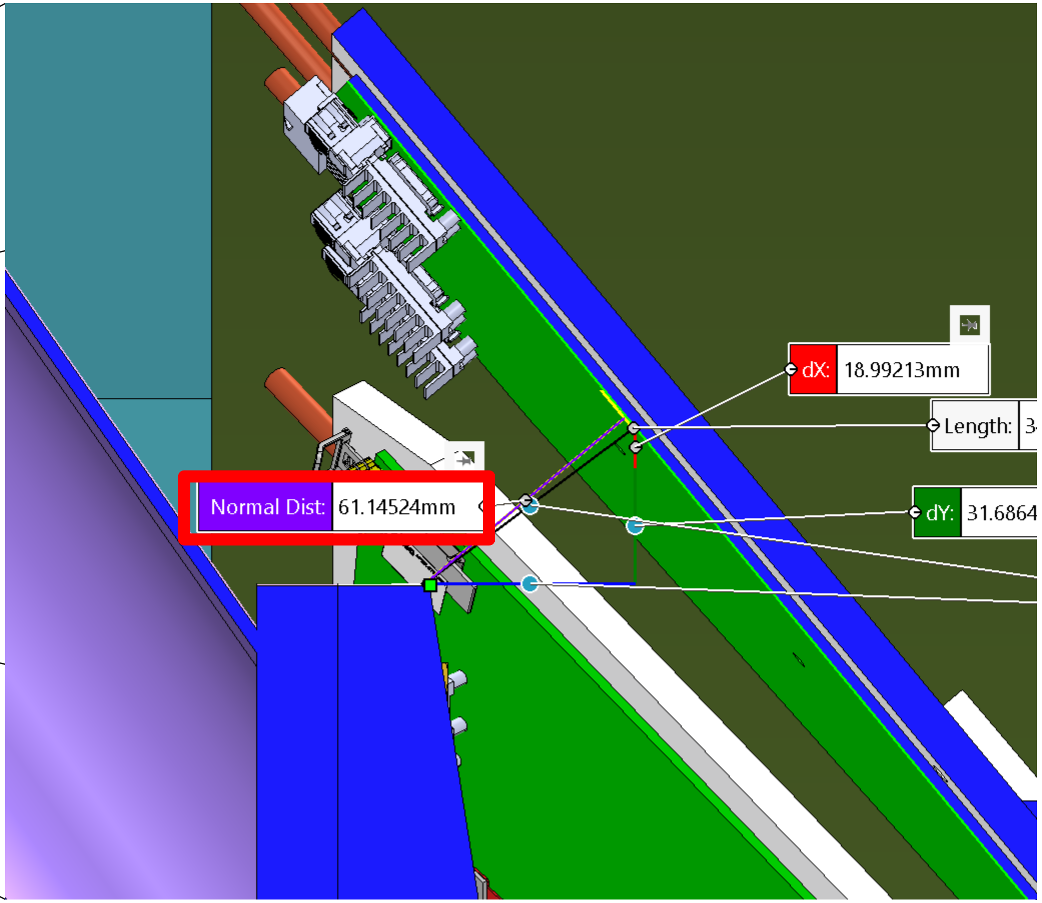
New (Mk8)
Mass: 41 kg
Aluminum with Bronze & Nitronic inserts
Adjustable
No interference – installation bracket can be retracted without any disassembly

X-wing clearance to INTT read-out electronic boards

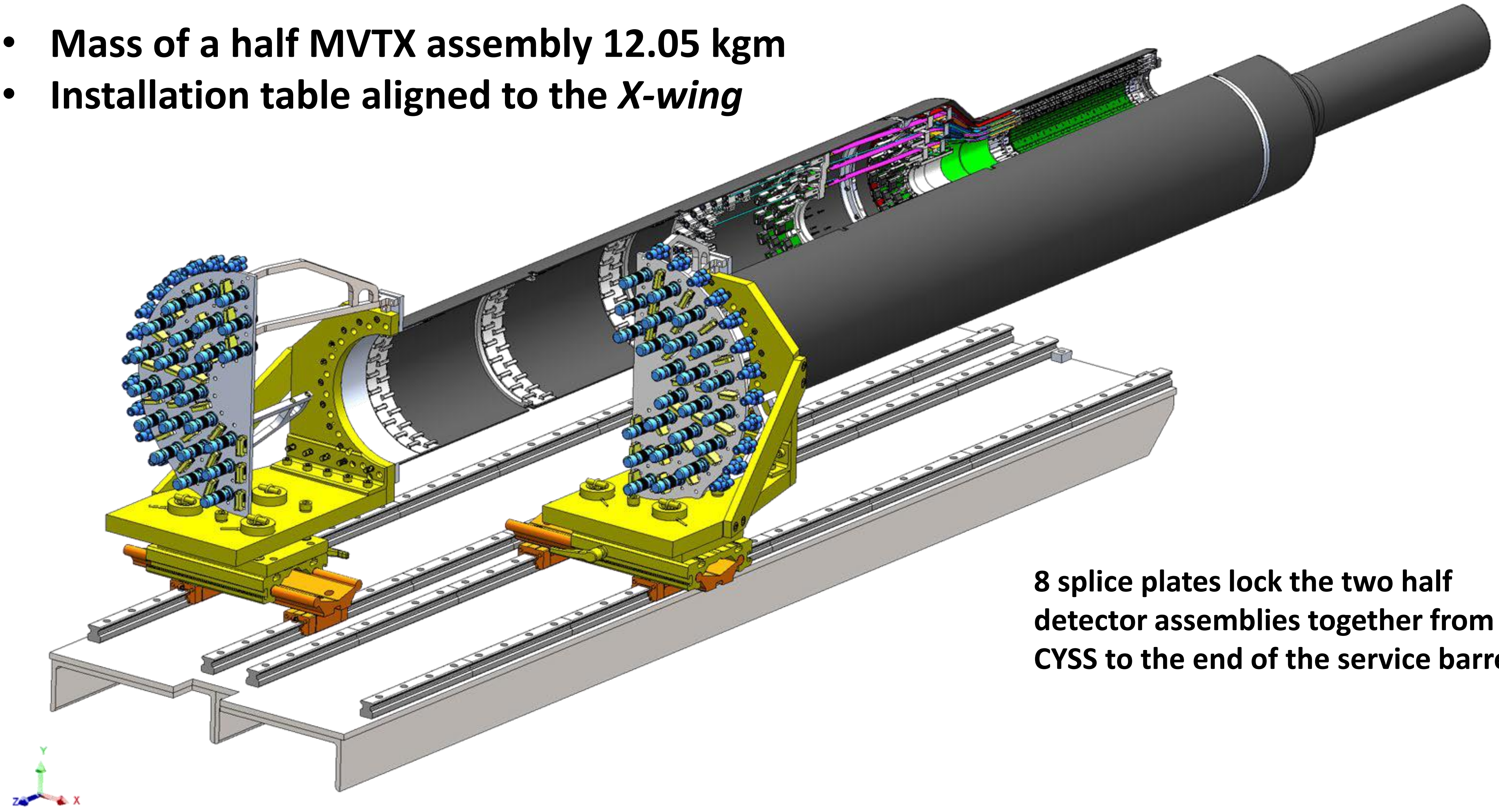


Cross section through XWing Truss (nearest approach to INTT)



Insertion Mechanism – with X-Y rails, stainless steel table

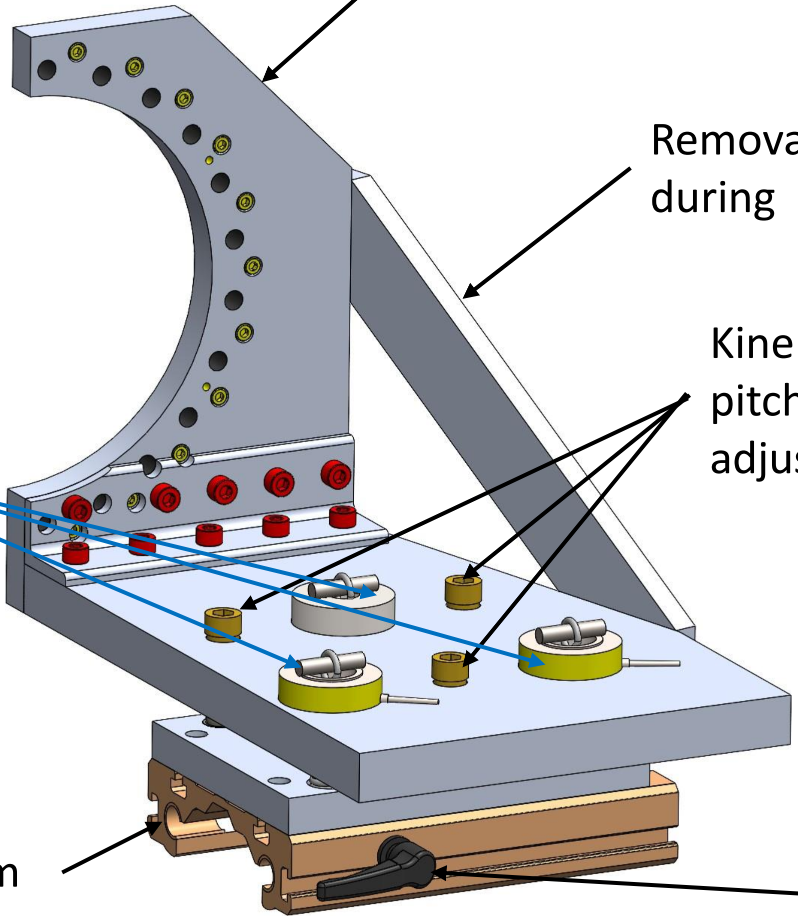
- **Mass of a half MVTX assembly 12.05 kgm**
- **Installation table aligned to the *X-wing***



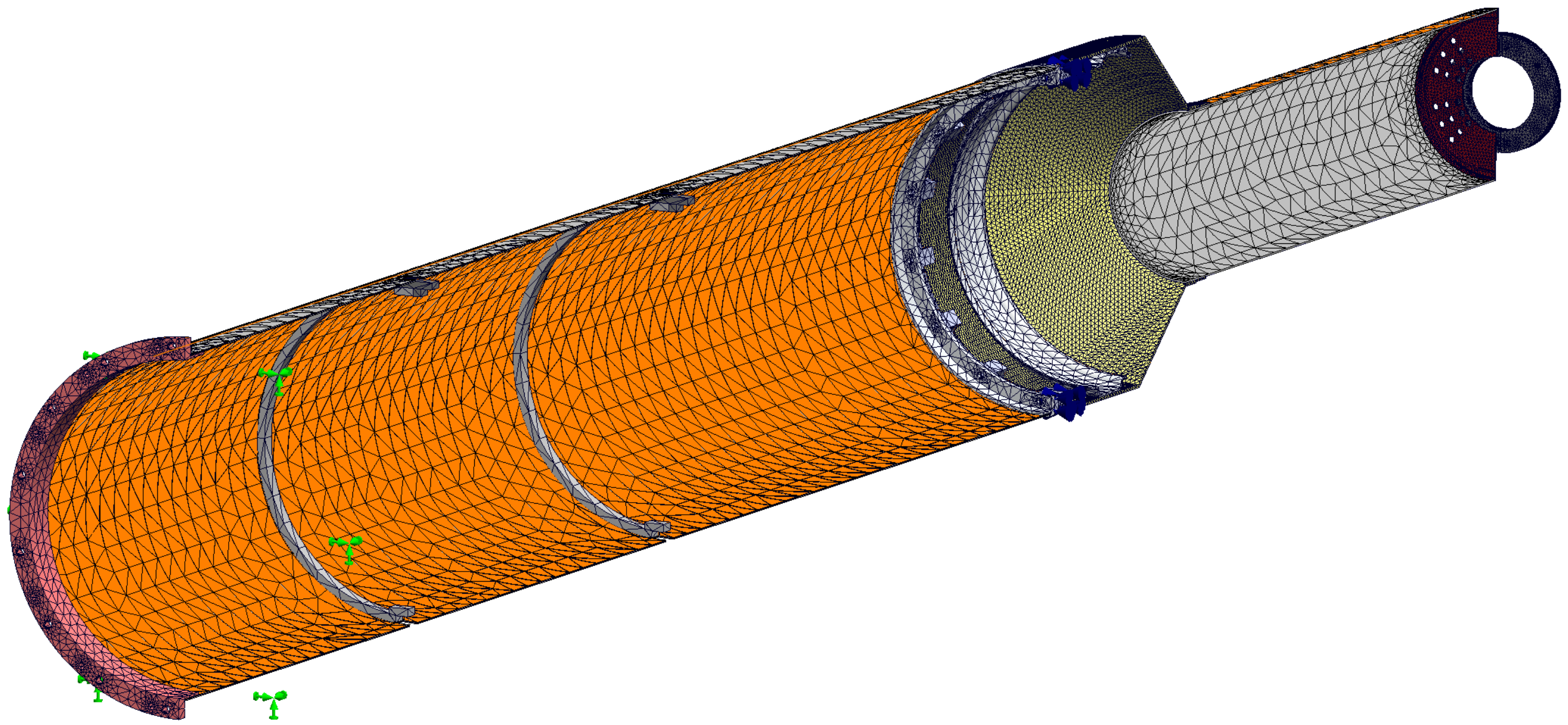
8 splice plates lock the two half detector assemblies together from the CYSS to the end of the service barrel.

Insertion mechanism continued, half detector mount

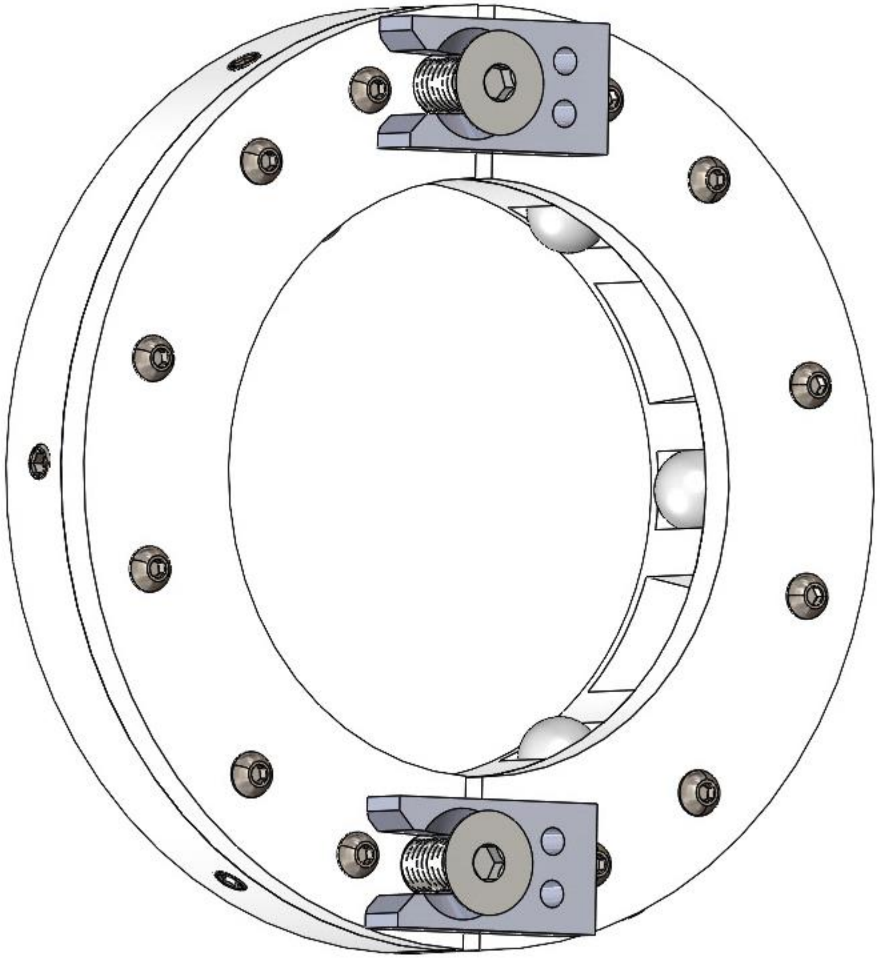
Material, 316 stainless steel



MVTX FEA (Remodel) 2.SLDASM, mesh -



Nose roller ball assembly



Two halves locked together using two M4 flat head screws, access from North end -

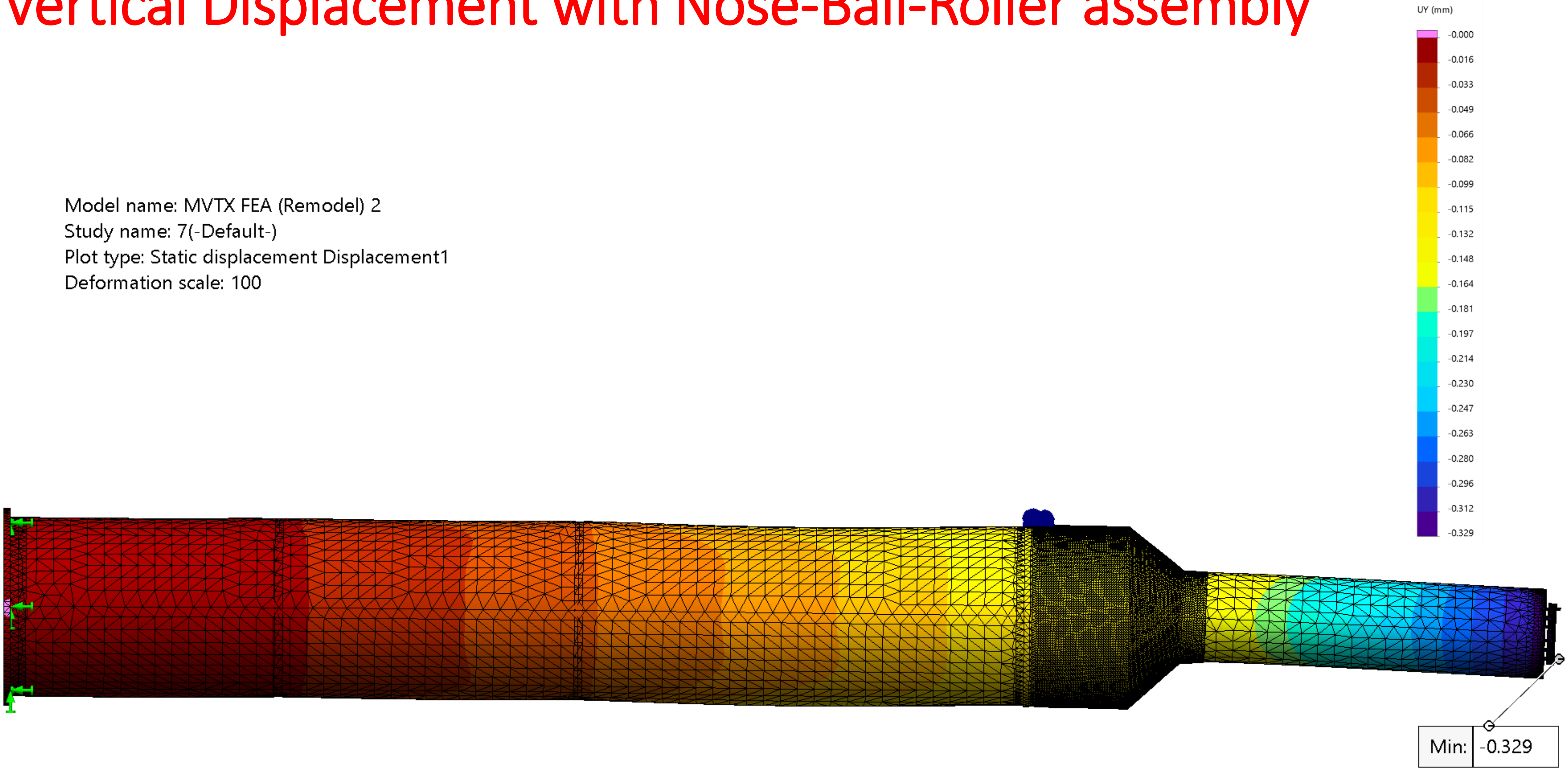
Mass values used in FEA calculation of deflection due to gravity

Loads	Value	Type	Location
Gravity	-9.81 m/s2	Global free body	Everywhere
Signal Cables	2226 g	Distributed Force, per side	SB inside face
Power Cables	3612.3 g	Distributed Force, per side	SB inside face
L0	261.26 g	Remote mass, per side	CYSS Clamp ring and Nose Plate
L1	312.9 g	Remote mass, per side	CYSS Clamp ring and Nose Plate
L2	418.9 g	Remote mass, per side	CYSS Clamp ring and Nose Plate
water 4mm + Air Tubes	1122.054 g	Distributed Force, per side	SB Inside face
Nose rollers	Self weight	Mass	Self

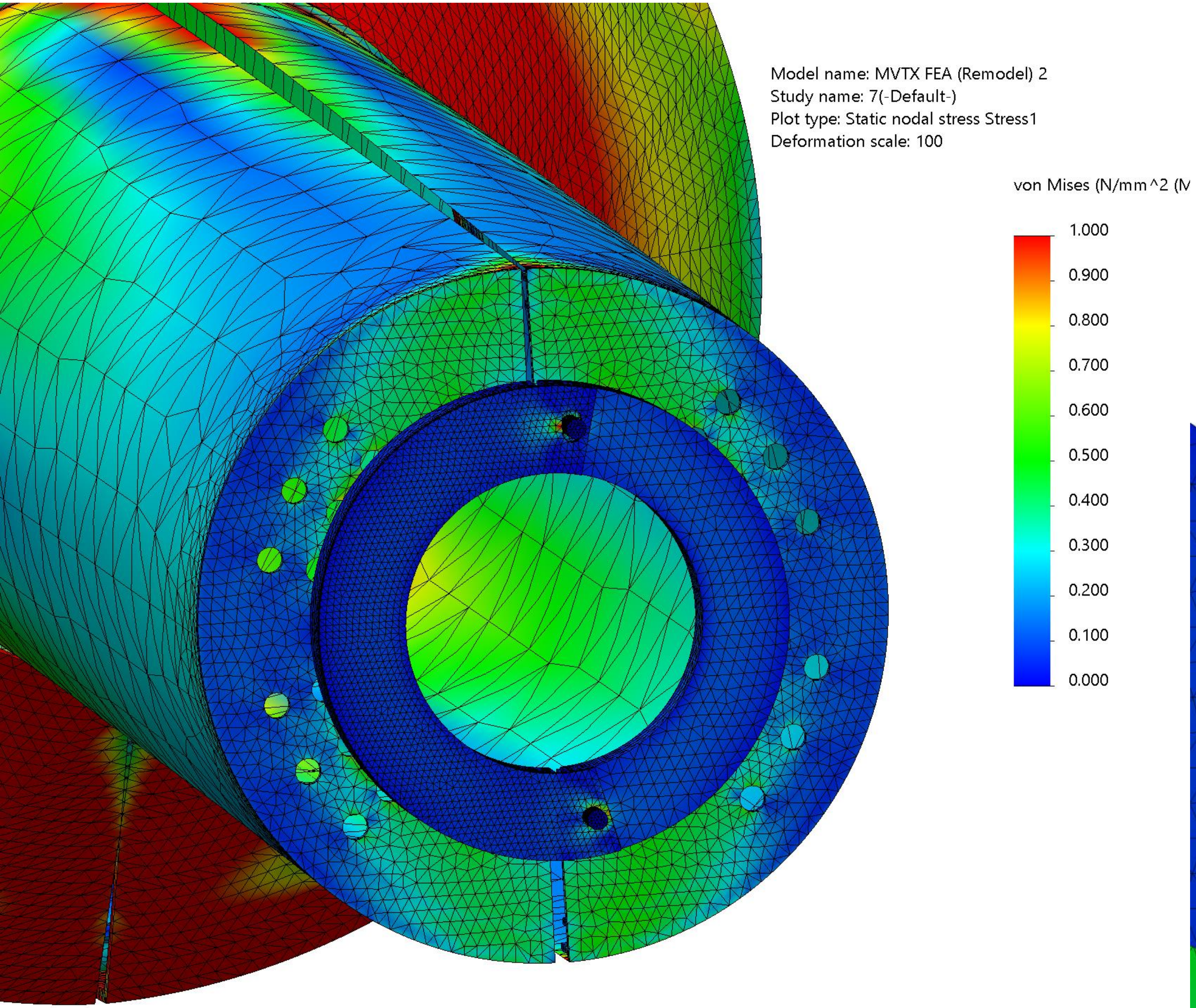
Total Mass: 18.75 kg

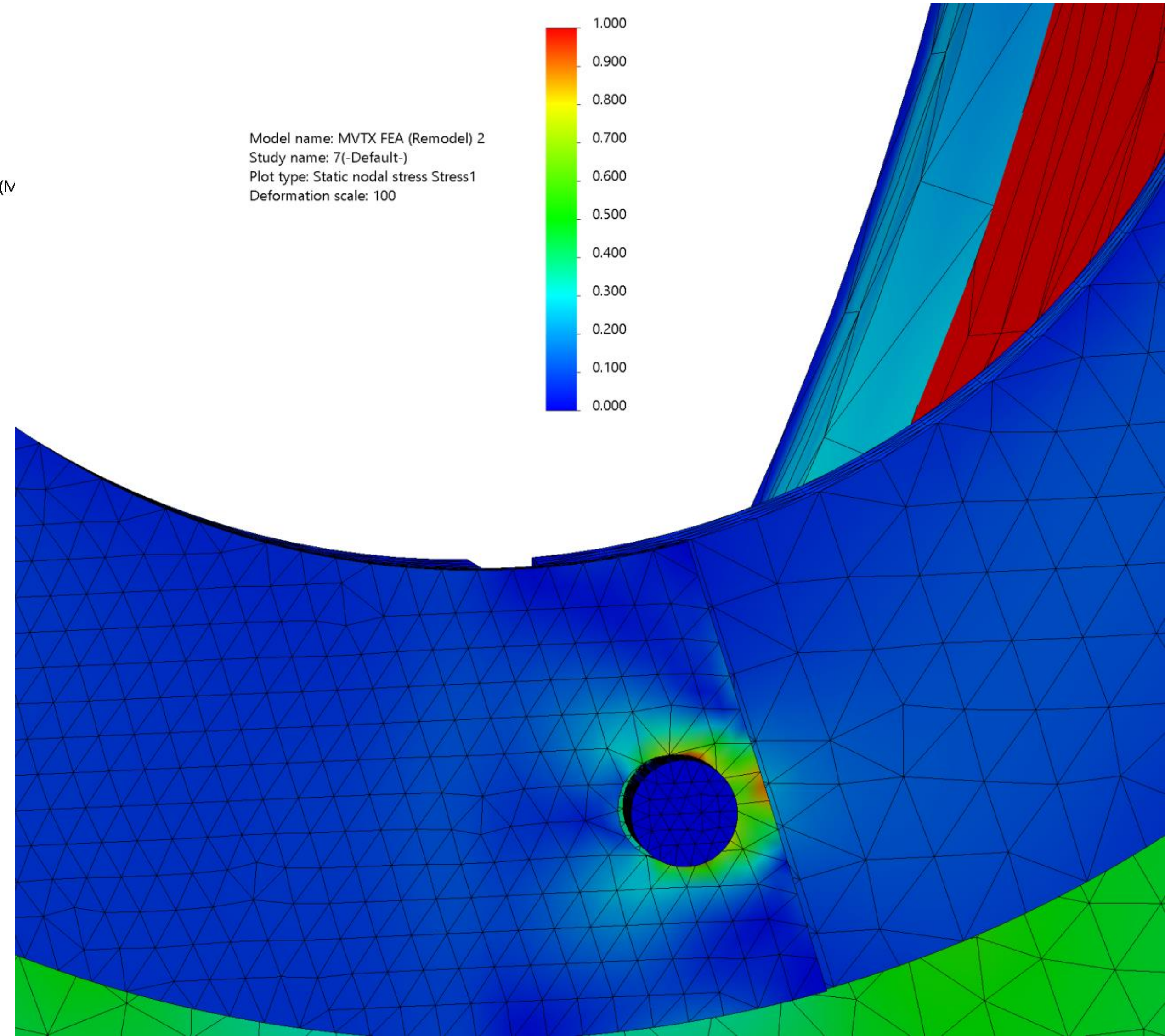
Vertical Displacement with Nose-Ball-Roller assembly

Model name: MVTX FEA (Remodel) 2
Study name: 7(-Default-)
Plot type: Static displacement Displacement1
Deformation scale: 100

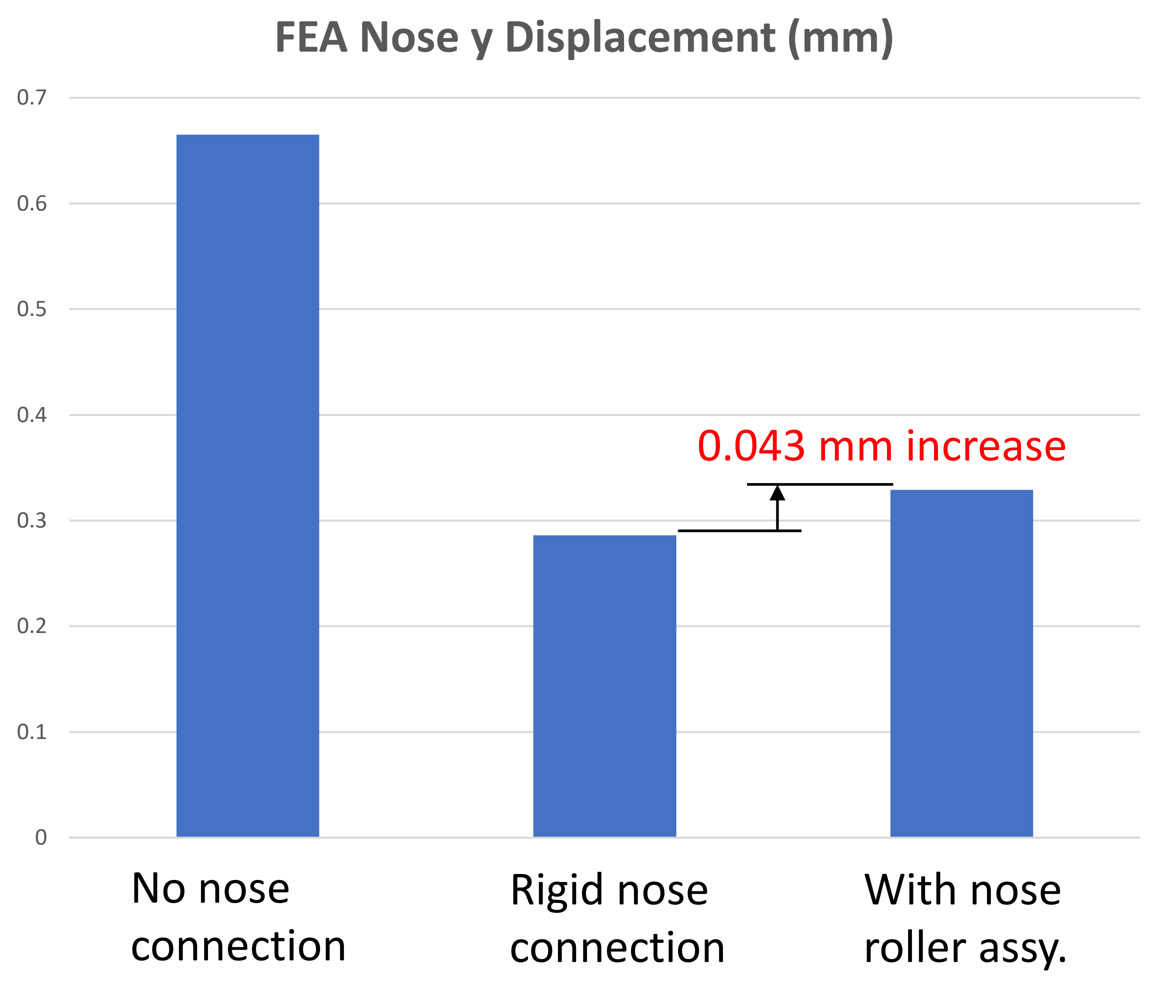


Stress at nose, showing proper contact mesh behavior





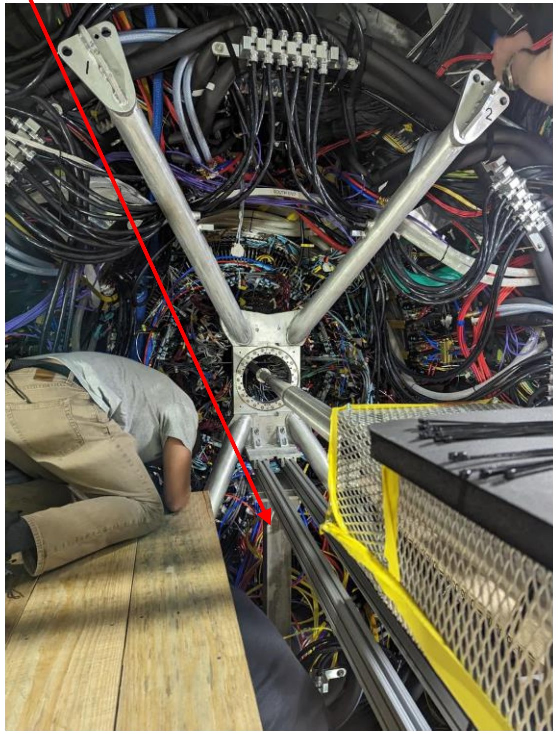
Roller Ball Assembly is effective at reducing nose sag



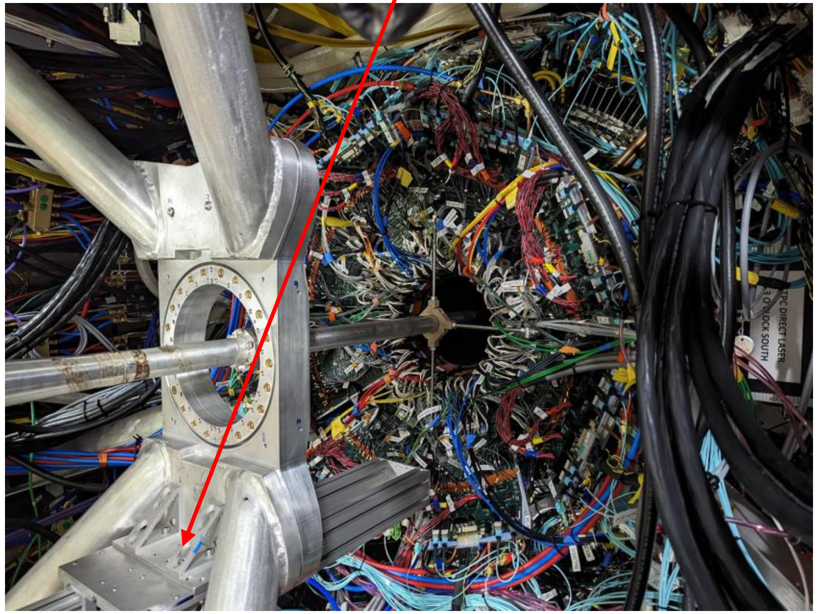
X-wing, insertion table, detector mock-up, test insertion, with dump beam-pipe

X-wing installation on 80-20 rails, connects to inner HCAL

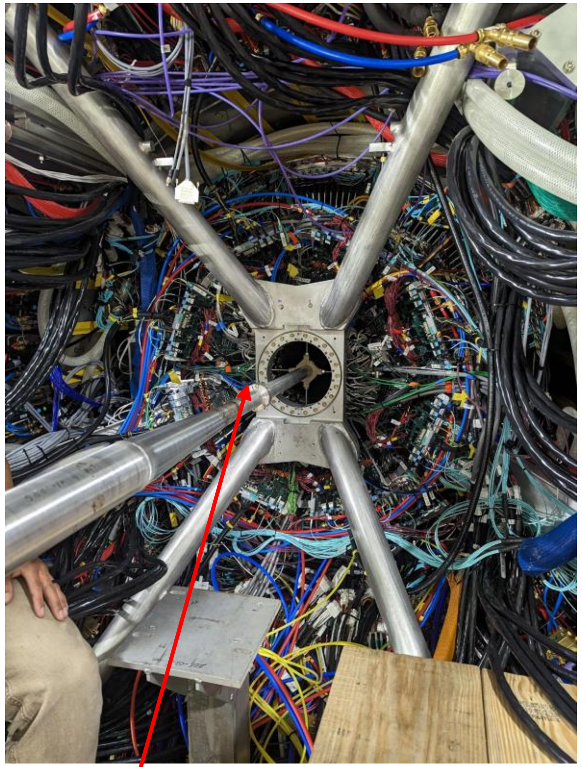
X-wing translates on rails



X-wing attachment to rails, angle bracket

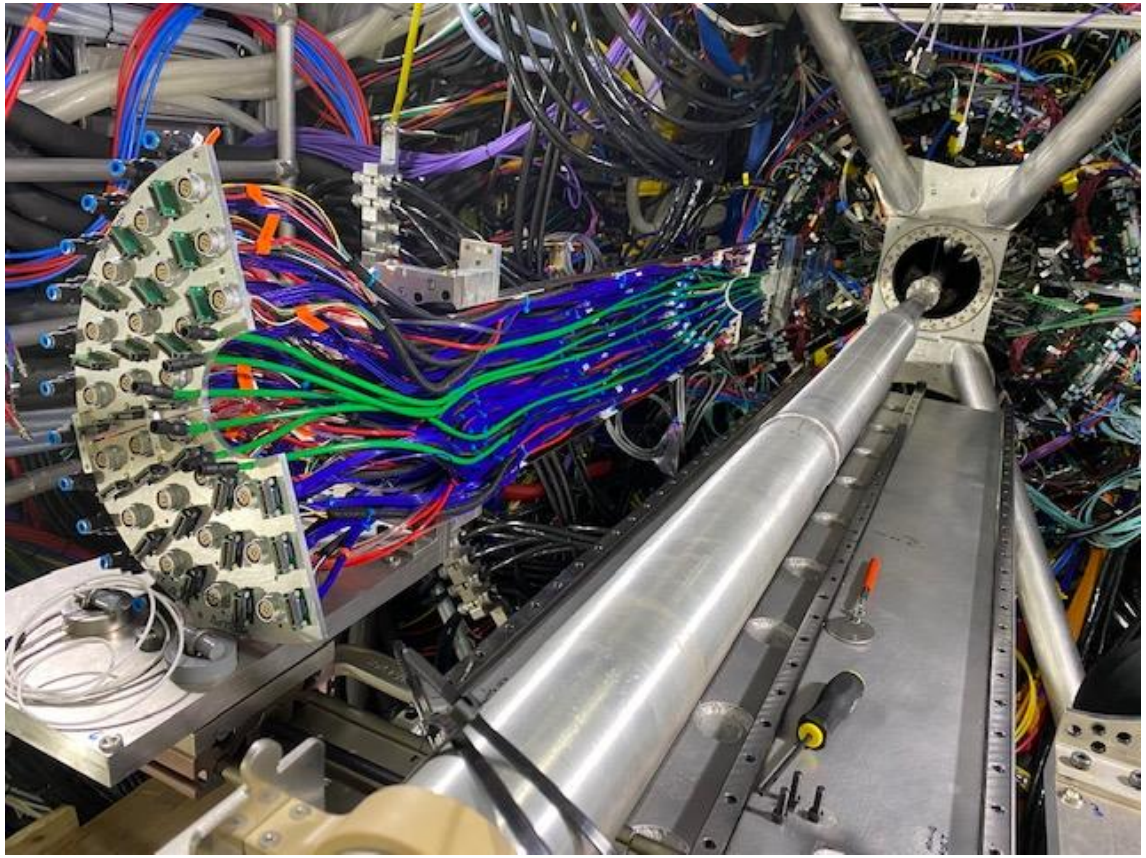


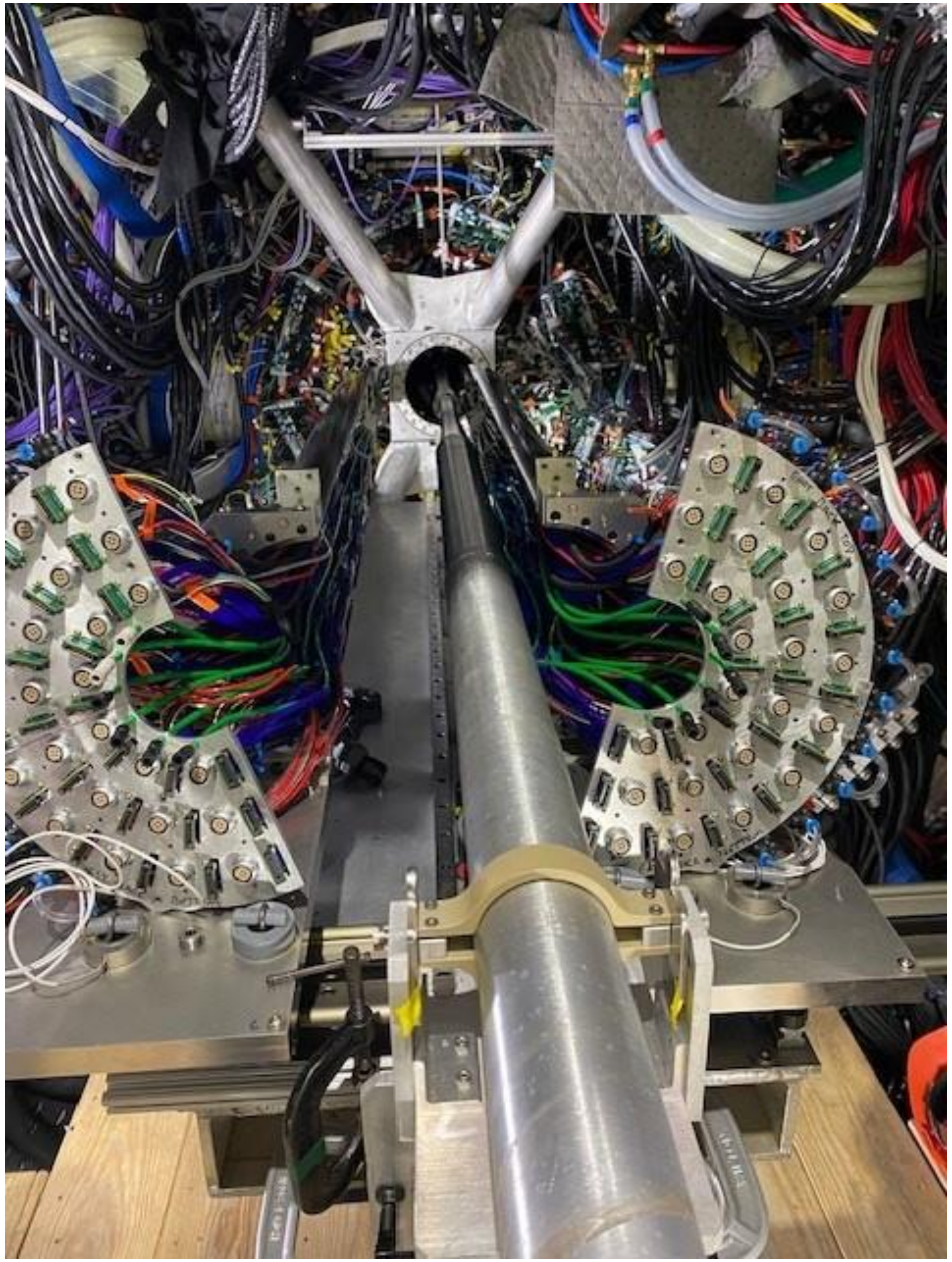
X-wing after installation rails removed



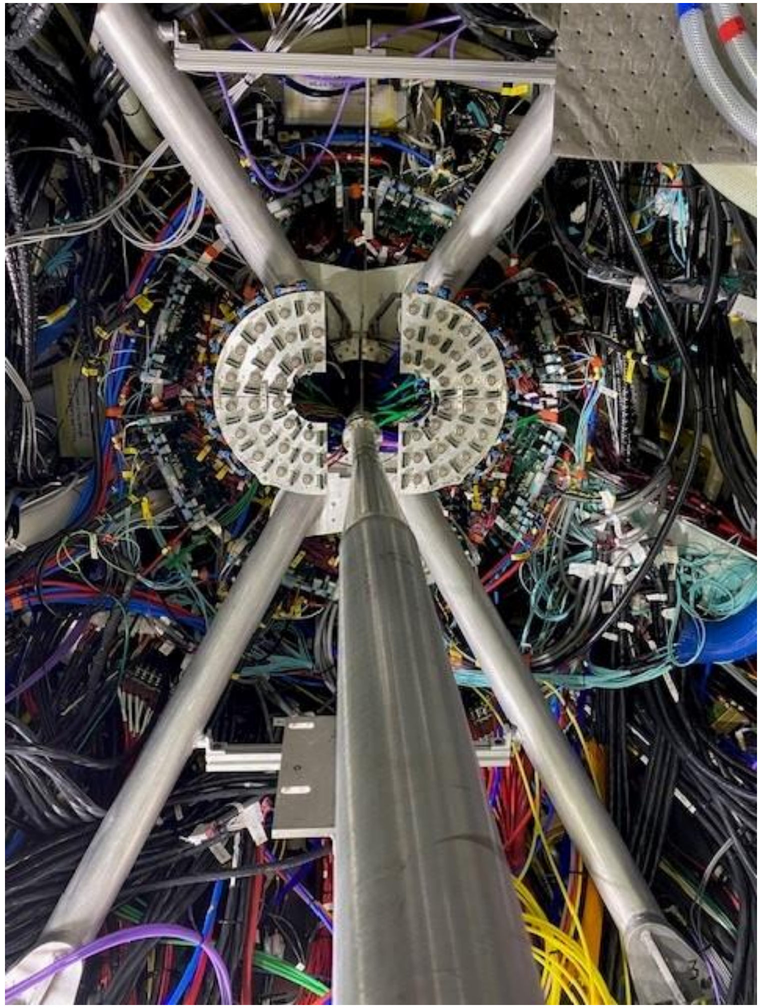
Existing flange in beam-pipe assembly prohibits closure of the two MVTX half detectors until the stave assembly passes this flange

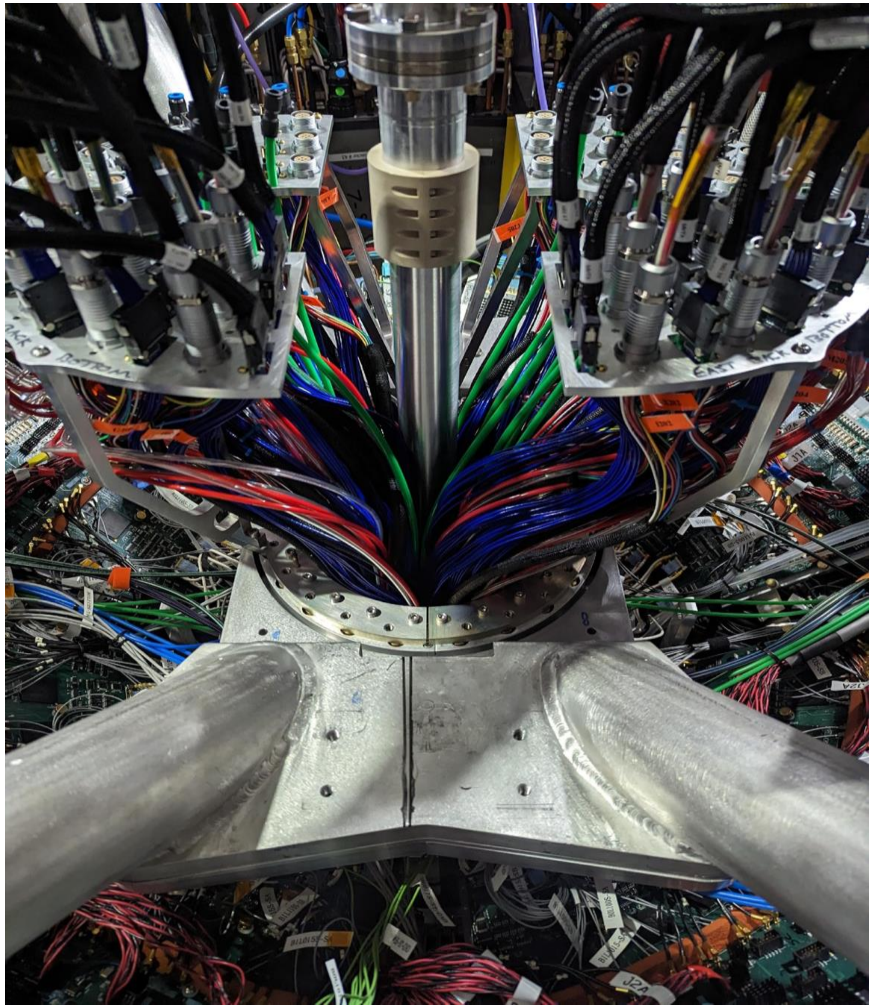
Installation of the MVTX detector





MVTX detector after installation and services connected





MVTX design, fabrication, assembly and installation team:

LANL;

Walter Sondheim, Christopher O'Shaughnessy, Eric Renner, Jakub Kvapil, Zhaozhong Shi, Ming Liu*, Anton Navazo, Yasser Morales Corrales, Sho Uemura, Alex Tkatchev

MIT:

James Kelsey*, Ross Corliss, Jason Bessuille, Joseph Dodge, Danielle Petterson, Cameron Thomas Dean

BNL:

Dan Cacace, Russell Feder*, Mike Lenz, James Labounty, Richie Ruggiero, Mickey Chiu – sPHENIX integration coordinator

LBNL:

Abdennacer Hamdi, Yu Hu, Ho-San Ko, Richard Lew, Yuan Mei, Grazyna Odyniec*, Hanseul Oh, Joseph Silber, Eric Anderssen

ORNL:

Joe Schambach*

CERN:

Antonello Di Mauro, Corrado Gargiulo

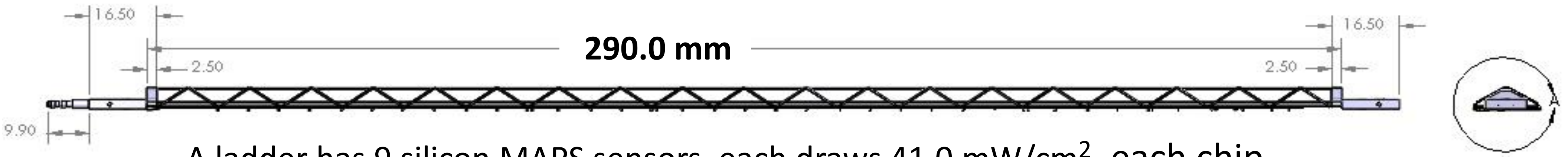
CNRS, France:

Camelia Mironov – project management

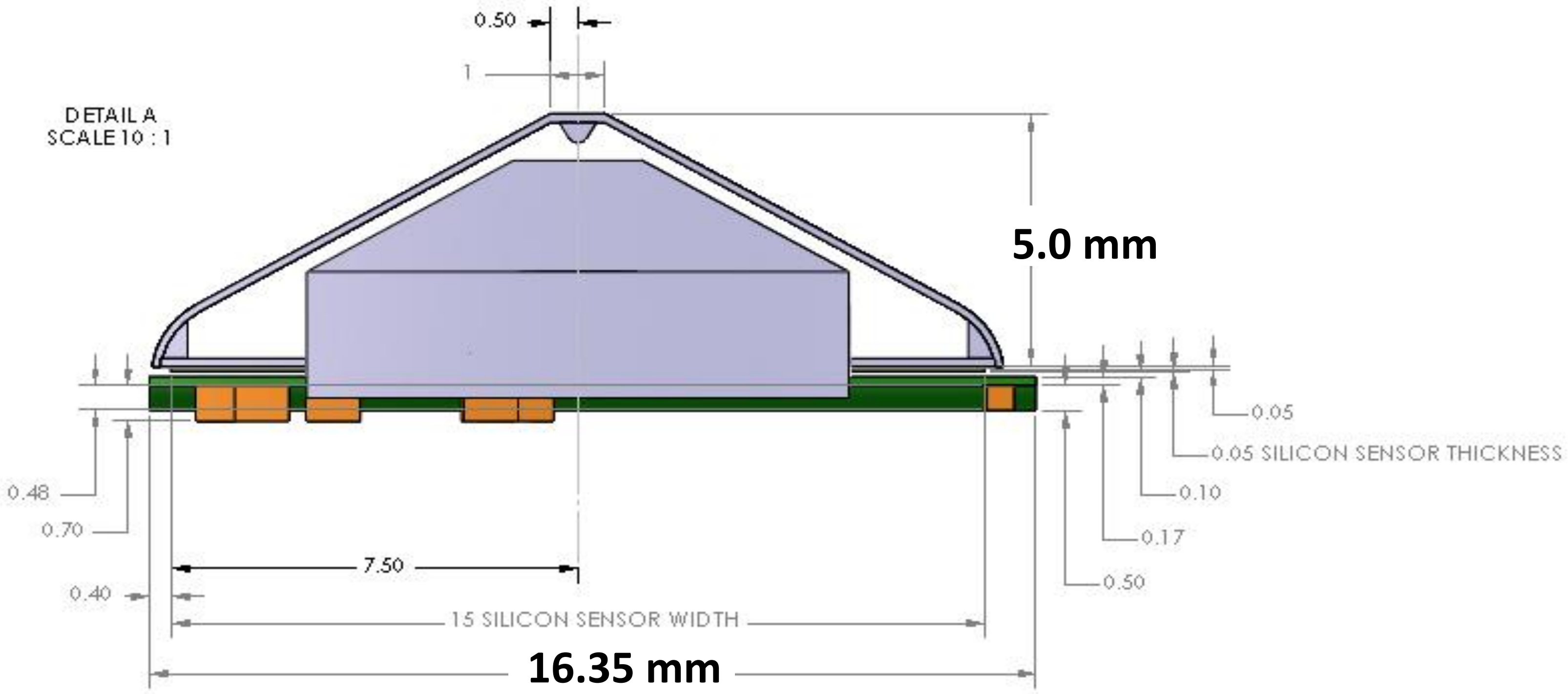
******* designates institute PI on this project**

Back up slides:

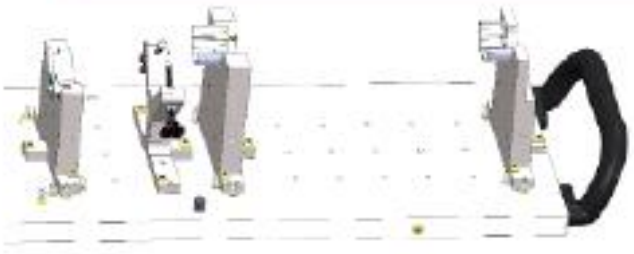
Detail drawing of stave assembly for ITS2 and MVTX



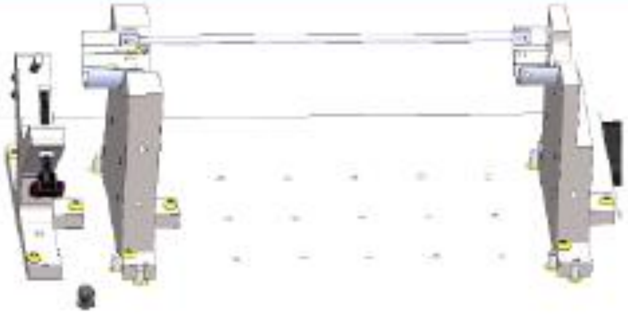
A ladder has 9 silicon MAPS sensors, each draws 41.0 mW/cm^2, each chip 50.0 microns thick, (0.3%X_0) Alpide3 chip



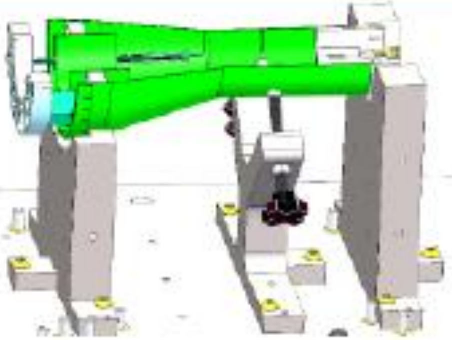
Fixtures and assembly steps to make a layer assembly, one of six



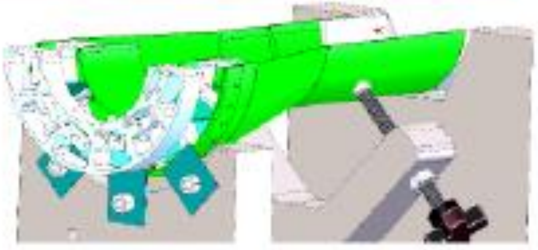
1) Install North & South EndWheel in A5 and A4



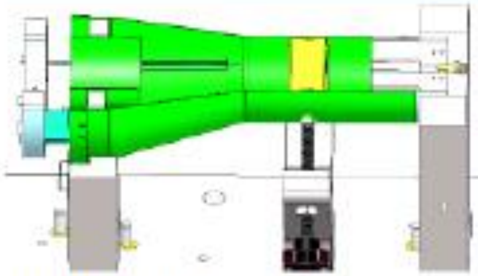
2) Check alignment w/ CMM & testing also w/ a dummy stave



3) Install Carbon Fiber cone, and align into place

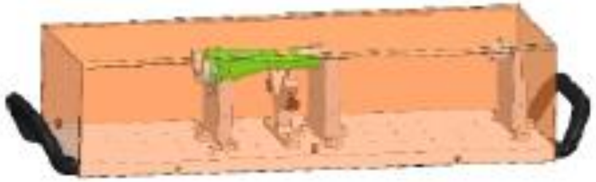


4) Install springs to lock cone in z



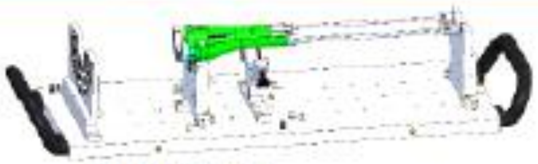
5) Install fixture weight

6) Reverse: 5, 4, 3
7) Applying epoxy for bonding
7) Repeat: 3,4,5



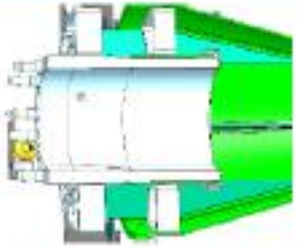
8) Cover and allow epoxy to fully cure before proceeding

9) Install dummy staves
10) Remove from fixture
11) Test-fit into next layer



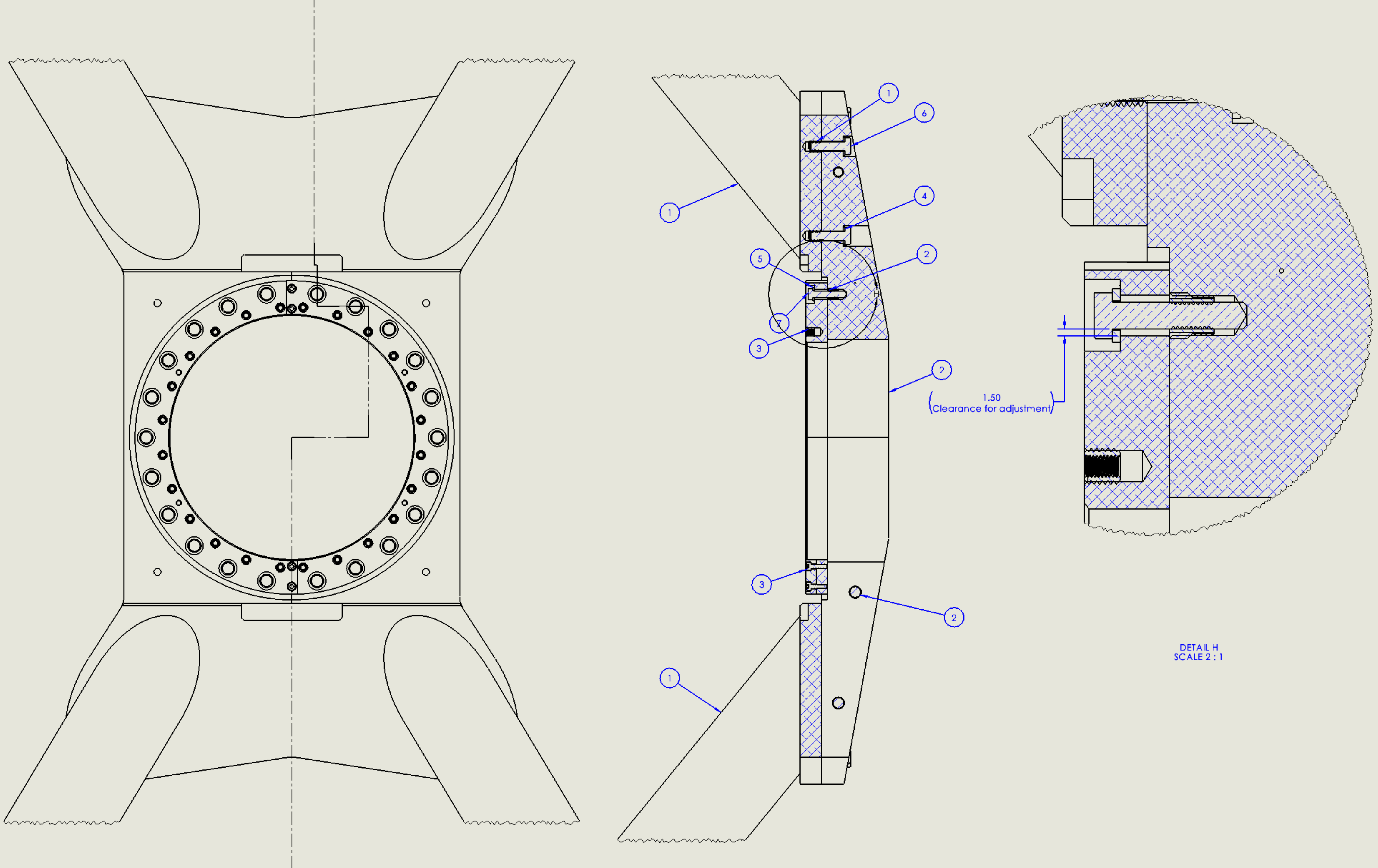
12) Install A1
13) Install back in Fixture

14) Replace Dummy Staves with Staves – Testing as you go



14) Install cooling lines on Air Manifold

16) Test all Staves again
17) Ready to install

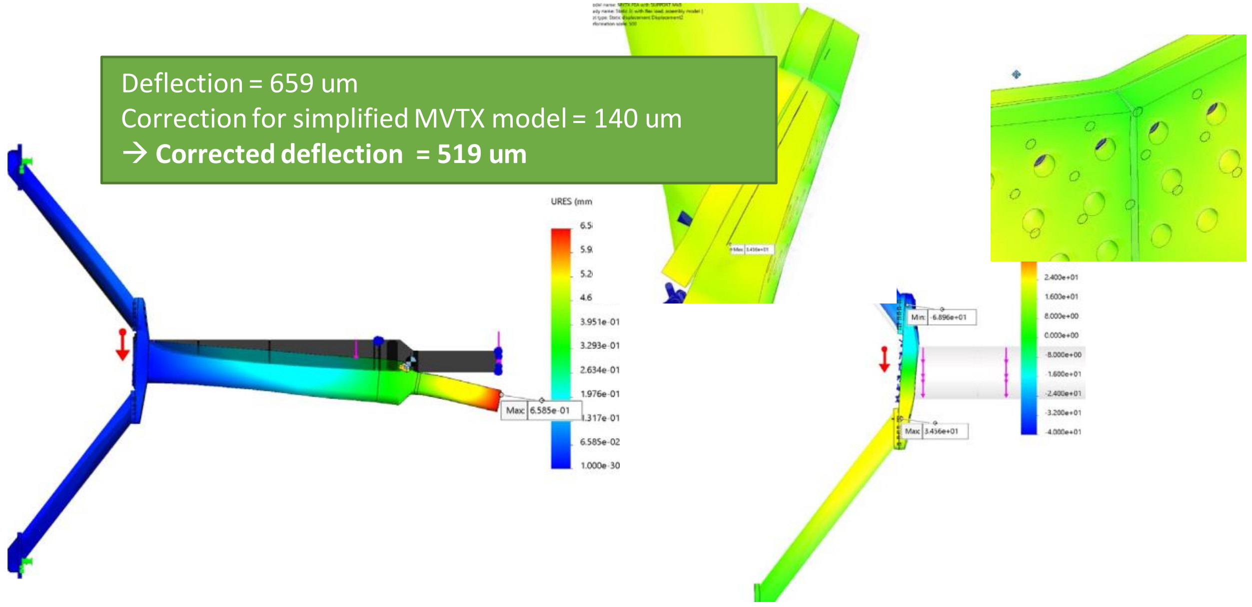

1
6
1
4
5
2
7
3
2
1.50
(Clearance for adjustment)
3
2
1
DETAIL H
SCALE 2 : 1

FEA analysis MVTX attached to X-wing

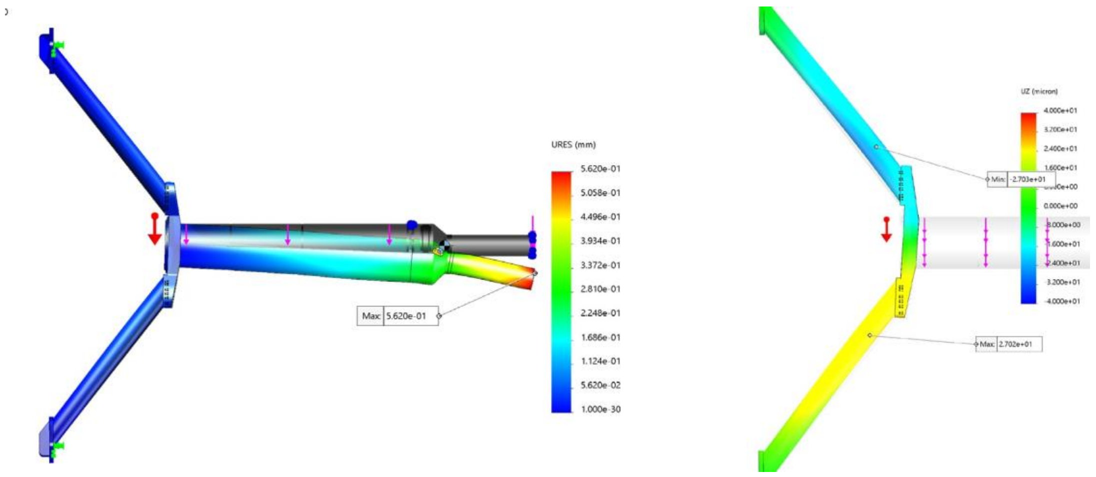
Rev 10: All bolt holes; dowel holes

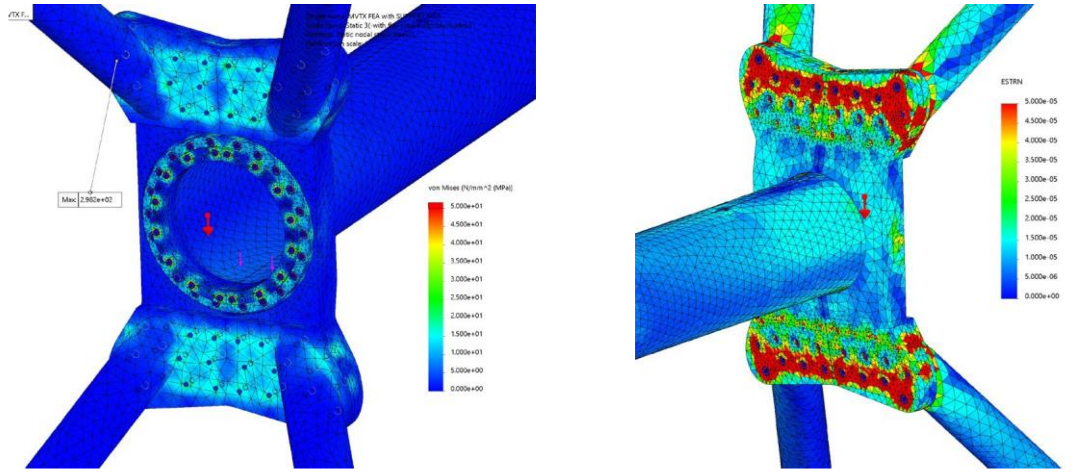
Bolted connections included

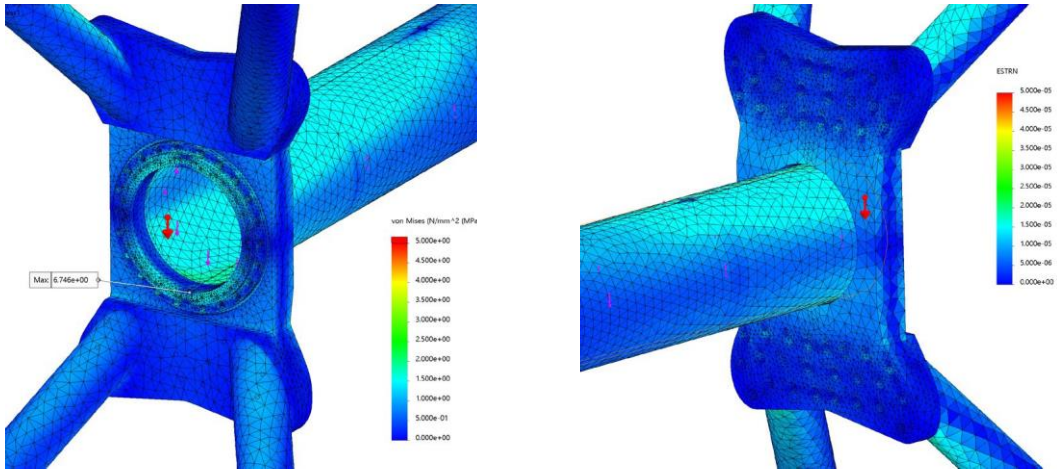
Deflection = 659 um
Correction for simplified MVTX model = 140 um
→ **Corrected deflection = 519 um**



All parts Bonded



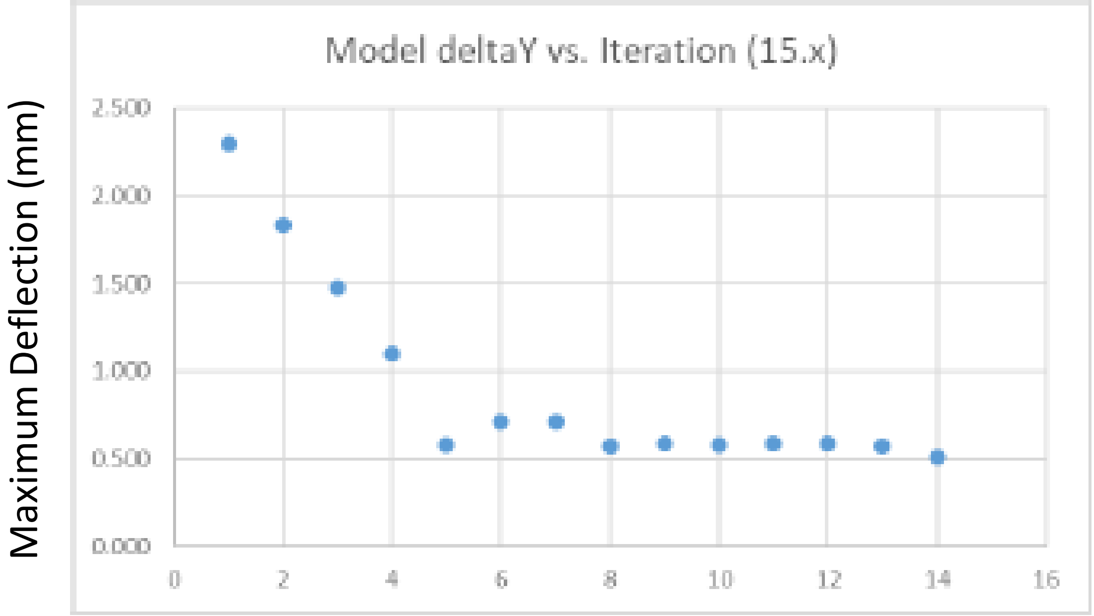




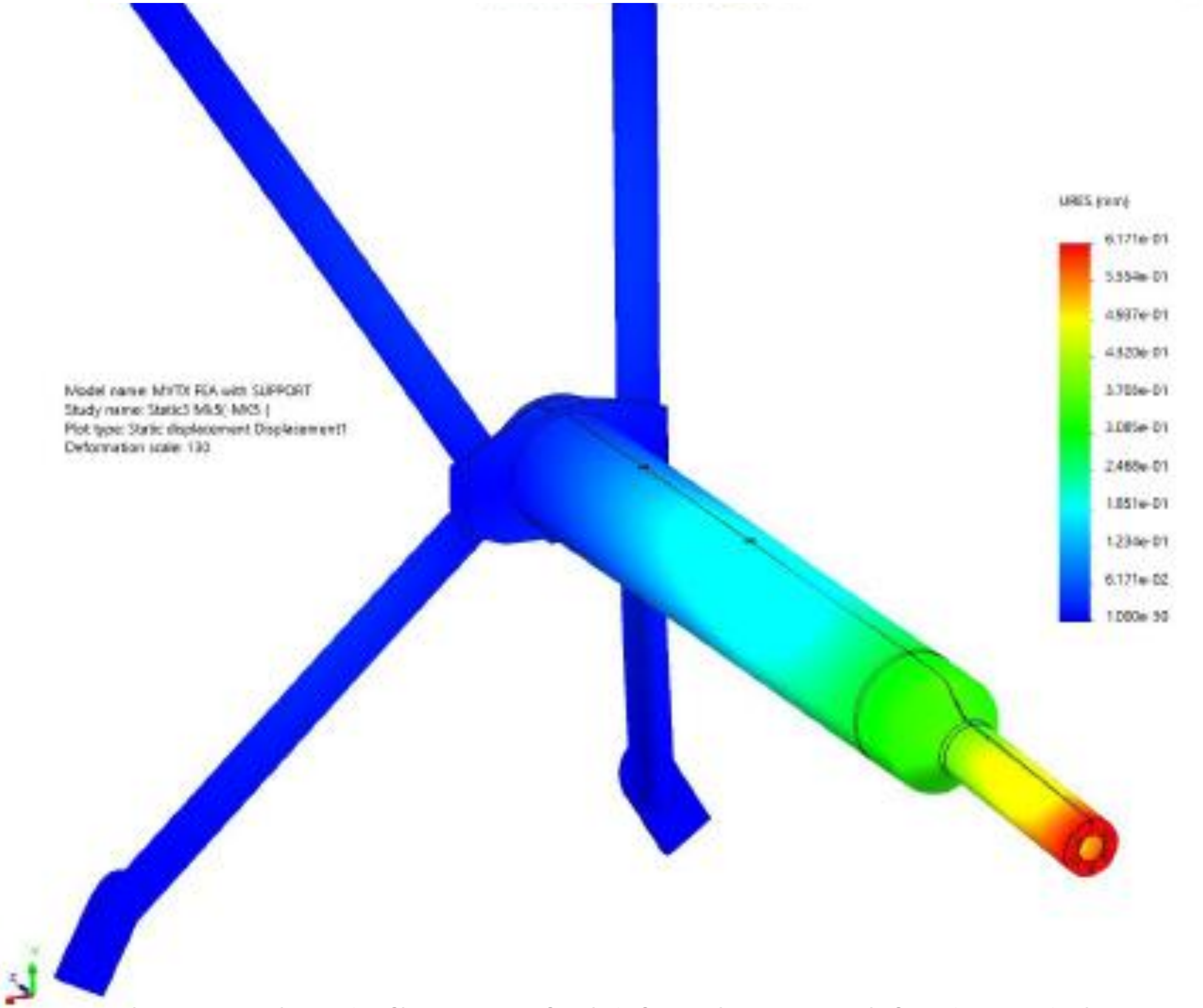
X-wing FEA with MVTX detector

- Study shown is done with a simplified MVTX model:
    - MVTX with isotropic titanium in place of orthotropic carbon fiber composite
        - Titanium has a similar stiffness to weight ratio, important for s supporting structure
    - it uses 1/8” thick tubes; (final design uses ¼” thick aluminum)
    - Shown maximum deflection is 0.617 mm
- After correcting for thicker tubes and simplified MVTX model, the total

Predicted deflection is 0.37 mm at *nose roller* end (nb, clearance to BP ~1.15mm)

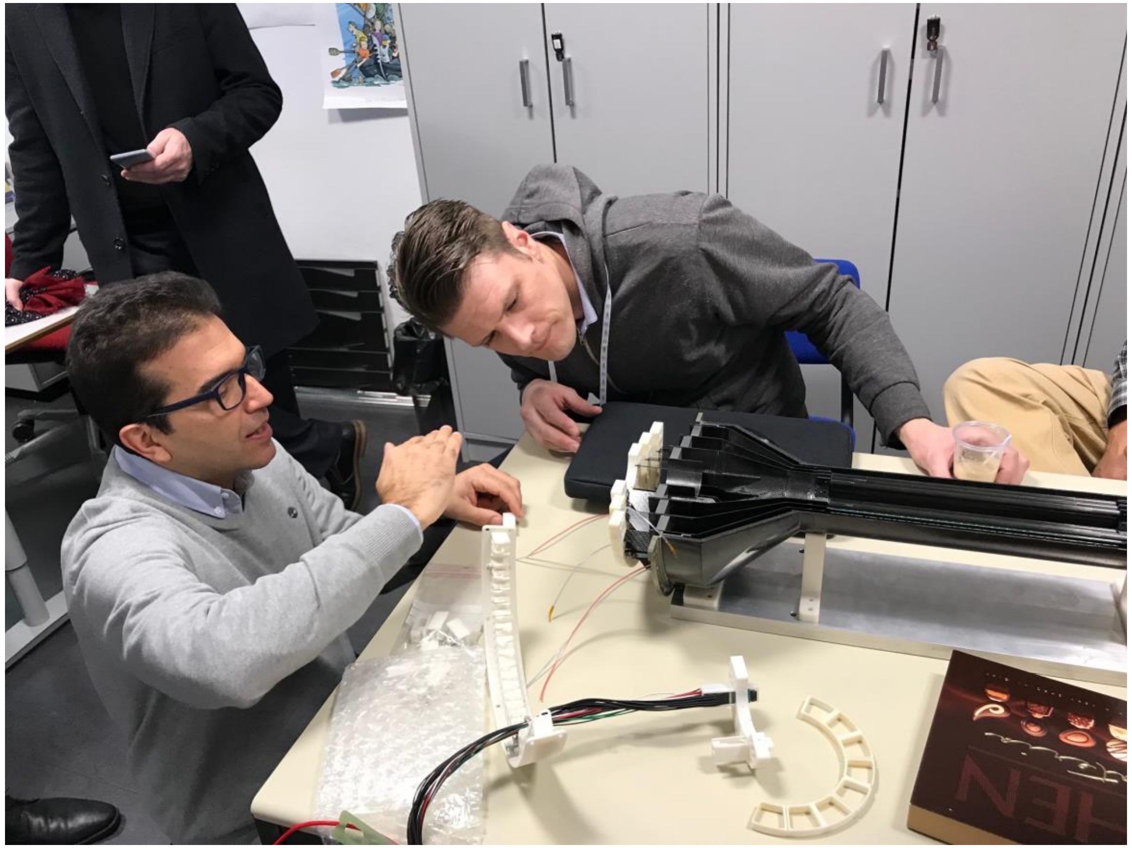


Design Iteration



Shown: the deflection field for the simplified model

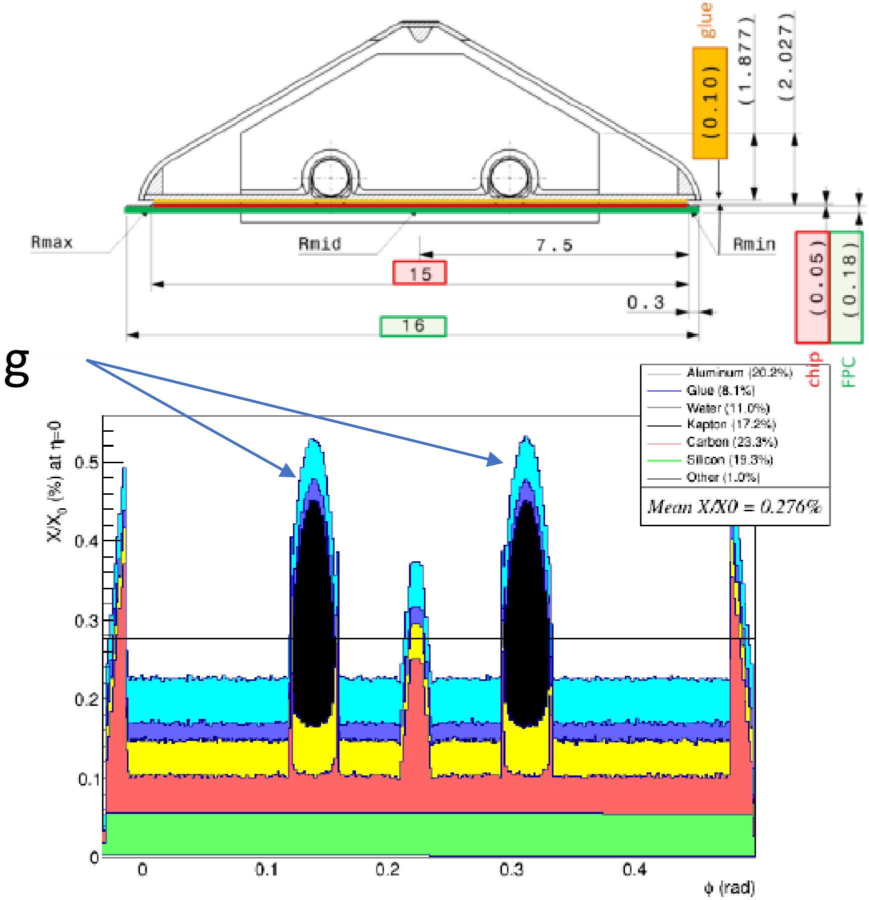
MIT, LANL engineers study prototype detector at CERN



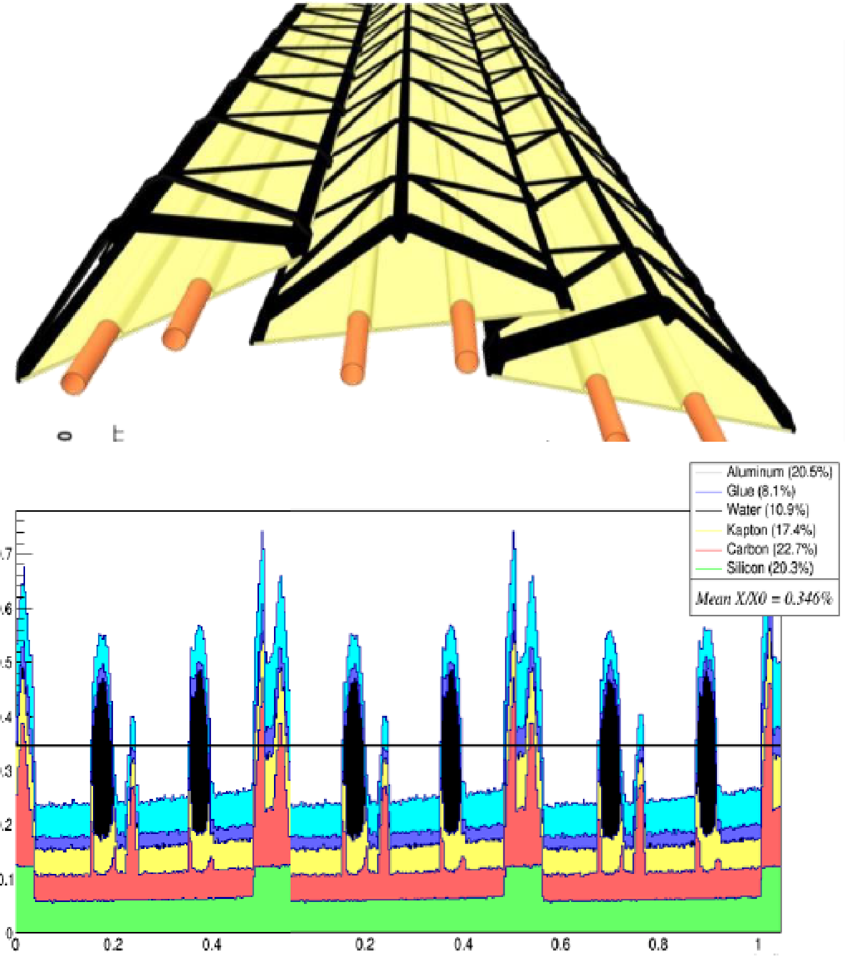
Radiation budget for stave assembly, ITS2 and MVTX

Material budget

Water cooling



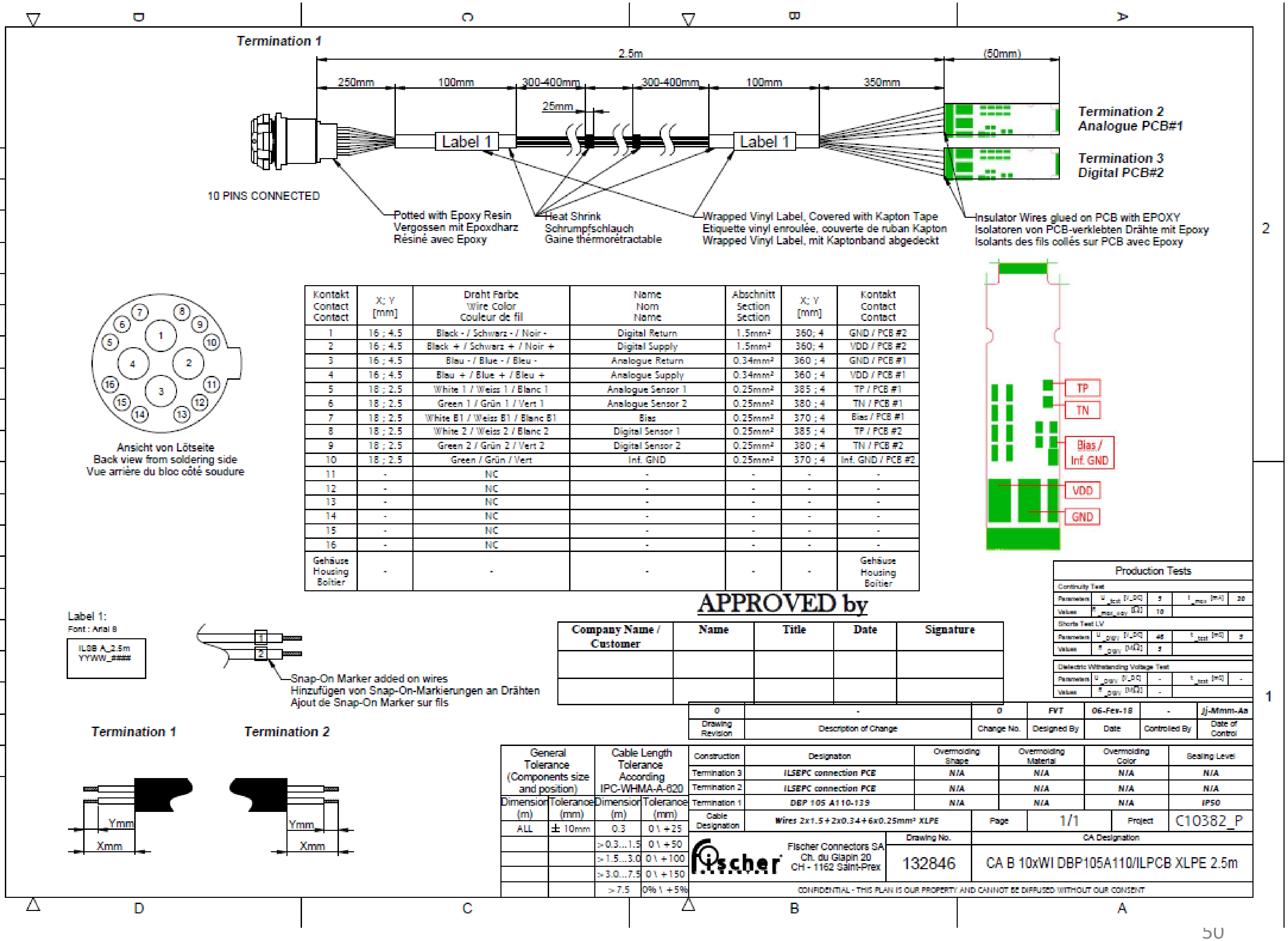
Single stave, for perpendicular tracks 0,276% X/X_0



Tilted stave with overlap, inclined tracks

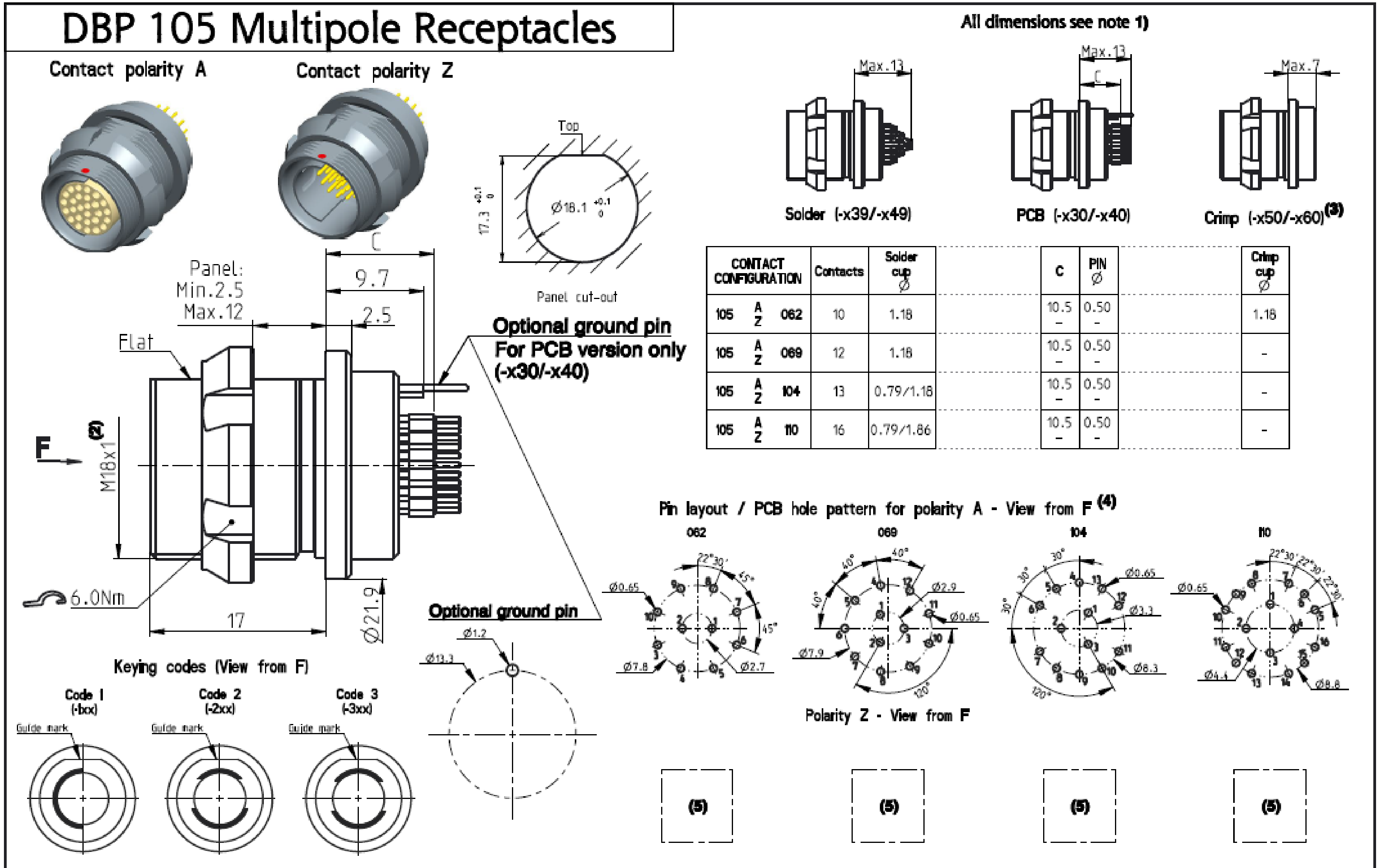
Proposed power cable bundle assembly, note they call out 16 wires, only 10 are used, 2 our 16 gauge for digital power and return, 2 our 22 gauge for analog power and return and 6 are 24 gauge wires for sensors, bias and ground.

If we order these cable assemblies we will request they NOT to include the Heat-shrink jacket, we may request the labels.



Kontakt / Contact / Contact	X; Y [mm]	Draht Farbe / Wire Color / Couleur de fil	Name / Nom / Name	Abschnitt / Section / Section	X; Y [mm]	Kontakt / Contact / Contact
1	16 ; 4.5	Black - / Schwarz - / Noir -	Digital Return	1.5mm²	360; 4	GND / PCB #2
2	16 ; 4.5	Black + / Schwarz + / Noir +	Digital Supply	1.5mm²	360; 4	VDD / PCB #2
3	16 ; 4.5	Blau - / Blue - / Bleu -	Analogue Return	0.34mm²	360 ; 4	GND / PCB #1
4	16 ; 4.5	Blau + / Blue + / Bleu +	Analogue Supply	0.34mm²	360 ; 4	VDD / PCB #1
5	18 ; 2.5	White 1 / Weiss 1 / Blanc 1	Analogue Sensor 1	0.25mm²	385 ; 4	TP / PCB #1
6	18 ; 2.5	Green 1 / Grün 1 / Vert 1	Analogue Sensor 2	0.25mm²	380 ; 4	TN / PCB #1
7	18 ; 2.5	White B1 / Weiss B1 / Blanc B1	Bias	0.25mm²	370 ; 4	Bias / PCB #1
8	18 ; 2.5	White 2 / Weiss 2 / Blanc 2	Digital Sensor 1	0.25mm²	385 ; 4	TP / PCB #2
9	18 ; 2.5	Green 2 / Grün 2 / Vert 2	Digital Sensor 2	0.25mm²	380 ; 4	TN / PCB #2
10	18 ; 2.5	Green / Grün / Vert	Inf. GND	0.25mm²	370 ; 4	Inf. GND / PCB #2
11	-	NC	-	-	-	-
12	-	NC	-	-	-	-
13	-	NC	-	-	-	-
14	-	NC	-	-	-	-
15	-	NC	-	-	-	-
16	-	NC	-	-	-	-
Gehäuse / Housing / Boîtier	-	-	-	-	-	Gehäuse / Housing / Boîtier

Fisher panel mount for the end of the stave power cable in PP3, with solder pins, and female sockets for a cable connector.



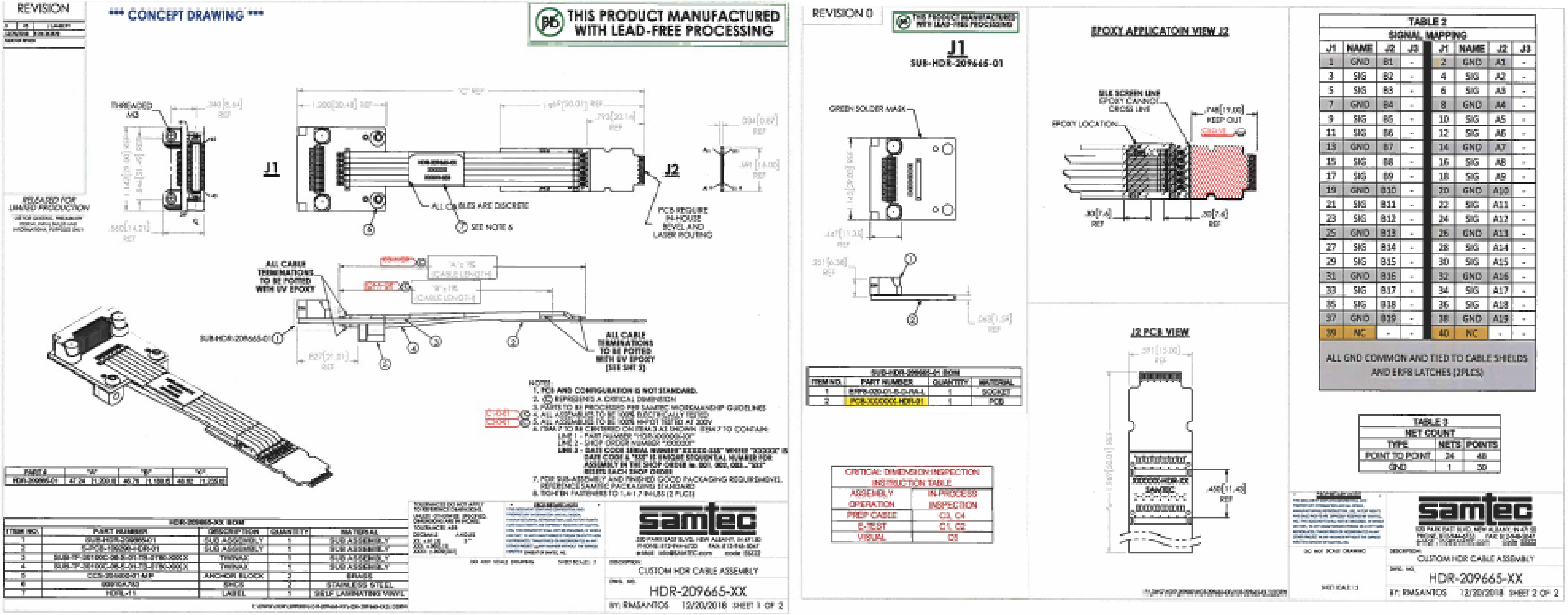
CONTACT CONFIGURATION			Contacts	Solder cup Ø	C	PIN Ø	Crimp cup Ø
105	A Z	062	10	1.18	10.5	0.50	1.18
105	A Z	069	12	1.18	10.5	0.50	-
105	A Z	104	13	0.79/1.18	10.5	0.50	-
105	A Z	110	16	0.79/1.86	10.5	0.50	-

All dimensions in mm	Rev.	Pages
600495	4	3/4

Notes :
1) All tolerances resulting from connector assembly are typically ± 0.3mm
2) If receptacle is screwed directly into threaded hole, oversize thread by +0.05mm
3) For optimum crimping refer to available crimping manual.
4) Recommended PCB hole dimensions may be adjusted to application
5) Please contact us.
Part number example : DBP 105 A102-130

Information provided herein is believed to be accurate at time of publishing. Fischer Connectors reserves the right to make modifications on products for continuous improvement without prior notice.

www.fischerconnectors.com



SAMTEC signal cable assembly from PP1 to PP3, individual wires are 14 gauge Twinax, measure .073 inches in diameter. Approximate diameter of cable bundle 6.5 mm

Composite material data sheets:

Technical Data

PITCH BASED CARBON FIBER

Granoc WOVEN FABRIC PREPREG F8O01-2437C

		F8O01-2437C
Fabric Type		PF-XN80-240
CF Type		XN-80-30S
CF Tensile Strength	ksi	500
	kgf/mm^2	350
	MPa	3430
CF Tensile Modulus	msi	114
	$10^3 kgf/mm^2$	80
	GPa	780
CF Density	g/mm^3	2.17
CF Thermal Conductivity	W/m·K	320
Weaving Structure		Plain
Fiber Areal Weight	g/m^2	240
Resin Type		NM31 (Polycyanate resin)
Resin Content	wt%	32
Glass Transfer Temperature	℃	188 (cured at 180 deg.C x 2hrs 246 (post cured at 232 deg.C x 2hrs)
Prepreg Total Weight	g/m^2	353
Prepreg Width	mm	1000

Notes : (1) XN-80 grade is based on coal tar pitch.
(2) Above figures are typical values at room temperature, not guaranteed values.
(3) These data may be revised if necessary.

Technical Data NM31

GRANOC Polycyanate Resin NM31 (180 deg.C cure)

Features
- High Tg : 246 deg.C
- Low outgassing and low moisture absorption
- Toughness

Neat resin physical properties

· Specific gravity	1.16	
· Tg (DSC method)	188 deg.C cured at 180 deg.C x 2hrs 246 deg.C post cured at 232 deg.C x 2hrs	
· Moisture absorption	0.4 % (80 deg.C , 80% RH, 24Hr)	
· Outgas	TML	0.22%
	CVCM	0.01%
· Flexural properties	Strength	133MPa
	Modulus	3190MPa
	Elongation	4.7%
· Shelf life	Refrigeration (-18℃)	About one year
	Room Temperature (25℃)	About one month
· Curing cycle	180 deg.C x 2hrs	

NIPPON GRAPHITE FIBER Corp.
1, Fuji-cho, Hirohata-ku, Himeji, Hyogo 671-1123 JAPAN
TEL +81-79-236-7010 FAX +81-79-237-8427

The Work-Shape Composite lay-up Details:

DRAWING	DESCRIPTION	SUBASSY	MATERIAL	LAYUP PATTERN	PART NOMINAL THICKNESS, mm
MVTX-2-S-00082	MVTX - SB - Cylinder	SB	NGF GRANOC F8A01-2437C	20 plies, (0°/45°/0°/45°/0°/0°/45°/0°/45°/0°)s	2.16
MVTX-2-S-00079	MVTX - CYSS - Cylinder	CYSS	NGF GRANOC F8A01-2437C	10 plies, (0°/45°/0°/45°/0°)s	1.12
MVTX-2-S-00078	MVTX - CYSS - Rib	CYSS	NGF GRANOC F8A01-2437C	16 plies {(0°/45°/0°/45°)s}s	1.7
	MVTX - CYSS - Cone cone	CYSS	NGF GRANOC F8A01-2437C	20 plies, (0°/45°/0°/45°/0°/0°/45°/0°/45°/0°)s	2.16
MVTX-2-S-00077	MVTX - CYSS - Cone cylinder	CYSS	NGF GRANOC F8A01-2437C	20 plies, (0°/45°/0°/45°/0°/0°/45°/0°/45°/0°)s	2.16
MVTX-2-S-00054	MVTX - L2 - PP1 Divider	L2	NGF GRANOC F8A01-2437C	9 plies, (0°/45°/0°/45°/0°/45°/0°/45°/0°)	0.91
MVTX-2-S-00051	MVTX - L2 - Pass Through Divider	L2	NGF GRANOC F8A01-2437C	9 plies, (0°/45°/0°/45°/0°/45°/0°/45°/0°)	0.91
MVTX-2-S-00050	MVTX - L2 - S. EW - Rib	L2	NGF GRANOC F8A01-2437C	12 plies, (0°/0°/45°/45°/45°/0°)s	1.33
MVTX-2-S-00049	MVTX - L2 - C Ring	L2	NGF GRANOC F8A01-2437C	15 plies, (0°/45°/0°/45°/0°/45°/0°/45°/0°/45°/0°/45°/0°/45°/0°)	1.53
MVTX-2-S-00048	MVTX - L2 - S. EW - Spring	L2	NGF GRANOC F8A01-2437C	21/6 plies: Full surface (0°/45°/0°)s, then (0°/45°/0°/45°/0°/45°/0°/45°/0°/45°/0°/45°/0°/45°/0°)	2,37/0,69
MVTX-2-S-00047	MVTX - L2- S. EW - Cone	L2	NGF GRANOC F8A01-2437C	10 plies, (0°/45°/0°/45°/0°)s	1.12
MVTX-2-S-00039	MVTX - L1 - PP1 Divider	L1	NGF GRANOC F8A01-2437C	9 plies, (0°/45°/0°/45°/0°/45°/0°/45°/0°)	0.91
MVTX-2-S-00036	MVTX - L1 - Pass Through Divider	L1	NGF GRANOC F8A01-2437C	9 plies, (0°/45°/0°/45°/0°/45°/0°/45°/0°)	0.91
MVTX-2-S-00035	MVTX - L1 - S. EW - Rib	L1	NGF GRANOC F8A01-2437C	12 plies, (0°/0°/45°/45°/45°/0°)s	1.33
MVTX-2-S-00034	MVTX - L1 - C Ring	L1	NGF GRANOC F8A01-2437C	15 plies, (0°/45°/0°/45°/0°/45°/0°/45°/0°/45°/0°/45°/0°/45°/0°)	1.53
MVTX-2-S-00033	MVTX - L1 - S. EW - Spring	L1	NGF GRANOC F8A01-2437C	18/6 plies: Full surface (0°/45°/0°)s, then (0°/45°/0°/45°/0°/45°)s	1,95/0,62
MVTX-2-S-00032	MVTX - L1- S. EW - Cone	L1	NGF GRANOC F8A01-2437C	10 plies, (0°/45°/0°/45°/0°)s	1.12
MVTX-2-S-00022	MVTX - L0 - Pass Through Divider	L0	NGF GRANOC F8A01-2437C	9 plies, (0°/45°/0°/45°/0°/45°/0°/45°/0°)	0.91
MVTX-2-S-00011	MVTX - Divider Mount	L0, L1, L2	NGF GRANOC F8A01-2437C	3 plies, (45°/0°/45°)	0.3
MVTX-2-S-00009	MVTX - L0 - PP1 Divider	L0	NGF GRANOC F8A01-2437C	9 plies, (0°/45°/0°/45°/0°/45°/0°/45°/0°)	0.91
MVTX-2-S-00008	MVTX - L0 - S. EW - Spring	L0	NGF GRANOC F8A01-2437C	18/6 plies: Full surface (0°/45°/0°)s, then (0°/45°/0°/45°/0°/45°)s	1,95/0,62
MVTX-2-S-00007	MVTX - L0 - C Ring	L0	NGF GRANOC F8A01-2437C	10 plies, (0°/45°/0°/45°/0°)s	1.12
MVTX-2-S-00006	MVTX - L0 - S. EW - Rib	L0	NGF GRANOC F8A01-2437C	12 plies, (0°/0°/45°/45°/45°/0°)s	1.33
MVTX-2-S-00005	MVTX - L0 - S. EW - Cone	L0	NGF GRANOC F8A01-2437C	10 plies, (0°/45°/0°/45°/0°)s	1.12

MVTX composite manufacturing notes, Jason Bessuille, MIT

Drawing Notes which apply to all carbon fiber parts

1 Nominal material for all plies:
- a Fiber shall be Granoc CN-80 (or XN-80), tensile modulus 780 GPa.
- b Each ply shall be bidirectional fabric, 240 gsm, plain weave (PF-XN80-240).
- c Resin shall be EX-1515 cyanate ester.
- d Fiber shall be pre-impregnated with resin (prepreg).
- e Prepreg shall have resin mass fraction 32% ± 2%.

2 Alternative materials:
- a Vendor may propose equivalent alternate fiber or resin.
- b Approval of any alternate(s) is entirely at customer's discretion, and shall be made in writing.

3 Processing:
- a Cured part shall have fiber volume fraction between 50% and 60%.
- b Cured part shall have void fraction <= 1%.
- c Cure temperature shall 121°C for 3 hour minimum hold time (EX-1515).
- d Any alternate resin shall be cured according to resin manufacturer's recommendations. Cure profile shall be approved by customer in writing.
- e Minimum vacuum pressure 25 inHg shall be applied during cure.
- f Additional autoclave pressure of 40-100 psig is preferred.
- g Surface texture for bonded interfaces shall be generated by incorporating peel ply in the vacuum bag stackup during cure.

4 Fiber directions, unless otherwise specified on drawings:
- a 0° direction is parallel to center axis for cylindrical parts.
- b 0° direction is parallel to longest orthogonal direction for planar parts.

5 Material coupons shall be delivered to customer with parts.
- a Coupons shall be laid up and cured alongside / simultaneous to production parts.
- b Coupons shall be at least 1" wide x 5" long, and of same thickness.
- c Vendor shall deliver minimum of 2 coupons per unique layup definition.

6 Vendor shall deliver the following documentation with parts:
- a Material certifications from fiber and resin manufacturer(s).
- b Measured time, temperature, and vacuum pressure data during cure of all parts.
- c Clear documentation of no loss of vacuum pressure during cure.
- d Measured autoclave pressure data (if applicable).
- e Total storage and out times of prepreg prior to cure.

Estimated laminate properties

Assumed values for manufacturing process

Mm	32.0%		resin mass fraction in prepreg
FAW	240	gsm	fiber areal weight
Vv	0.5%		
surface texture thickness	70	um	both sides, from LBNL measurements 2013-04-24 with peel-ply surface

Estimates of cured ply thickness and prepreg areal weight

CPT woven	209.2	μm	cure ply thickness
PAW	353	gsm	prepreg areal weight

Fiber and Matrix Properties

Fiber	CN-80		
E1f	780	GPa	CN series data sheet
E2f	8.9	GPa	by analogy to P-55S fibers
Em	4.4	GPa	Kollar&Springer. Approx value for structural epoxies
v12f	0.23		by analogy to P-55S fibers
vm	0.35		Kollar&Springer. Approx value for structural epoxies
pf	2.17	g/cm³	CN series data sheet
pm	1.17	g/cm³	EX-1515 data sheet
G12f	317.1	GPa	
Gm	1.6	GPa	

Uni Ply Properties

weave stiffness reduction factor	5%		LBNL typical value, based on 2013-04-12 tensile test data
Vf	53.1%		
Vm	46.4%		
vVf	0.73		
E11	395.7	GPa	
E22	6.4	GPa	
G12	5.9	GPa	
nu12	0.284		

MVTX-9-R-00106

Rev. A

MVTX Composites Manufacturing Notes

20 JULY 2020

Assembly	Description	Drawing MVTX-2-5-	Location where layup applies	Comment	no. plies	Thickness (mm)	Layup ID	Layups: Stackup definitions start at inner surface --> outer surface									
CYSS	CYSS - Cone	00077	most of part	ply drop defined in separate row	10	2.16	A.1	0/90	0/90	0/90	0/90	±45	±45	0/90	0/90	0/90	0/90
			@ 13.4 mm ply drop off	±45 ply shall be on INNER surface	5	1.12	A.2	drop	drop	drop	drop	drop	±45	0/90	0/90	0/90	0/90
CYSS	CYSS - Cylinder	00079	complete part	-	5	1.12	B	0/90	±45	0/90	±45	0/90					
LAYER ONE	L1 - C Ring	00034	complete part	machine chamfer	7	1.53	C	0/90	±45	0/90	±45	0/90	±45	0/90			
LAYER ONE	L1 - Pass Through Divider	00036	complete part	-	4	0.91	D	0/90	±45	±45	0/90						
LAYER ONE	L1 - PP1 Divider	00039	complete part	-	4	0.91	D	0/90	±45	±45	0/90						
LAYER ONE	L1 - S. EW - Rib	00035	complete part	vendor may propose laying up to alternate thickness 2.5 mm (i.e. to save a mold)	6	1.33	E	0/90	±45	0/90	0/90	±45	0/90				
LAYER ONE	L1 - S. EW - Spring	00033	complete part	machine step down to 0.5 mm and chamfer	9	1.95	F	0/90	±45	0/90	±45	0/90	±45	0/90	±45	0/90	
LAYER ONE	L1- S. EW - Cone	00032	complete part	-	5	1.12	B	0/90	±45	0/90	±45	0/90					
LAYER TWO	L2 - C Ring	00049	complete part	machine chamfer	7	1.53	C	0/90	±45	0/90	±45	0/90	±45	0/90			
LAYER TWO	L2 - Pass Through Divider	00051	complete part	-	4	0.91	D	0/90	±45	±45	0/90						
LAYER TWO	L2 - PP1 Divider	00054	complete part	-	4	0.91	D	0/90	±45	±45	0/90						
LAYER TWO	L2 - S. EW - Rib	00050	complete part	vendor may propose laying up to alternate thickness 2.5 mm (i.e. to save a mold)	6	1.33	E	0/90	±45	0/90	0/90	±45	0/90				
LAYER TWO	L2 - S. EW - Spring	00048	complete part	machine step down to 0.5 mm and chamfer	11	2.37	G	0/90	±45	0/90	±45	0/90	±45	0/90	±45	0/90	0/90
LAYER TWO	L2- S. EW - Cone	00047	complete part	-	5	1.12	B	0/90	±45	0/90	±45	0/90					
LAYER ZERO	L0 - C Ring	00007	complete part	-	5	1.12	B	0/90	±45	0/90	±45	0/90					
LAYER ZERO	L0 - Pass Through Divider	00022	complete part	-	4	0.91	D	0/90	±45	±45	0/90						
LAYER ZERO	L0 - PP1 Divider	00009	complete part	-	4	0.91	D	0/90	±45	±45	0/90						
LAYER ZERO	L0 - S. EW - Cone	00005	complete part	-	5	1.12	B	0/90	±45	0/90	±45	0/90					
LAYER ZERO	L0 - S. EW - Rib	00006	complete part	vendor may propose laying up to alternate thickness 2.5 mm (i.e. to save a mold)	6	1.33	E	0/90	±45	0/90	0/90	±45	0/90				
LAYER ZERO	L0 - S. EW - Spring	00008	complete part	machine step down to 0.5 mm and chamfer	9	1.95	F	0/90	±45	0/90	±45	0/90	±45	0/90	±45	0/90	
SERVICE BARREL	SB - Cylinder	00082	complete part	-	10	2.16	A.1	0/90	0/90	0/90	0/90	±45	±45	0/90	0/90	0/90	0/90

* Expected thickness, including surface texture

Pictures at Work-Shape facility, La Roche-de-Glum, France

Simon Rubet, owner

Two half detector assemblies mounted to insertion table