Structural Composite Design, Simulation, and Testing of the HL-CMS Inner and Outer Tracker Support Tubes

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29 May 2024

12th Forum on Tracking Detector Mechanics

On behalf of CMS Tracker Group

Partially supported by NSF and by U.S. DEPARTMENT OF ENERGY

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CMSC Introduction

We offer world-class research facilities for composites manufacturing, characterization and experimental validation

Manufacturing

- Thermwood LSAM 105 Additive Manufacturing
- TP Sheet Forming
- Compression Molding
- AFP
- RTM, Autoclave, Machining

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Characterization

- Test frames, fixtures, Thermal chamber
- DMA, DSC, TGA Rheometer
- Microscopy, CT Scan

Thermwood LSAM 105 Printer

Thermoplastic Sheet Forming

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CMSC Introduction

We partner with Dassault Systemes to enrich and offer world-class modeling and simulation tools for research and engineering

Integrated Composites Workflow Applications

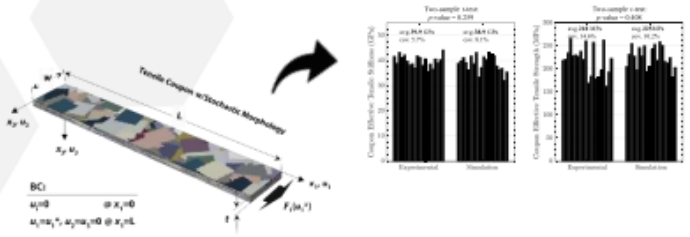
Combine multiple models and simulations to provide end-to-end virtual process twins

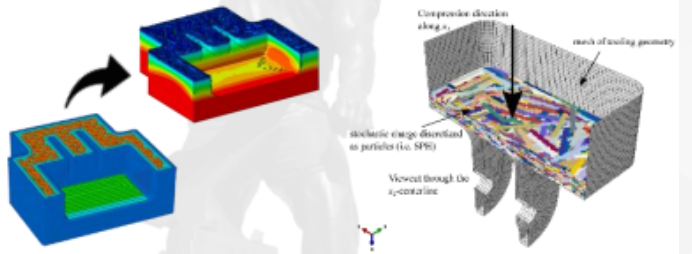
Composites Simulation Validation

Connect virtual twins to reality through characterization, rapid prototyping, and validation

New Composites Simulation Methods

Drive the development of robust and transformative predictive methods





Simulation for Manufacturing Informed Design

Simulation Driven Certification

Simulation as the Language of Innovation

Empowering a manufacturing-informed design experience for composites connected across the supply chain

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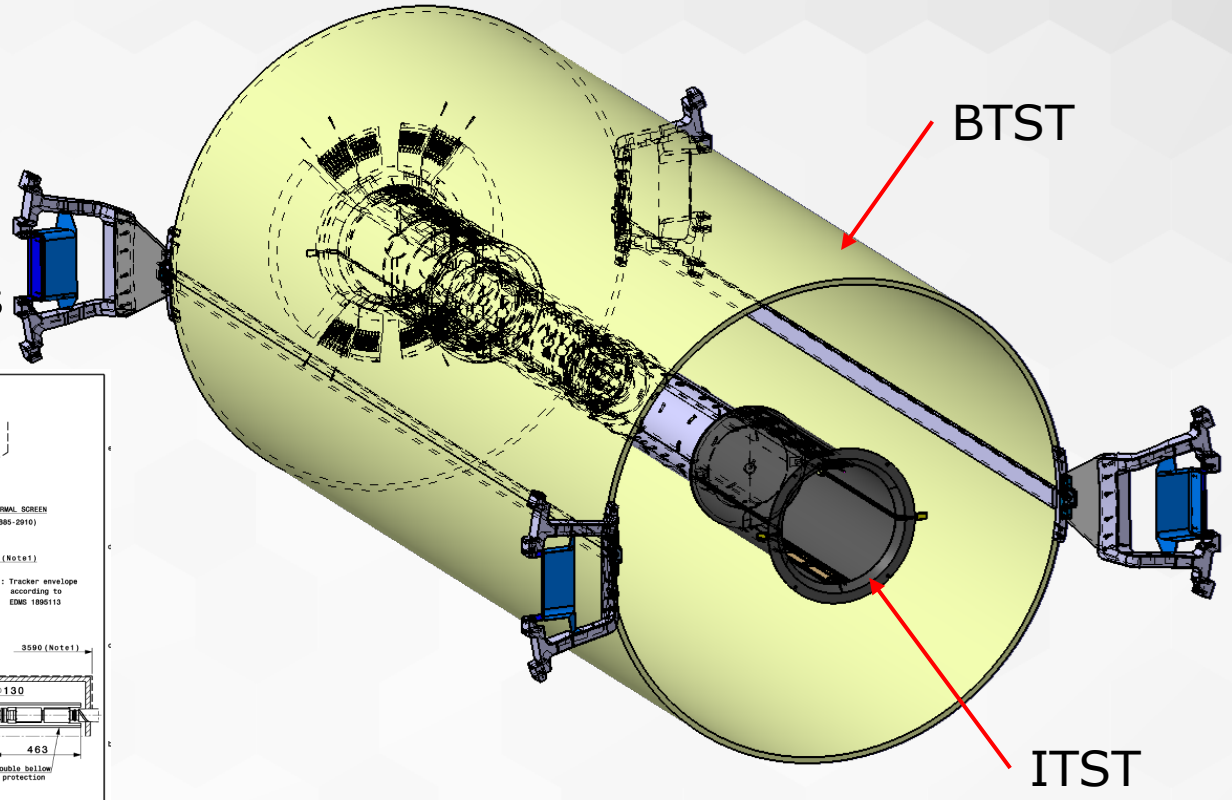
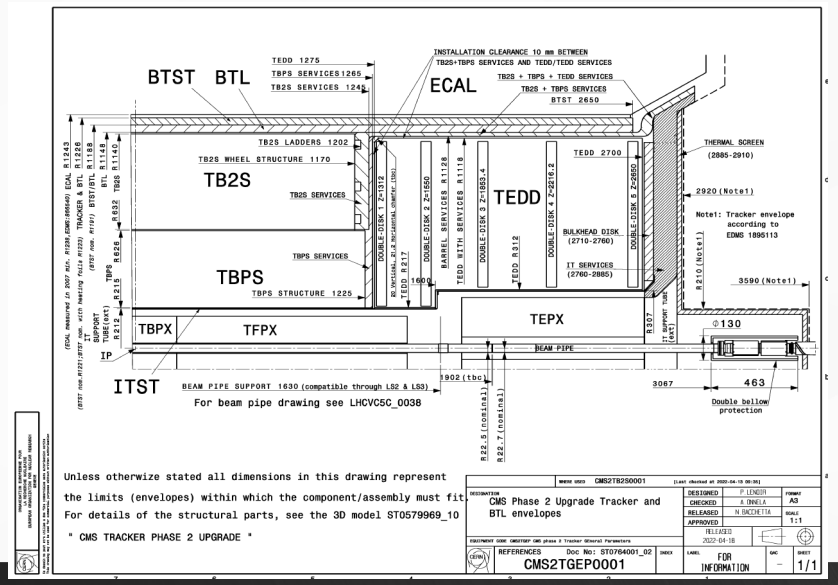
Outline

- CMS Barrel Timing Layer Tracker Support Tube (BTST) and inner tracker support tube (ITST) for the HL-LHC upgrade
- Challenges and lessons learned while
  - Prototyping
  - Re-designing for manufacturing in composites
  - Simulation
  - Testing





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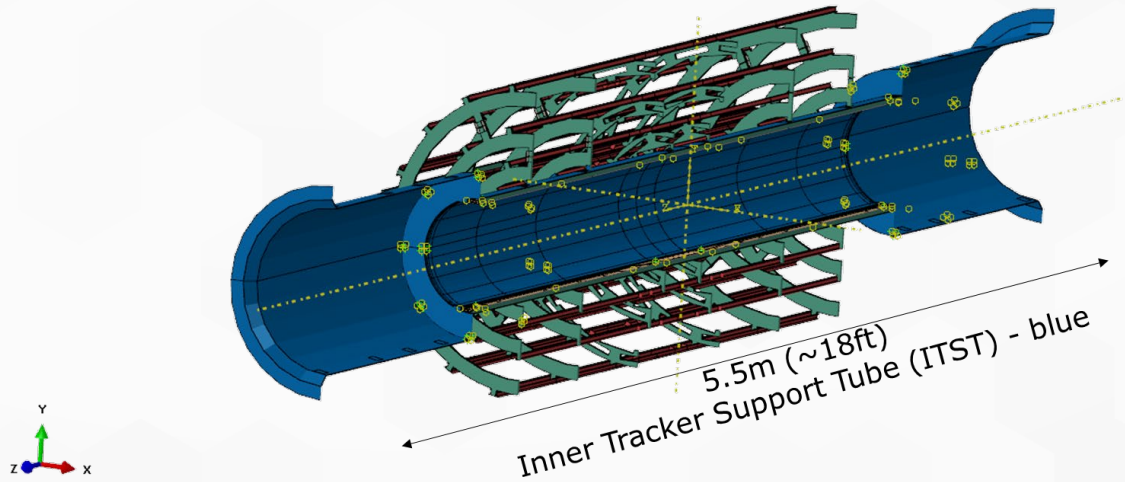
Outline - ITST

- Production of center and end sections
- Integration test of the TBPX and TFPX into the ITST center section prototype
- Track manufacturing for both center and ends
- Silicone seal between the inner and outer tracker volume
- Cyanate ester resin system considerations (including Airex foam interaction)



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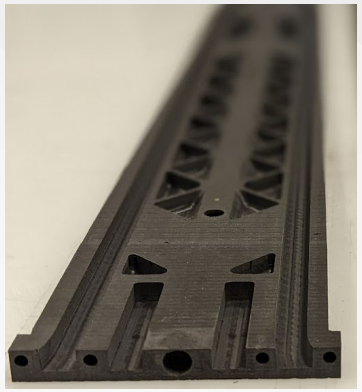
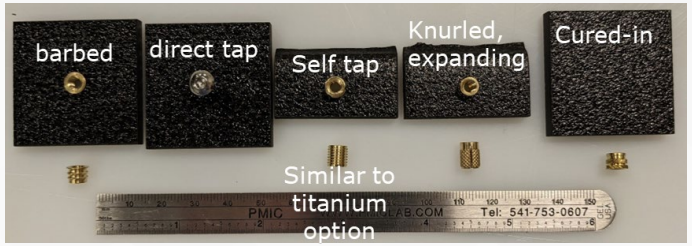
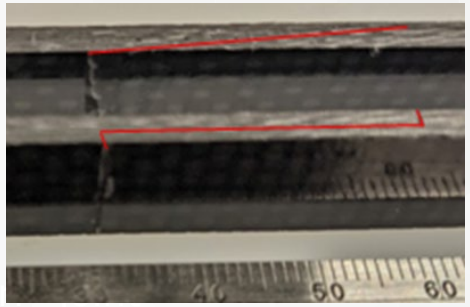
ITST Manufacturing Overview

- Prototype materials
  - AS4/ Proof Research 250P epoxy plain weave
  - [0/30/-30/0/30/-30/0/-30/30/0/-30/30/0]
  - 13 plies, 3mm thick
  - (final material IM7 / PMT-F6 plain weave)
  - Electrafil 1501 printed track block, then CNC
- Test and select threaded inserts and fasteners
- Test and select cylinder joint type
- Cure as half cylinder with scarf joints
- Use CNC'd I-beam to position tracks
- Bond half cylinders around tracks







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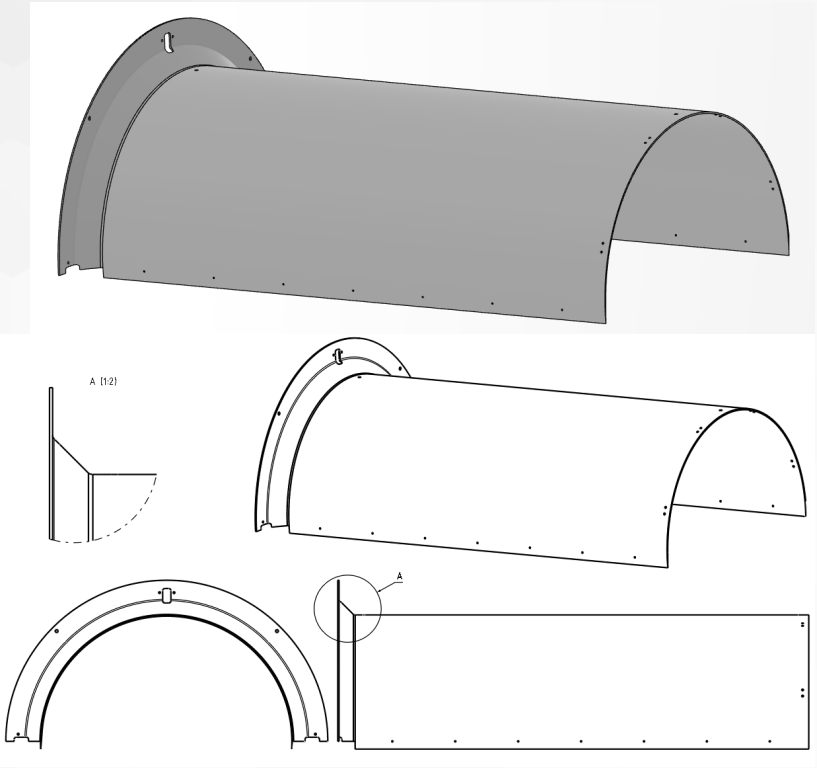
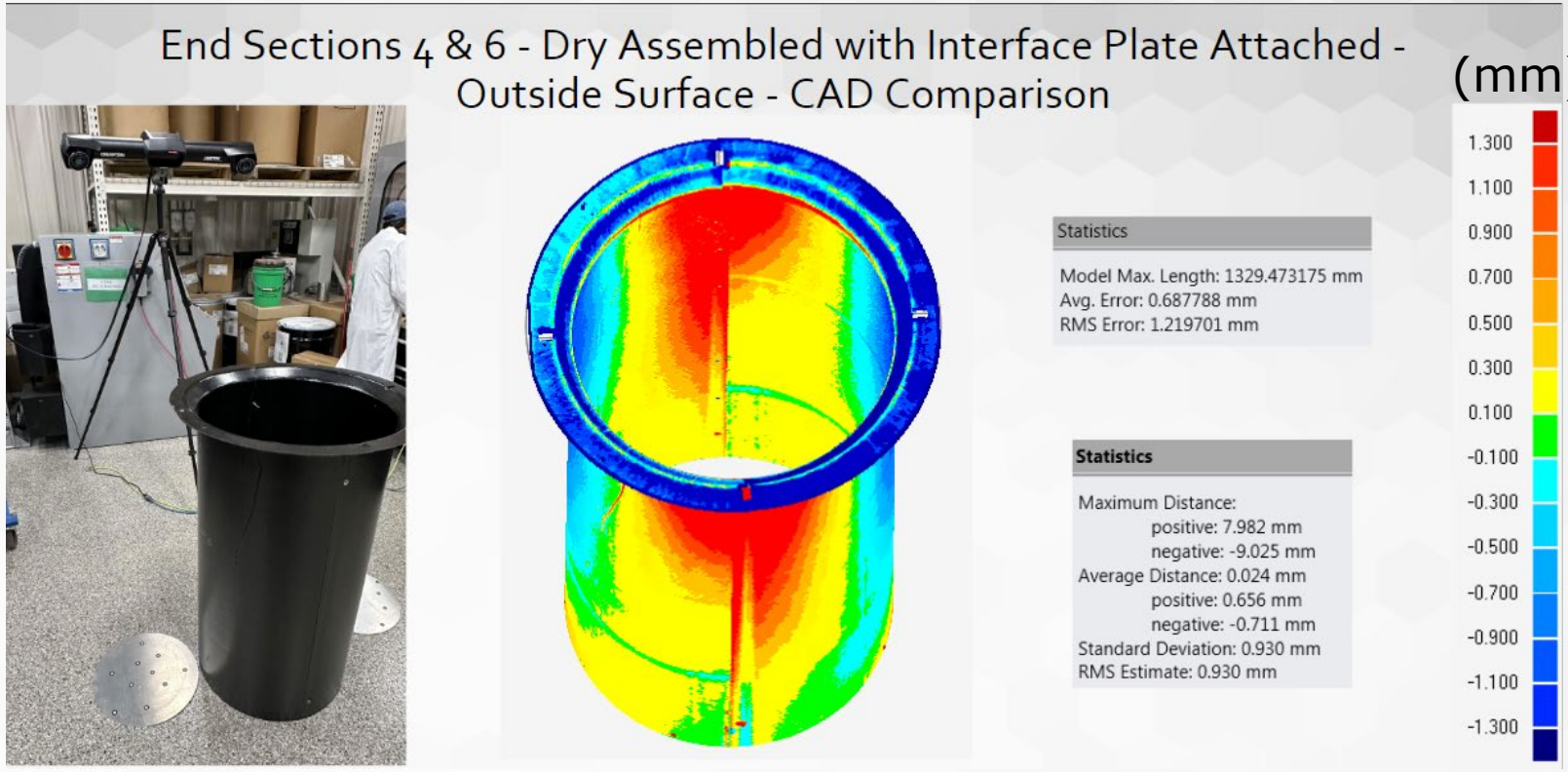
ITST End Section

- Produce from scarf-jointed halves, like ITST center
- Shape compensation more challenging with flange





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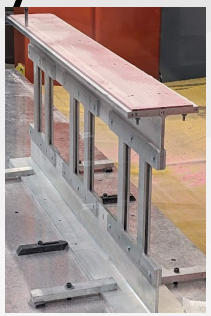
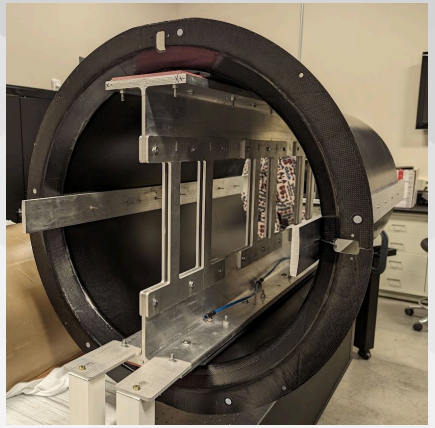
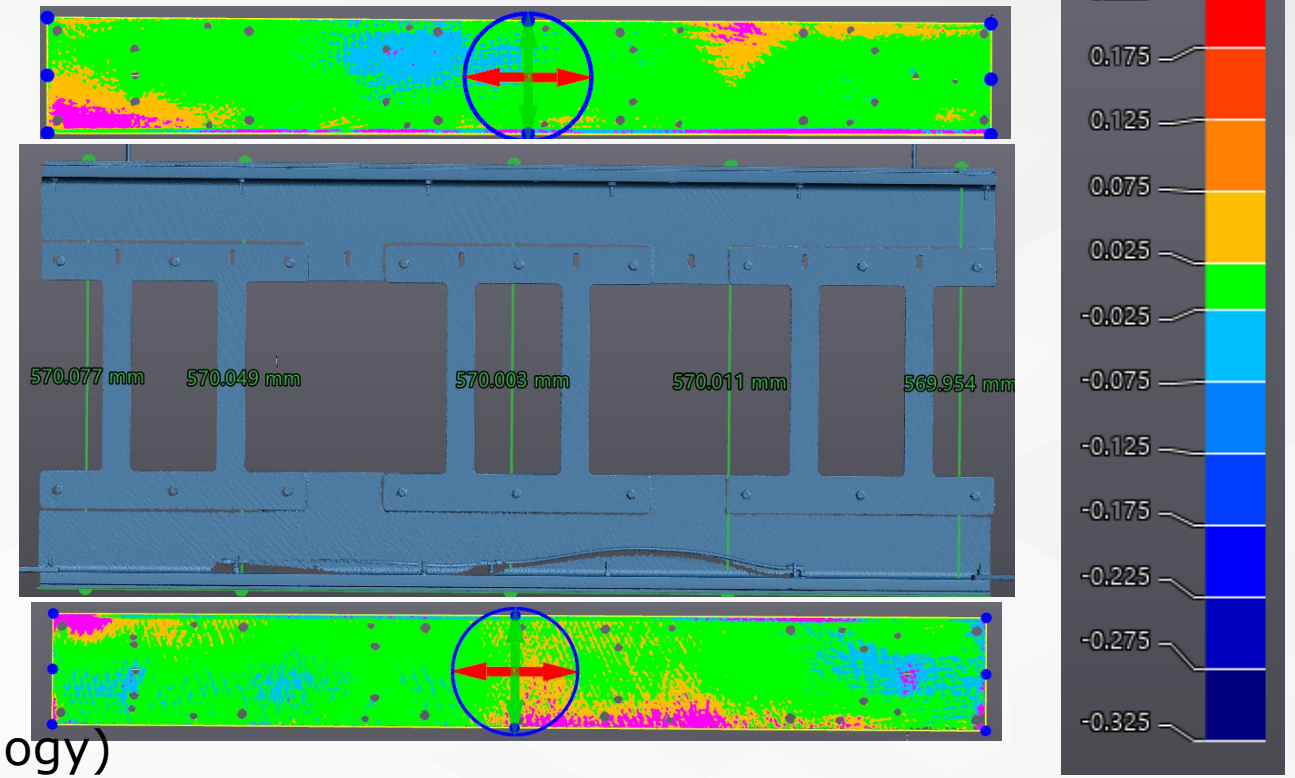
ITST End Section Assembly I-Beam

- Laser scanned
  - Face-to-face target distance: 570mm
    - Measured min: 569.95mm
    - Measured max: 570.08mm
  - Face flatness St. Dev. <0.02mm

- Precise starting point to attach tracks to for bonding







Justin Hicks (machining) and Jack Wheeler (metrology)

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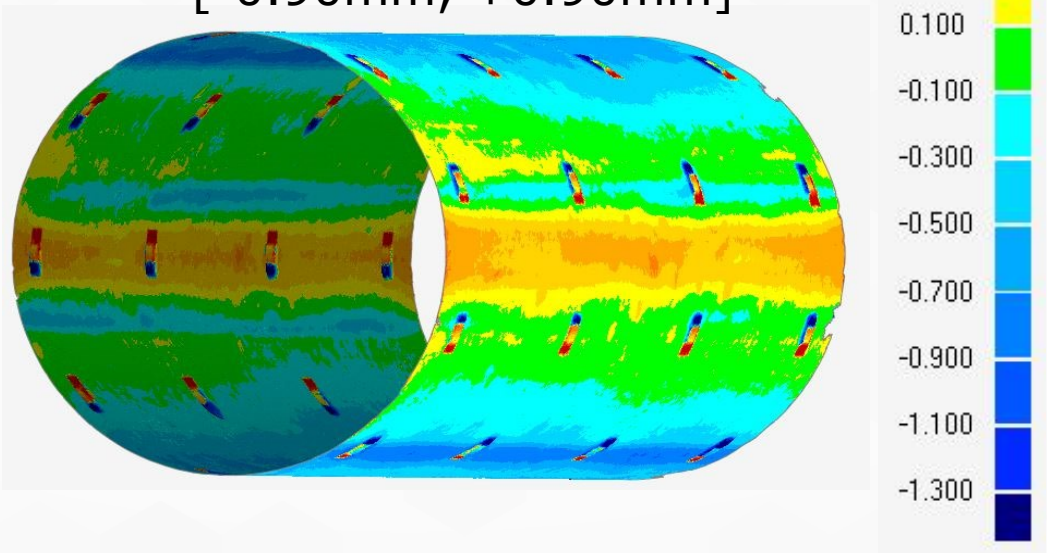
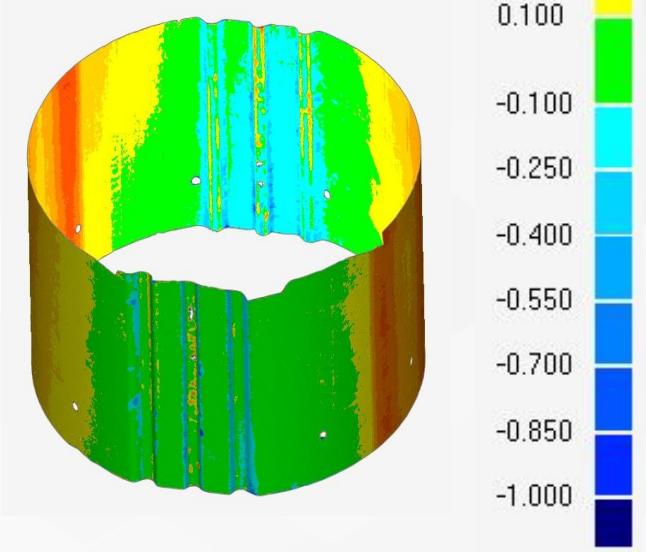
ITST 1m Prototype Bonded Surface CAD Fit

- Laser scan outside of 1m prototype
- Laser scan accessible end of inside
- Bonding helps to correct shape

[-0.90mm, +0.90mm]



[-0.40mm, +0.85mm]



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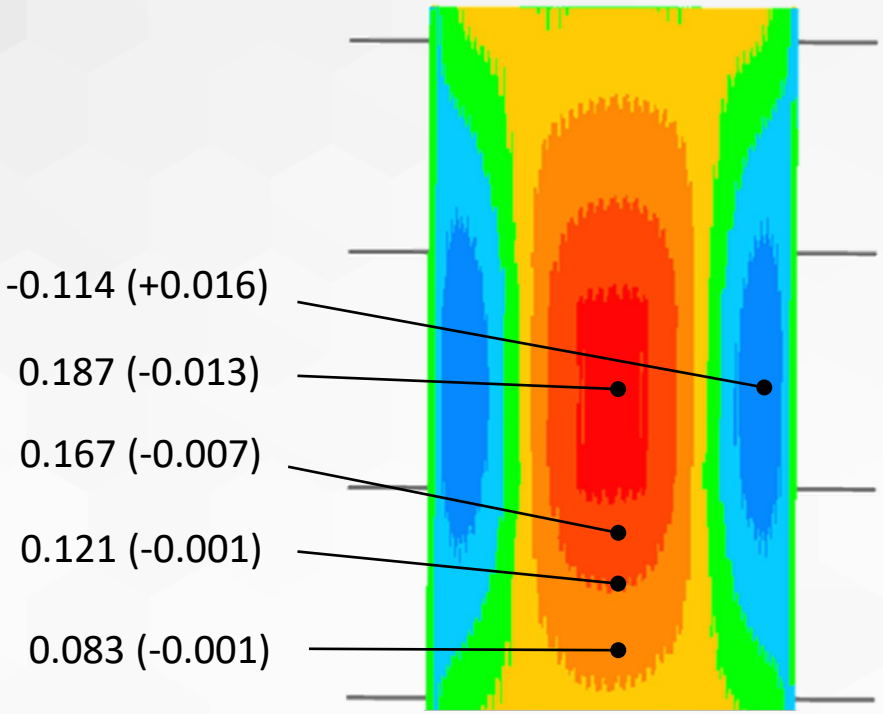
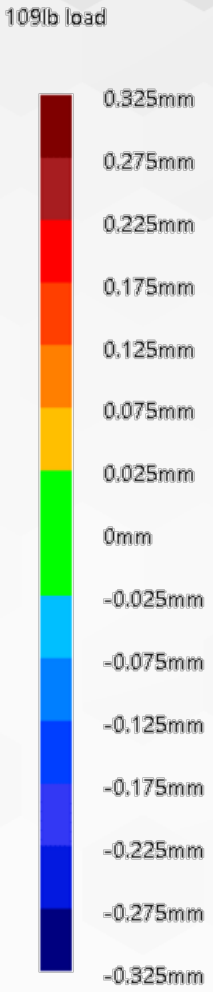
ITST-TBPS Mock Frame - Simulation vs. Experimental – 49.4 loading case (12.4kg/wheel)

Scan Under

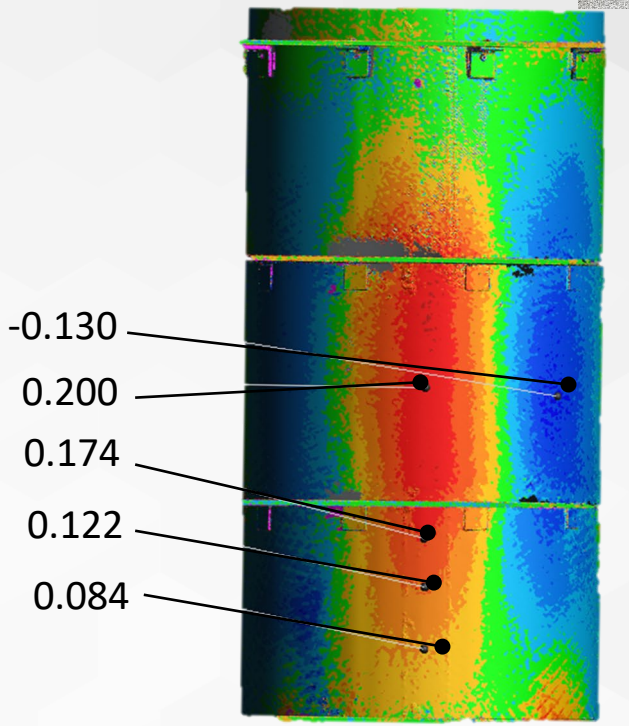
Simulation



Bottom view



Experimental



Bottom view

Outcomes:

- Scanner resolution 0.05mm
- All simulation points are within scanner resolution (experimental range).
- Deflection contours match well
- Simulation is validated

Justin Hicks (simulation) and Jack Wheeler (metrology)

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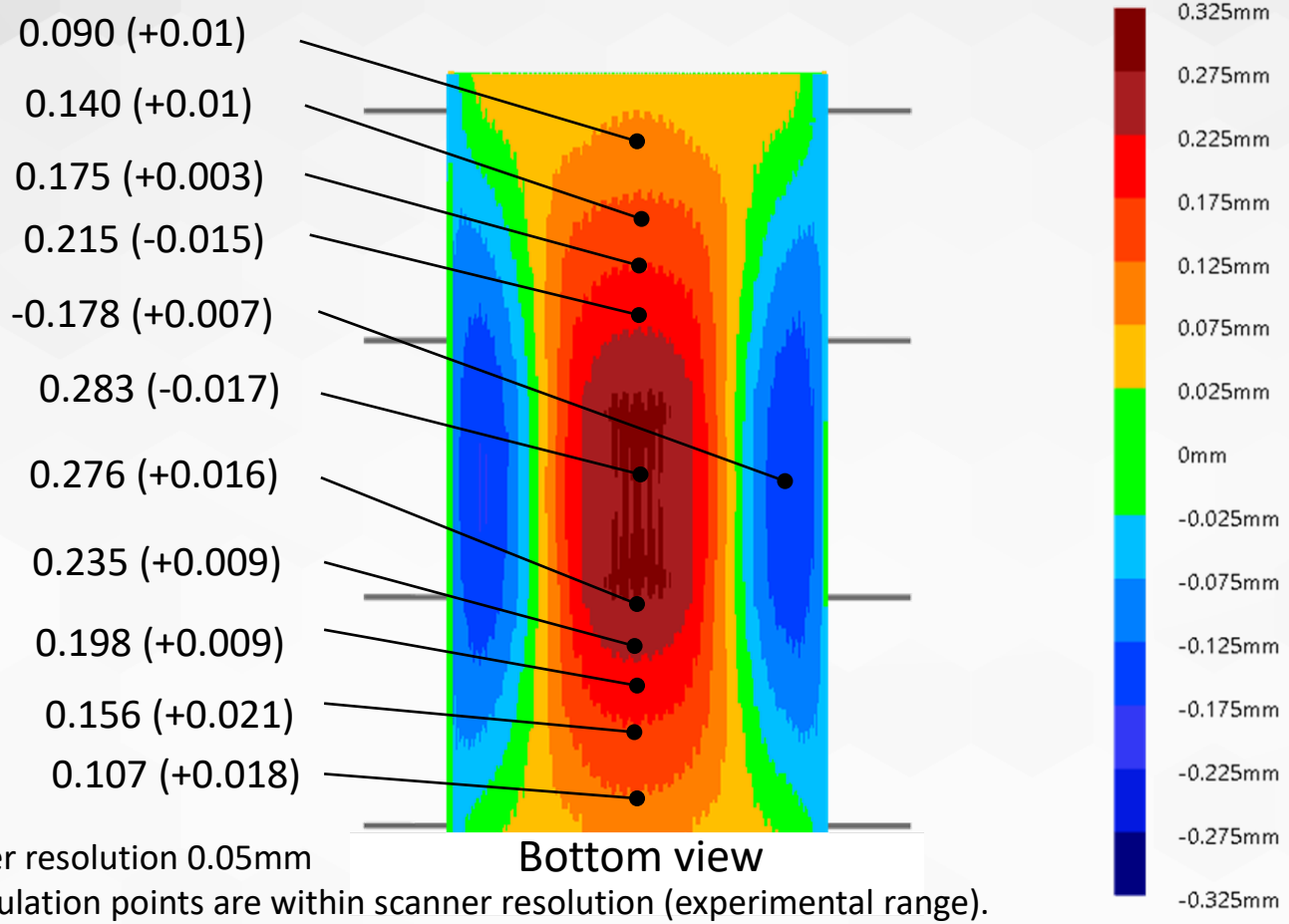
ITST-TBPS Mock Frame - Simulation vs. Experimental – 76.7kg loading case (19.2kg/wheel)

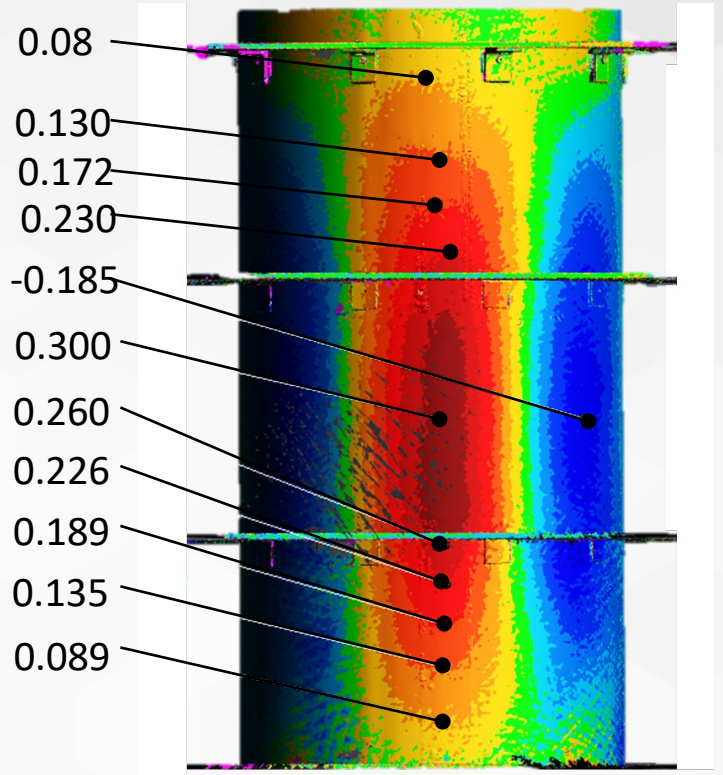
Scan Under

Simulation



Bottom view

Experimental



Bottom view

Outcomes:

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- Deflection contours match well
- Simulation is validated

Justin Hicks (simulation) and Jack Wheeler (metrology)

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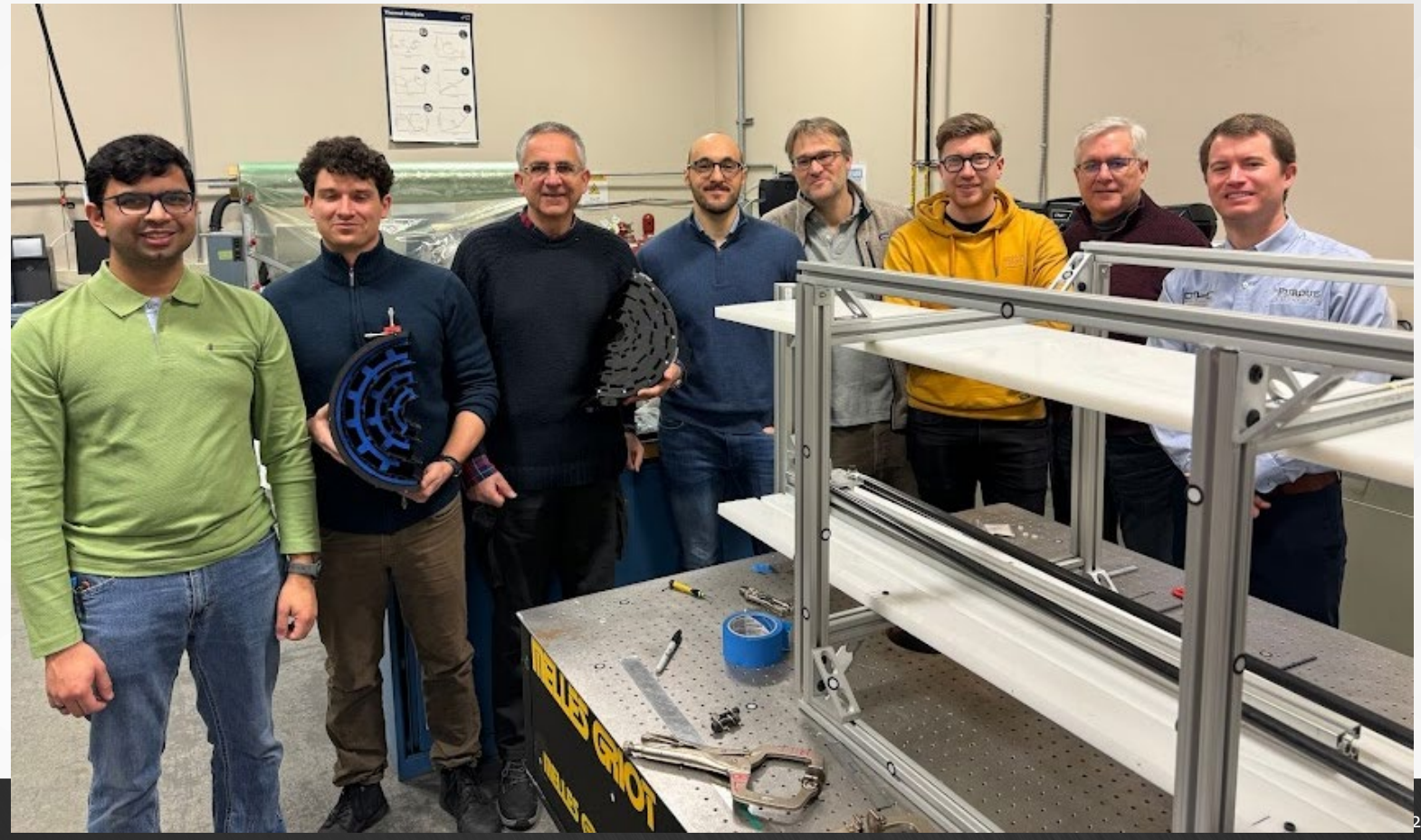
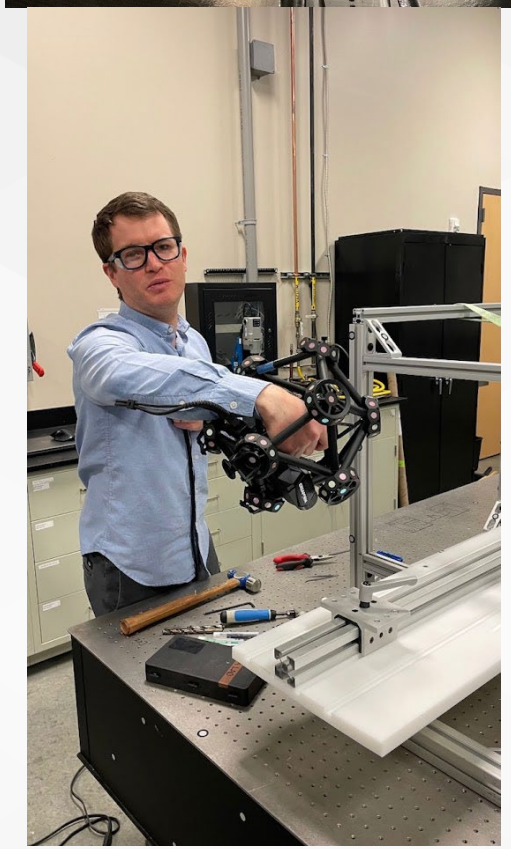
Team for ITST-TBPX Test

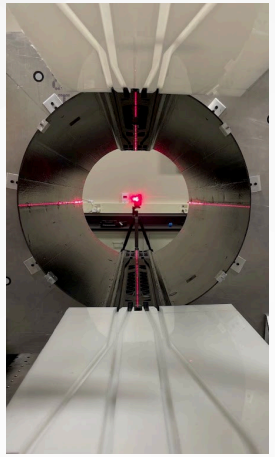
1. **Purdue University –**
   Sushrut Karmarkar, Ben Denos, Justin Hicks, Andy Jung, Archie
   UGs: Pau Simpson, Marco Herbsommer, Yuvraj Chauhan, Simon Snydersmith, Sam Langley-Hawthorne, Mathew Sanford, Lexing Xu, Xuli You, Xander Wells
   Past team: Jack Wheeler, Langdon Feltner, Jack Gulley, Swapneel Kulkarni, Harry Lee, Garam Kim, Sebastian Elizondo
2. **UC Davis –**
   John Conway, David Louis Hemer
3. **Cornell University –**
   Axel Filenius, Karl Smolenski
4. **INFN –**
   Daniele Benvenuti, Simone Garrafa, Andrea Basti, Roberto Dell'Orso, Silvia Coli

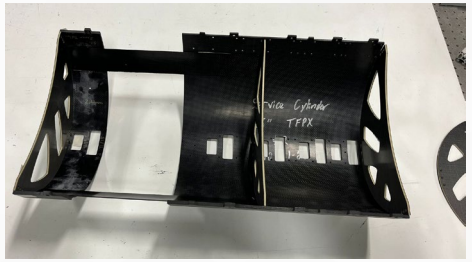


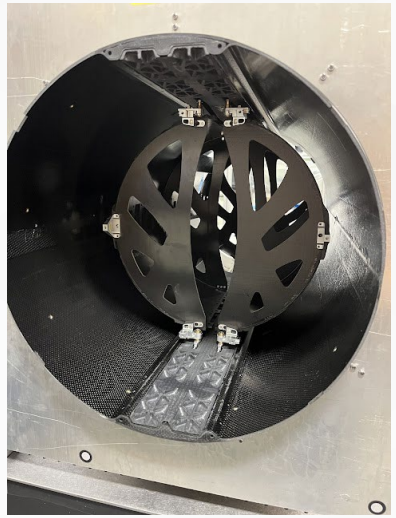
ITST Metrology Set Up

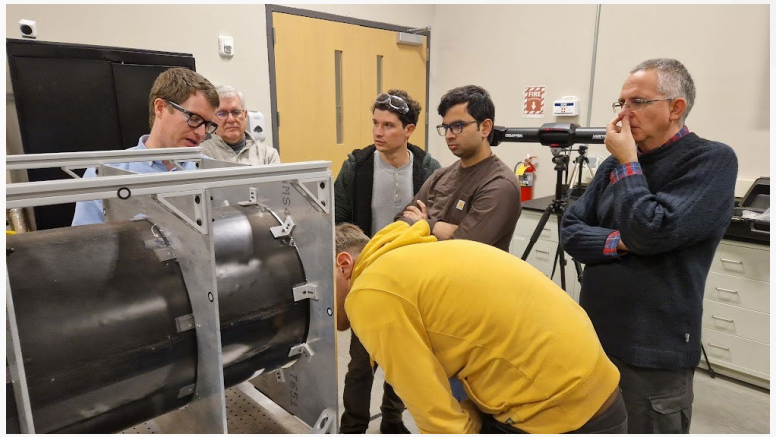
- Creaform Metrascan Black Elite + C-Track + HandyProbe
- Use upper and lower track to set reference frame
- Use UC Davis adjustable wheels to align service cylinder
- Use INFN barrel adjusters to set TBPX position











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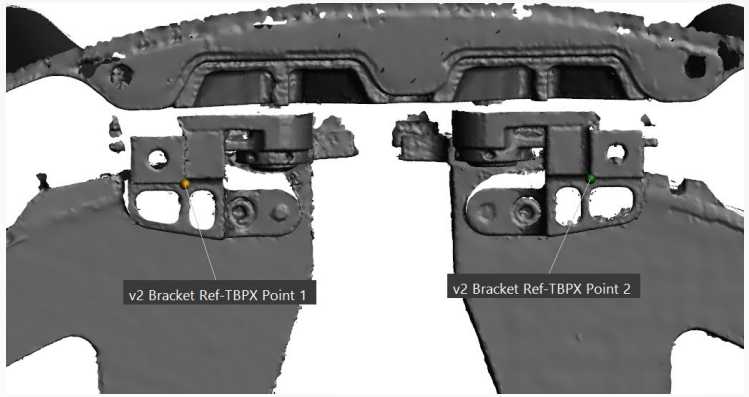
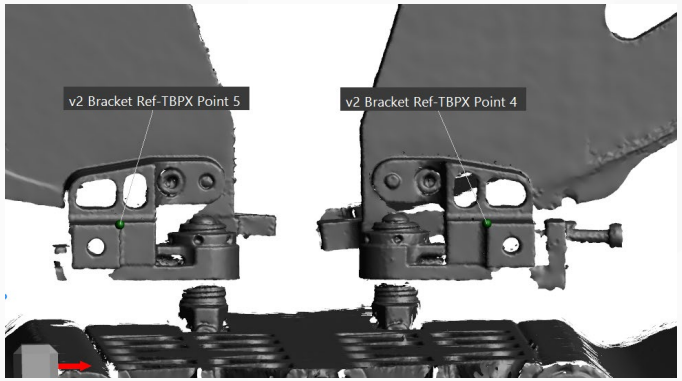
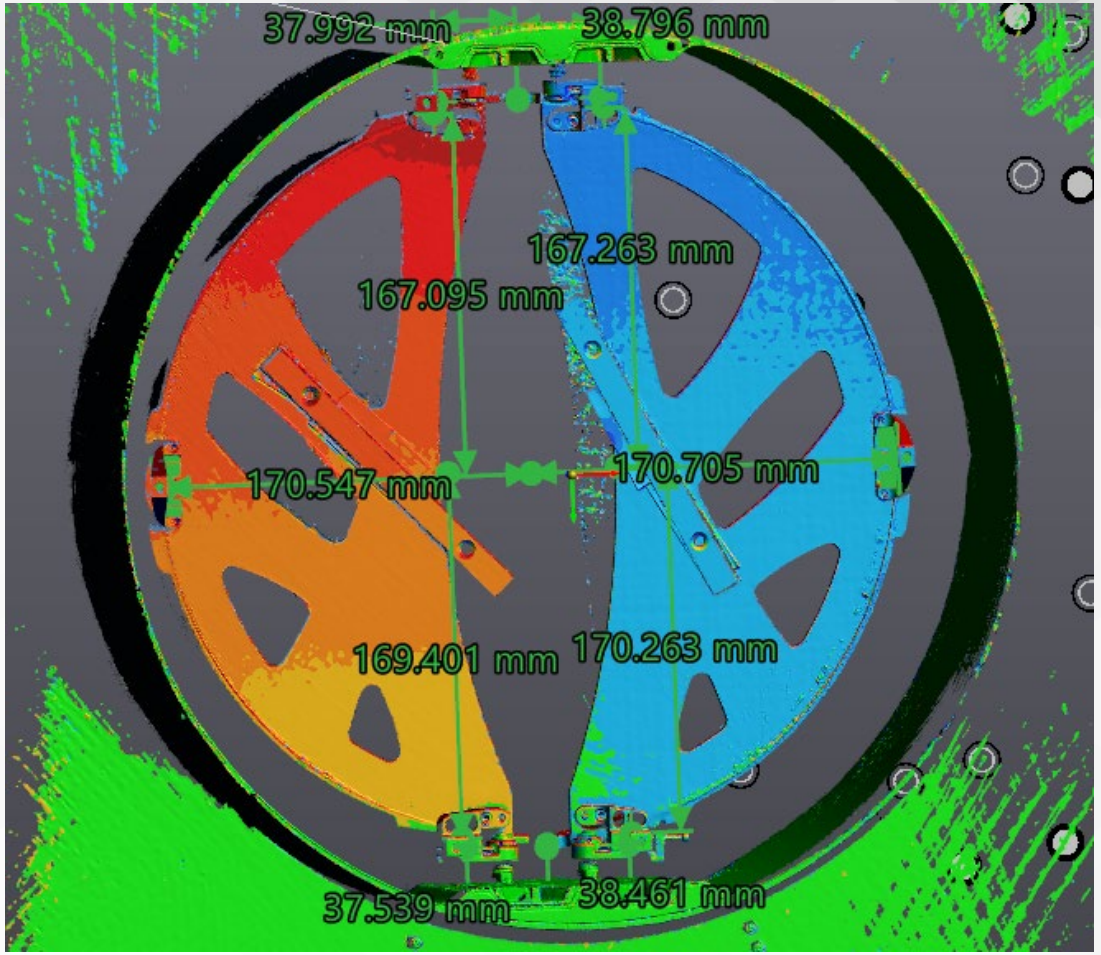
TFPX – TBPX bracket references used for Initial Alignment

- Starting alignment needs hard machined edges to find initial position
- Need more precise service cylinder for future tests
- Methods all feasible with minor changes







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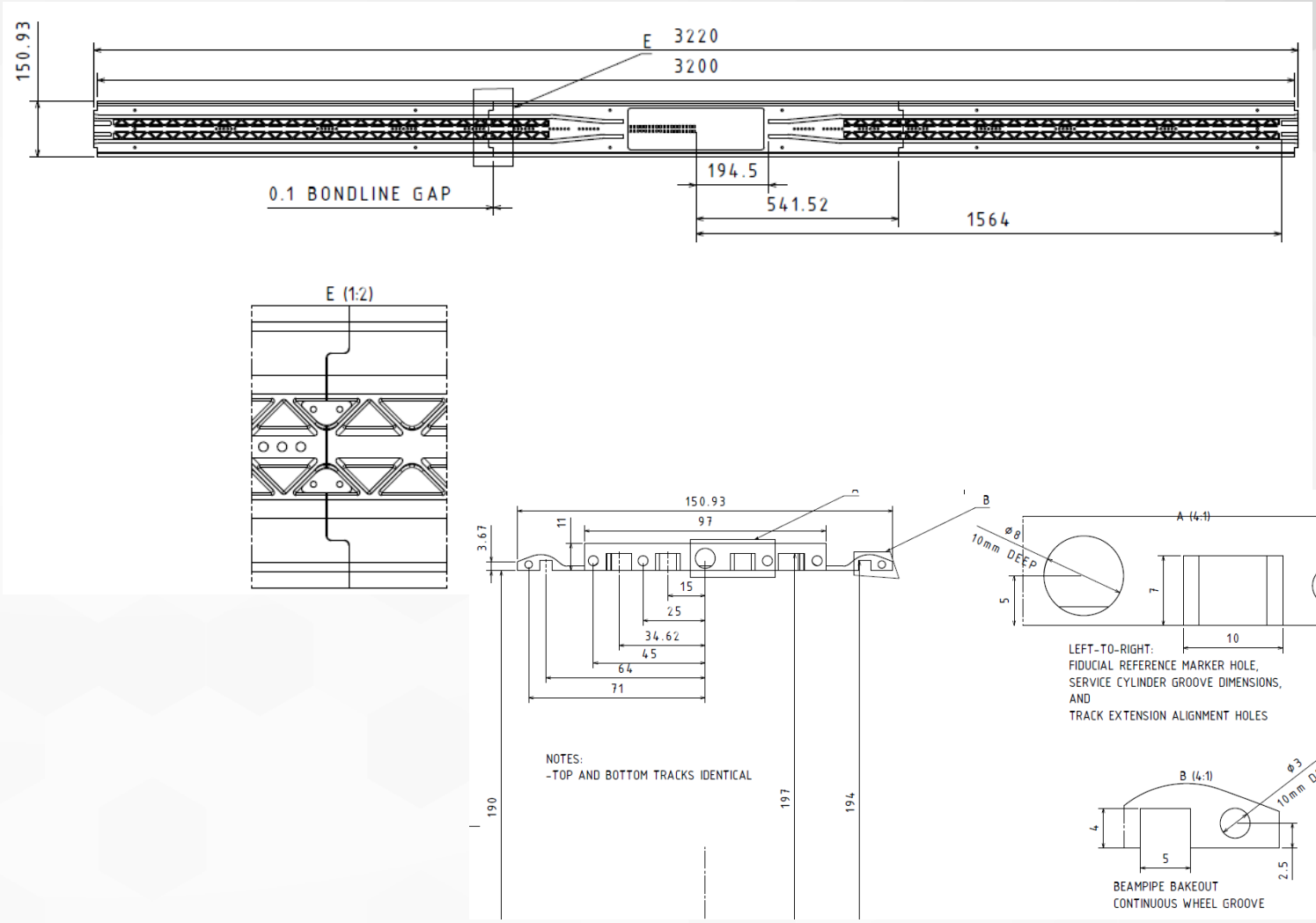
ITST Center Track Drawings

- Split into 3 segments
  - Align with step joint and joiner plates with pins
- Center section connected for greatest precision of innermost wheel stops
- Material nearest TBPX (barrel) removed
- Dry gas injection simplified near barrel



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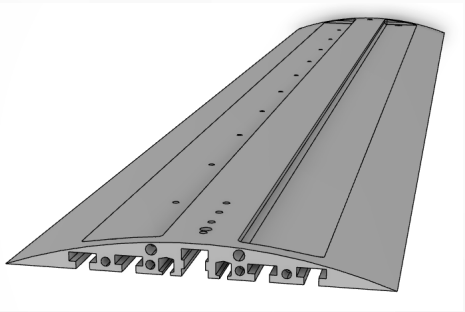
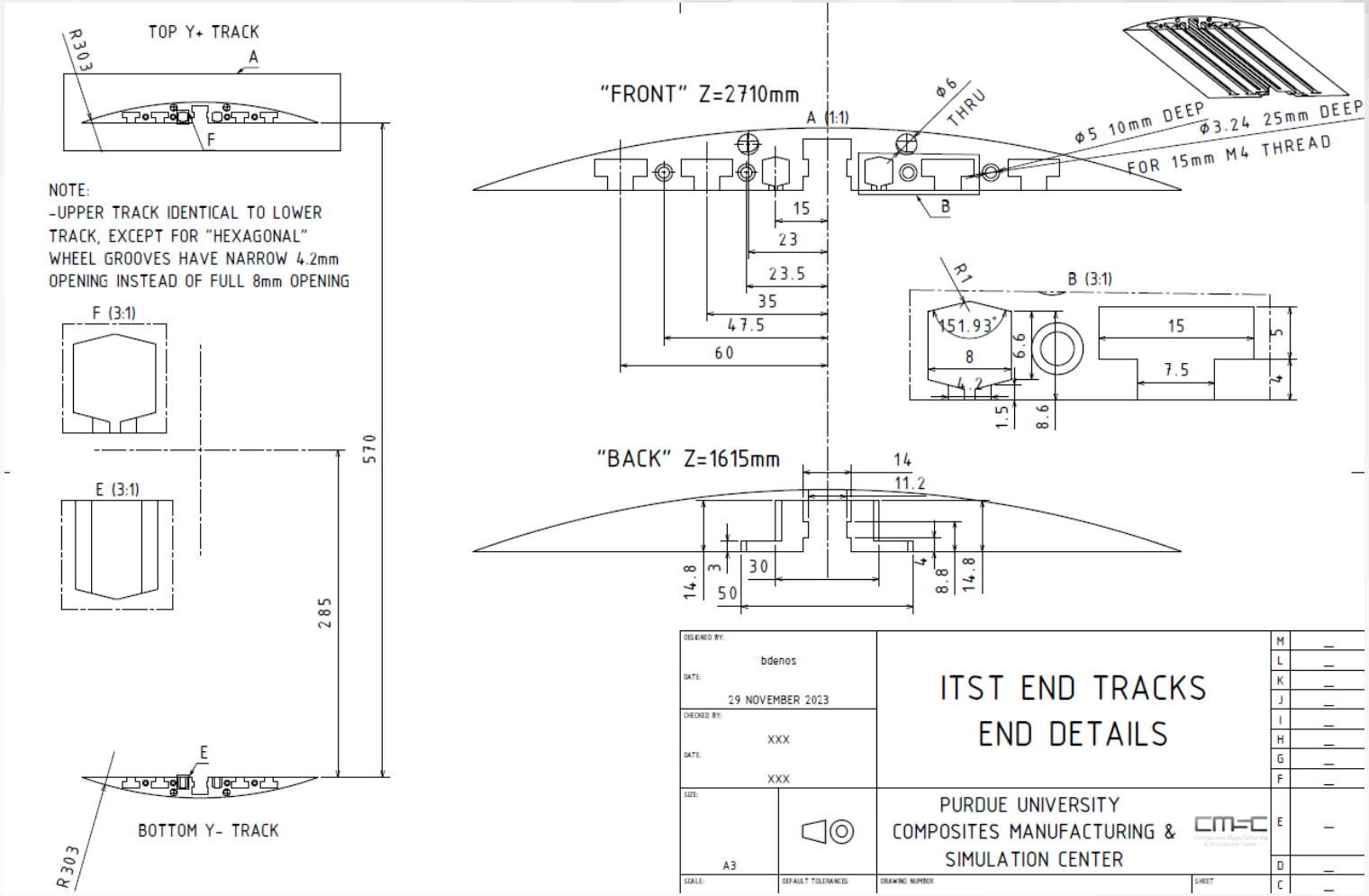
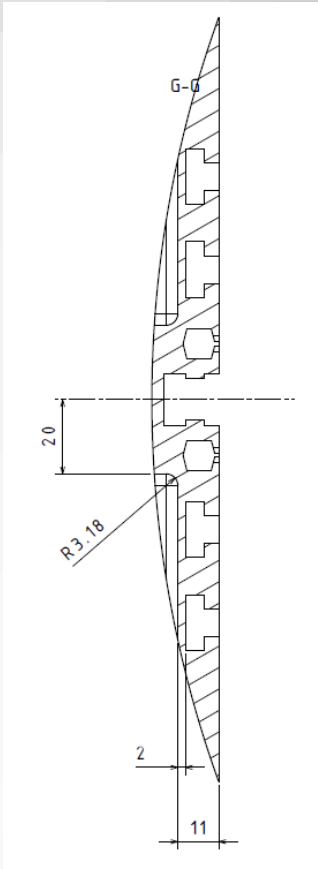
ITST End Section Drawings

- Prototype being machined now
- Machine final from solid CFRP (IM7 / PMT-F6) laminate







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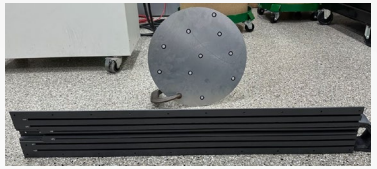
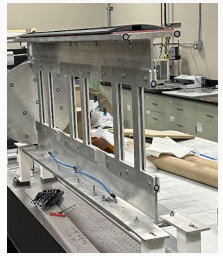
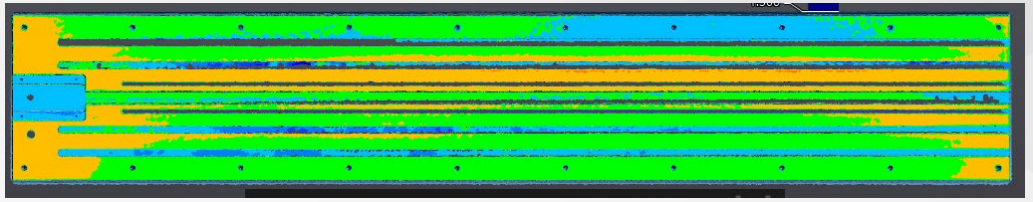
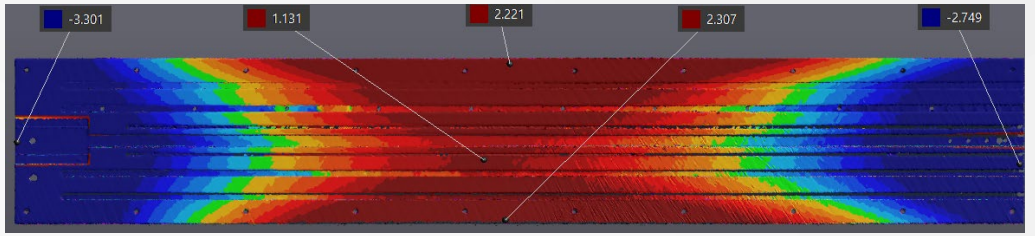
ITST End Section Track Machining

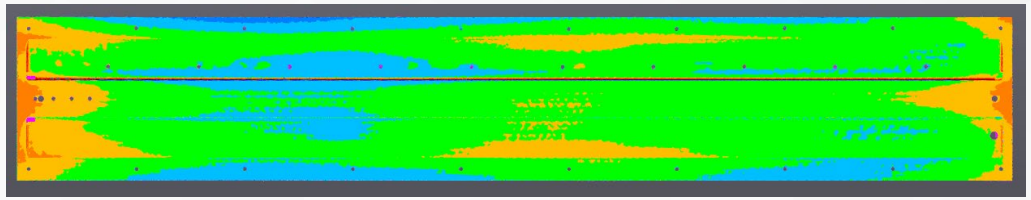
- Measure fixed on CNC
  - +/-0.30mm
- Measure free standing
  - [-3.30mm, +2.30mm]
- Measure on installation I-beam
  - +/-0.40mm

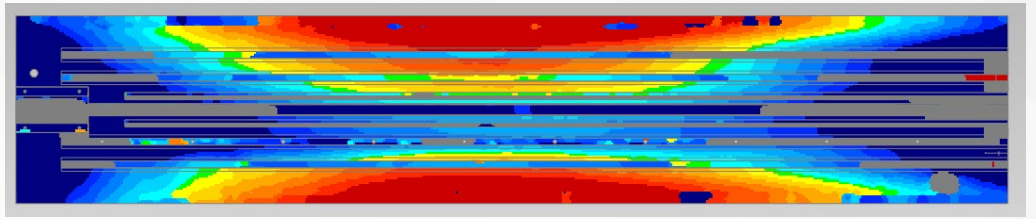












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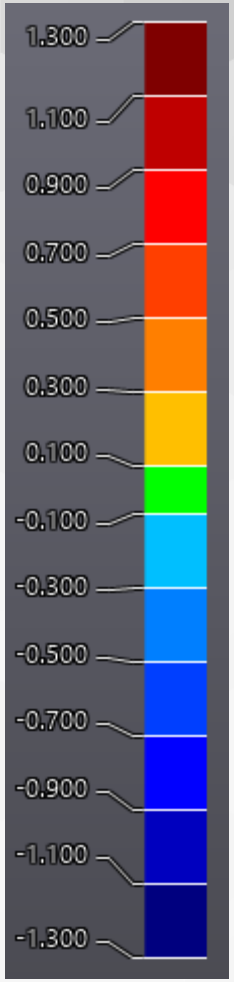

- Track attempt #2, measure free
  - Still warped, but 1.2mm less:
    [-2.40mm, +2.00mm]
- Pushed us toward solid CFRP for end track

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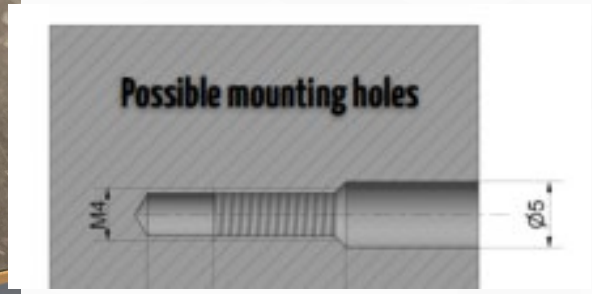
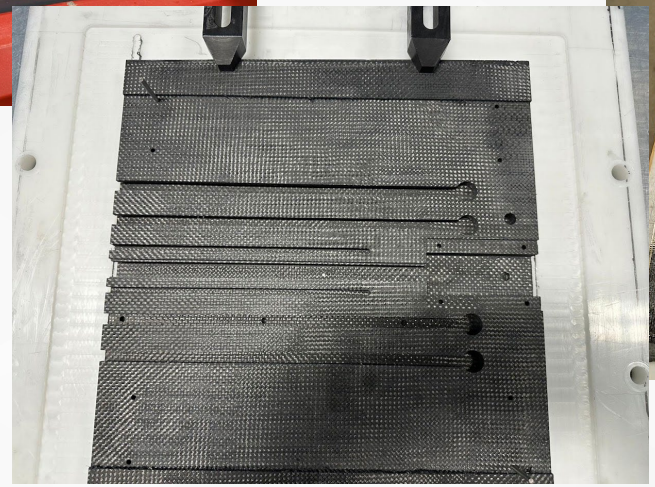
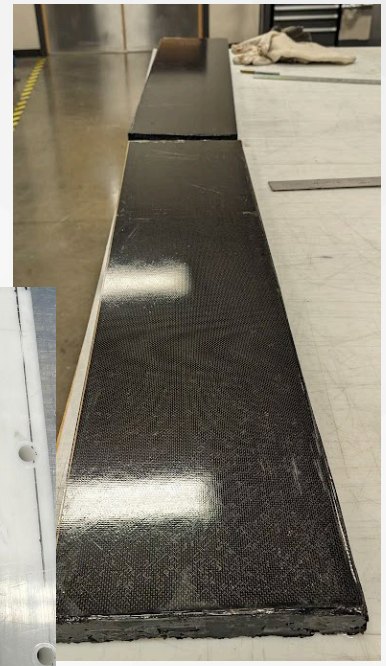
ITST End Track (Solid CFRP) Manufacturing

- End holes drilled with CNC'd fixture with drill guides
- Tested M4 screws to 2.4N-m (22 in-lb) torque failure on M4 helical thread inserts



- 20mm thick laminate in progress
  - Test with prototype material
  - Goal: less warpage than printed version





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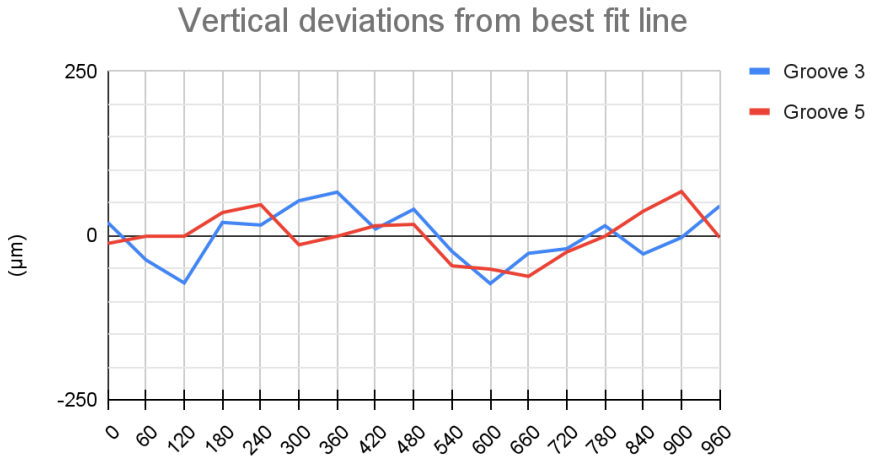
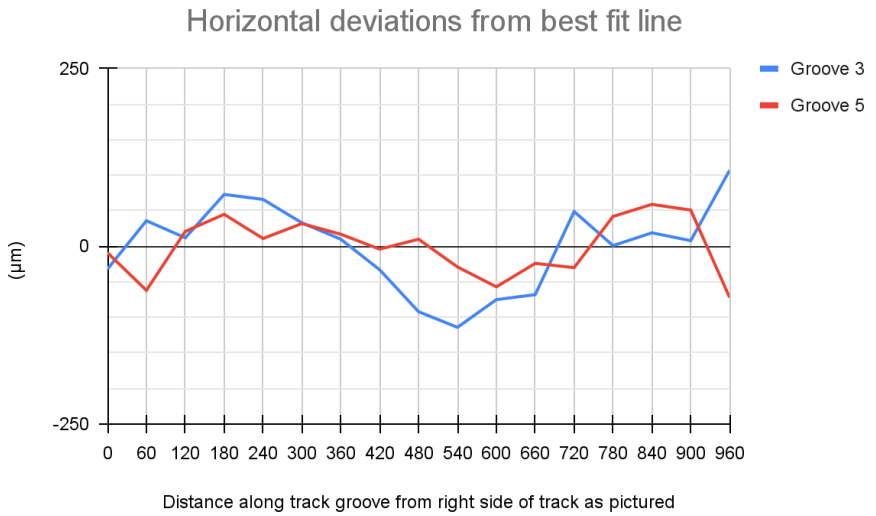
ITST End Track Wheel Groove Straightness

- Each groove measured with 2mm ball probe while on machining fixture
  - Vertical deviations from “flat” (Y)
  - Horizontal deviations from “straight” (X)
- Conclusion: CNC machines a straight flat groove over ~1.2m length





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Final Material Cure Cycle and Bagging
IM7 woven CF with F6 Cyanate Ester

- Airex R82.80 foam appears to collapse near cyanate ester (PMT-F6) resin
  - Confirmed by manufacturer

Previous Plate: Core collasped, "F" peel ply

- Seal ½ of core with polyurethan spray
  - Success! No/less collapse!

New Plate: Core held on side sealed with Polyurethane spray paint – 8 passes. "F" peel ply

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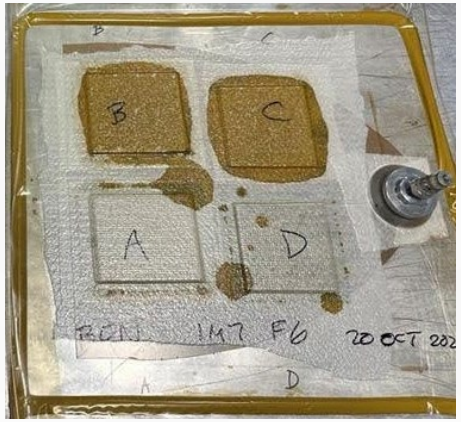
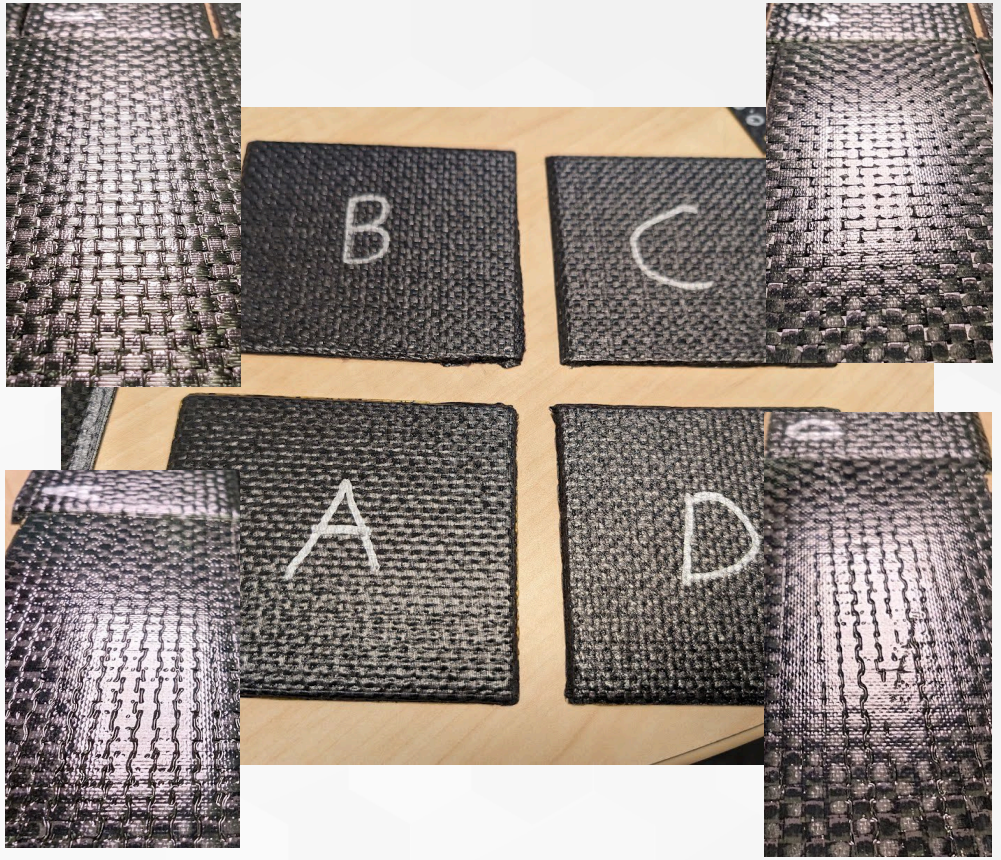
Final Material Cure Cycle and Bagging
IM7 woven CF with F6 Cyanate Ester

- Cyanate ester may need to vent significant moisture during cure – to prevent porosity
- Use polyester peel ply as extra breather on both sides – excess edges to contact primary breather
- Use fluoropolymer release against laminate
  - Flip order or use perforated if more bleed and/or peel ply surface desired

	Default	A	B	C	D
Vac. Bag	x	x	x	x	x
Breather	x	x	x	x	x
Peel Ply	"F"	"G"	"G"	"G"	
Release WL5200	Non Perf. (NP)	NP	P25	P25	NP
Laminate	x	x	x	x	x
Release WL5200	Non Perf. (NP)	NP	P25		NP
Peel Ply	"F"		"G"		
Tooltec PTFE	x	x	x	x	x
Alum. Tool	x	x	x	x	x





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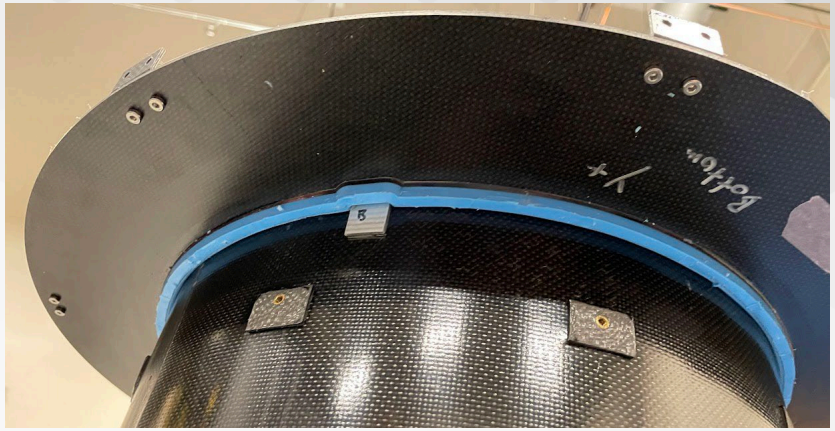
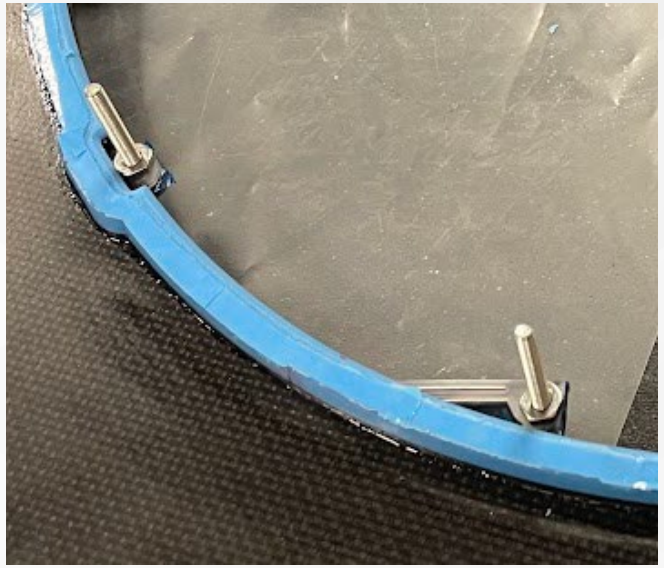
Silicone Seal for ITST Center-to-End Interface

- Cast with internal, resin printed “bones”
  - Stiffen profile
  - Provide bondable surface (not silicone)
  - Provide temporary tabs for bond alignment
- Must slide on and off of ITST center with minimal interaction at ~1.2m distance
- Quick lab tests show acceptable seal performance





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Outline - BTST

- Function and geometry
- 1m long prototype validation
- FEA simulation predictions
- As-manufactured metrology
- Tracker rail placement and bonding
- Partial loading of the final structure (Plan)

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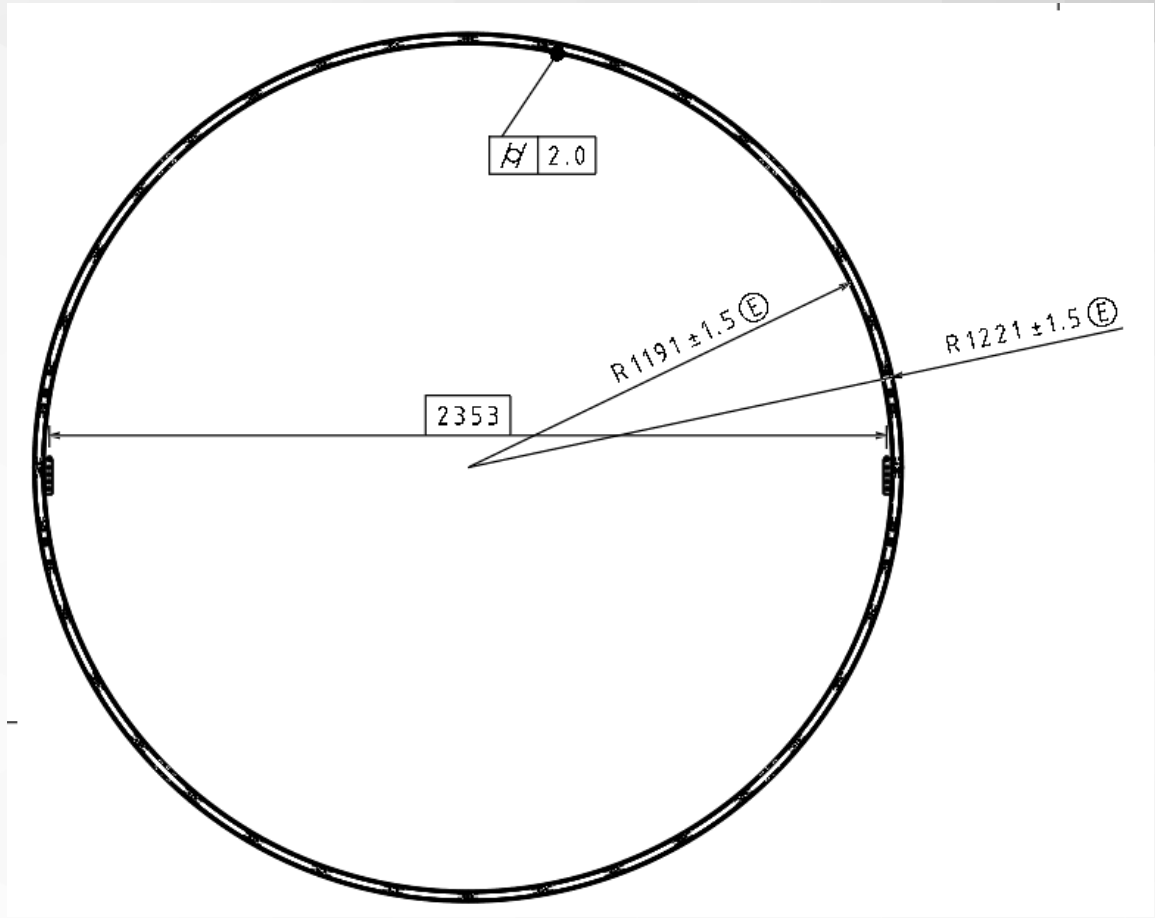
Boundary Timing Layer Tracker Support Tube (BTST)

- Manufactured by Rock West Composites San Diego
- 5300mm long, 2442mm diameter
- Structure weight: 390kg
- Supported weight: ~6,000kg
- Manufacturing tolerance: +/-1.5mm target
- Loaded deflection tolerance: +/-1.5mm target
- Materials:
  - Sandwich skins HM63 / PMT-F6
  - Core Nomex honeycomb
  - Tracker rails K13916 / PMT-F6
    - Nitronic 60 steel M8 and M10 helicoil inserts
  - Titanium end ring inserts (M16)
  - Aluminum BTL inserts (M3)



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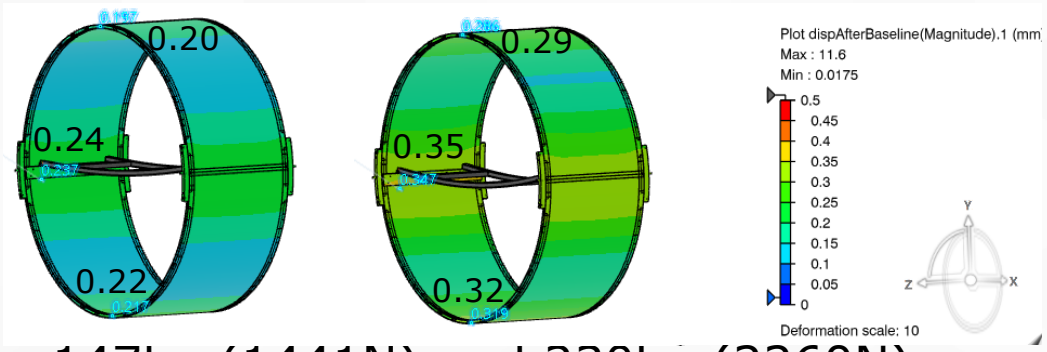
Validation Load Cases – Rack and Loads on Tracker Rails

- **Simulation**
  - Banana center bolts fixed in Y
  - 147kg (1441 N), and 230kg (2260N)
  - Add loading rack with hinged guide rod,
  - Soften Rail to Validated Props (44% FVF)
  - Add springs (245,000N/m) for frame BCs
- **Experiment**
  - Loads 147kg then 230kg
  - Guide rod feet precision located

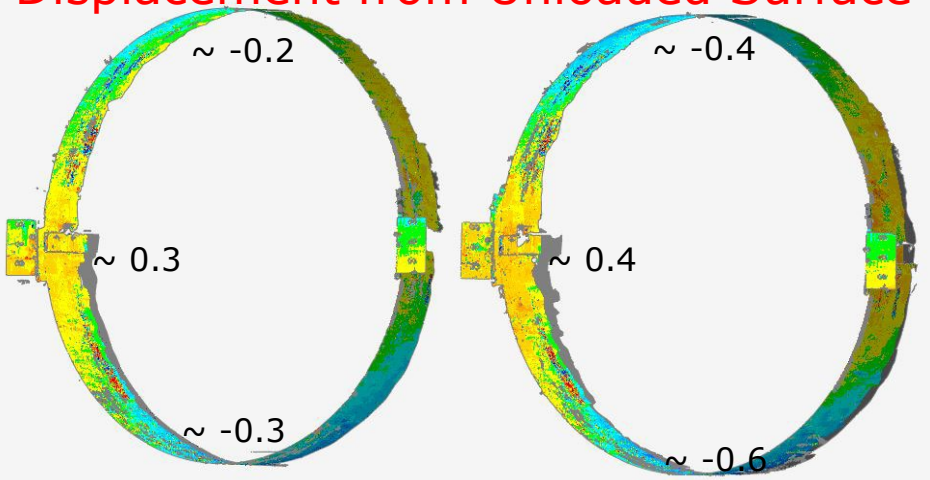
Displacement Magnitude



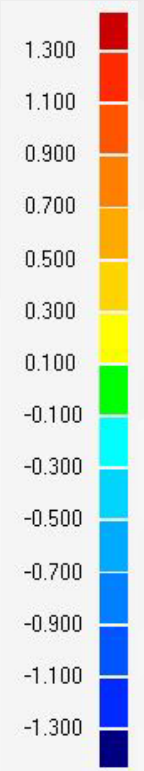
147kg (1441N) and 230kg (2260N)

All units (mm)

Displacement from Unloaded Surface



147kg (1441N) and 230kg (2260N)



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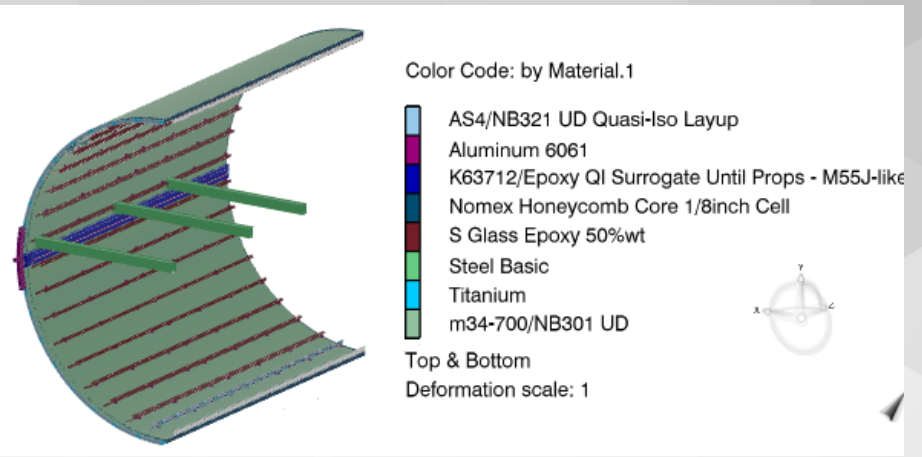
Materials Used in Simulations

- Finding and calculating properties is always difficult
- Validating properties with mechanical testing also difficult
- Balance effort vs benefit at each design step



Component	Fiber	Matrix	Density (g/cc)	Total Mass (kg)	E1 (Gpa)	E2 (Gpa)	E3 (Gpa)
Tube Face Sheets *High Mod. UD	HM63	F6	1.57	261	266	11	11
Tube Honeycomb Core	HRH-10-3.2-64		0.064	66	0.0009	0.0009	0.1
Tracker Rails – Quasi Iso Solid (44%fvf)	K63712	NB301	1.62	38	88	88	12
End Ring CFRP – Quasi Iso Solid	AS4	NB321	1.55	10	51	51	8
BTL I-beam	S-glass	Epoxy	1.63	42	29	5	5
End Ring Threaded Inserts	Titanium		4.5	12	116	116	116
Banana Bracket	Aluminum 6061		2.70	15+?	69	69	69

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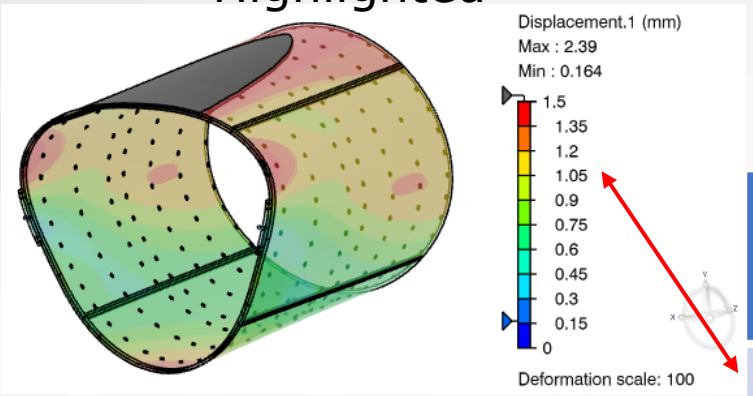
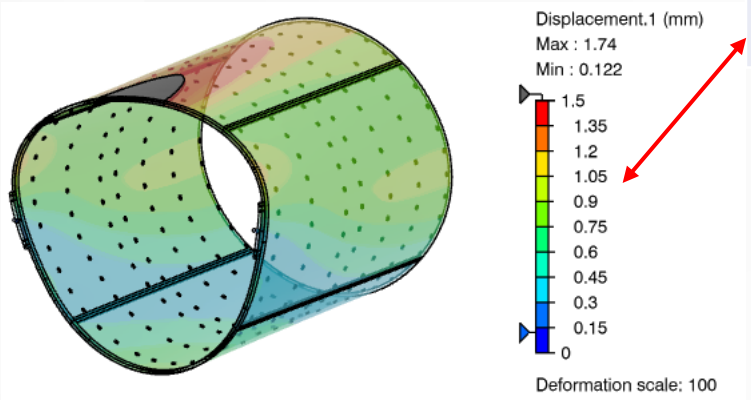
Materials, Max Deflection

All Loads, Warm, Above 1.5mm Highlighted





Face Sheet Material Choices	Fiber/ Matrix	Max Deflection (warm)	Max Deflection (cold)	Change Deflection (mm) warm
Standard Mod.	TR50s/F6	2.39	2.47	0
High Modulus	HM63/F6	1.74	1.62	-0.65

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BTST Load History "Complete", update TEDD and temps, HM63/F6

Case	End Ring BCs	Added Loads	Mass (kg) Item + Services (full tube)	"Added" Load Input Locations On BTST
1	- Small Ears	1 Tube Only	384.1	GRAVITY on full model
2	- Small Ears, Bananas*	" "	9.4	
3	" "	BTL	1884.3,18,23.7	Tube inner surface (38 BTL rail lines, distributed)
4	" "	TB2S	520,~~303.7~~ 153.7	Tracker Rails @ Z= +/- 781.3mm, BTL rails (next)
5	" "	TBPS + ITST Center (empty)	175.8, 150	Tracker Rails @ Z= +/- 781.3mm, BTL rails (prev.)
6	" "	TEDD + Seals	535,501,10.8,~~235.6~~	Tracker Rails @ Z= +/- 1474, 2494, 2650, ~~BTL rails~~
7	" "	Bulkhead Disk	327.2 (80%,20%)	Tracker Rail ends, 12 and 6 o'clock M16s (@2800)
8	" "	ITST Ends (empty)	57.4	Bulkhead (tracker rail ends)
9	- Small Ears, Bananas* - Nose Cone Brackets	Nose Cones	340	Nose cone corner brackets, offset mass to…3500?
10	" "	Services moved to cones	1452.6	Cone brackets during lift/lower, offset to…3500?
11	- Bananas* - Big Ears Z- - Eiffel+Nose Brackets Z+	Big ears* REMOVE SMALL EARS*	73.4* Z- only -31.2*	*if modeled explicitly Eiffel "reaches through" and supports Z+ nose cone
12	- Support Bracket	REMOVE NOSE CONES, EARS	120*,-1452.6, - 340	Banana support post, nose cone corner brackets
13	" "	Service Cylinder w/ TBPX	172, 67.9	Tracker Rails @ +/- 781.3mm, Bulkhead (rail ends)
14	" "	TEPX	117.0	Bulkhead via rail ends
15	" "	Cool to -5°C, +10°C outside		Outer face sheets (quarter, joint, end), end ring at +10°C

BTST_HalfSymm_2023-03-03_highMod_HM63_F6_K13916_F6rail.inp

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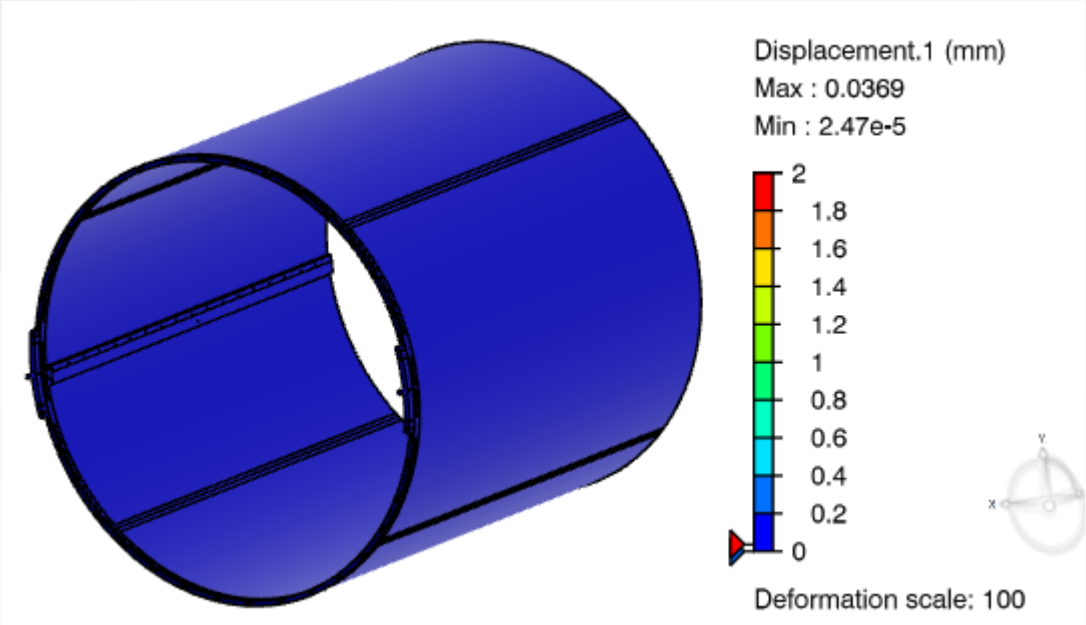
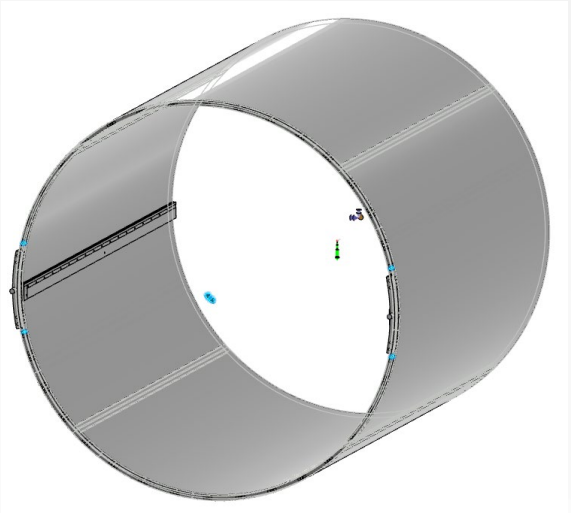
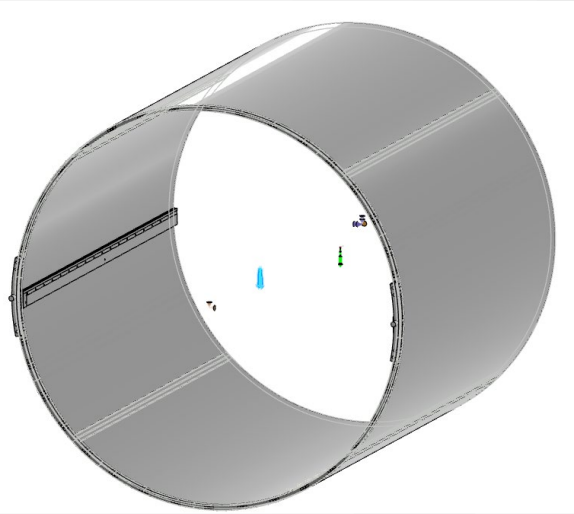
Small Ears + Tube Only + Bananas Installed







Case	BCs	Additions	Masses of Additions (kg)	Locations of Masses
1	**Small Ears**	**1 Tube Only**	**384.1**	
2	Small Ears, Bananas*	" "	9.4	GRAVITY on full model

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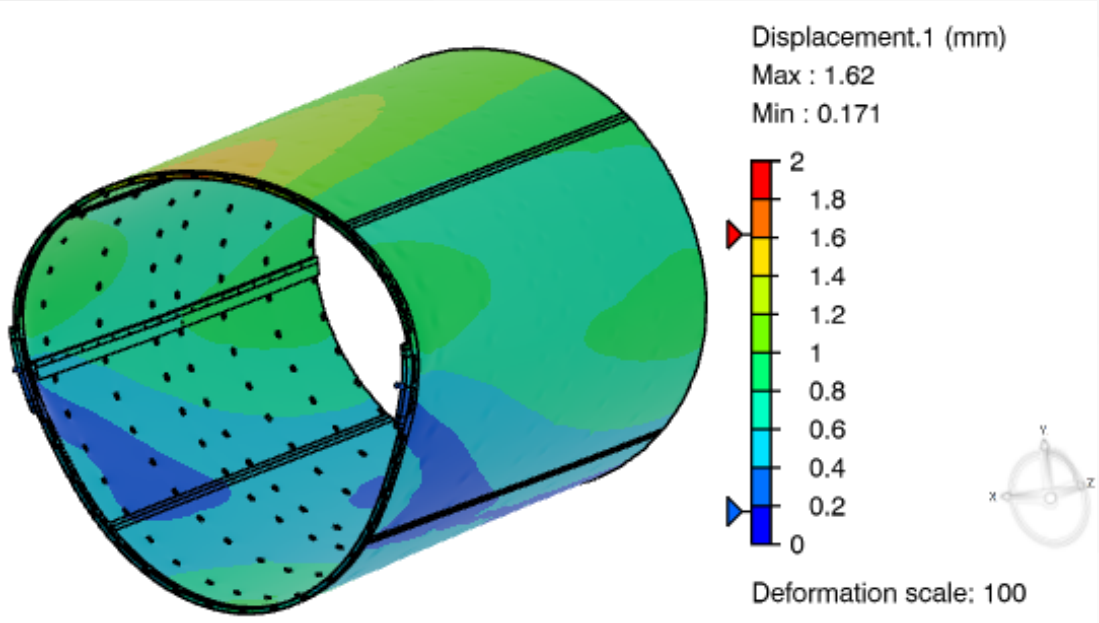
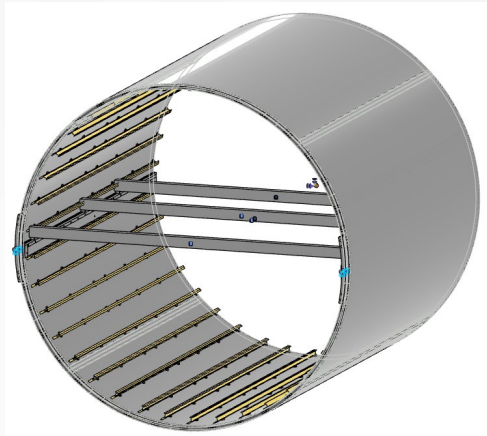
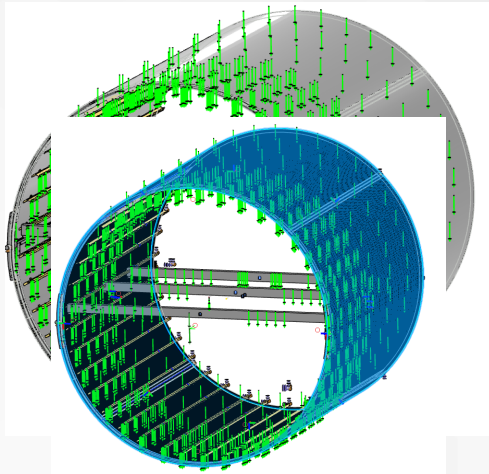
+ Cool to -5°C

- Move TEDD Services
- Outer face sheets and end ring at +10°C per Guillermo's models







Case	BCs	Additions	Masses of Additions (kg)	Locations of Masses
15	" "	Cool to -20°C, +10°C out		Outer face sheets at +10°C

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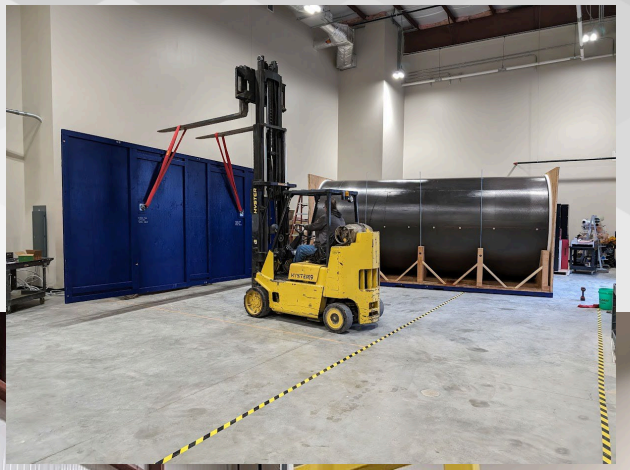
BTST Unboxing Video

- https://photos.app.goo.gl/AMXt6BNRZ4eQYrUNA



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BTST Metrology and Loading Plan

Manufacturing Tolerances	**Finish this week**
- setup completion: volume extension, reference targets, adjust tube to ~~nominal~~ neutral	done
- measure inner and outer surface, confirm cylindricity (~~2mm~~ 3.9mm), best fit radius (+/1.5mm)	done
- measure end ring bolt positions (0.2mm) NOT with "neutral" position sides 1mm off	90%
- measure selected BTL insert positions *across quarters* and map (if time) initial shared	done
Position and Bond Tracker Rails (practice with prototype, report before bond)	**June 5**
- measure direct bolted to tube	done
- measure, shim locally, measure, shim locally, etc – Confirm acceptable position, bond rods, check	Proto 90%, full 50%
- drill and "spot" inject adhesive, measure – ADDED lap shear test for filled adhesive	Strength tests now
- remove bolts, insert shear pins, fill remaining adhesive, measure	
Loading Validation	**June 14**
- design/order cart and wheel hardware, ID water tanks, modify cart	10% done
- measure with loads 100kg, 250kg, 500kg, 1000kg – watch for frame deflections	
- create and compare to simulations	
- adjust with 4pt bending sandwich panel test data as justifiable	

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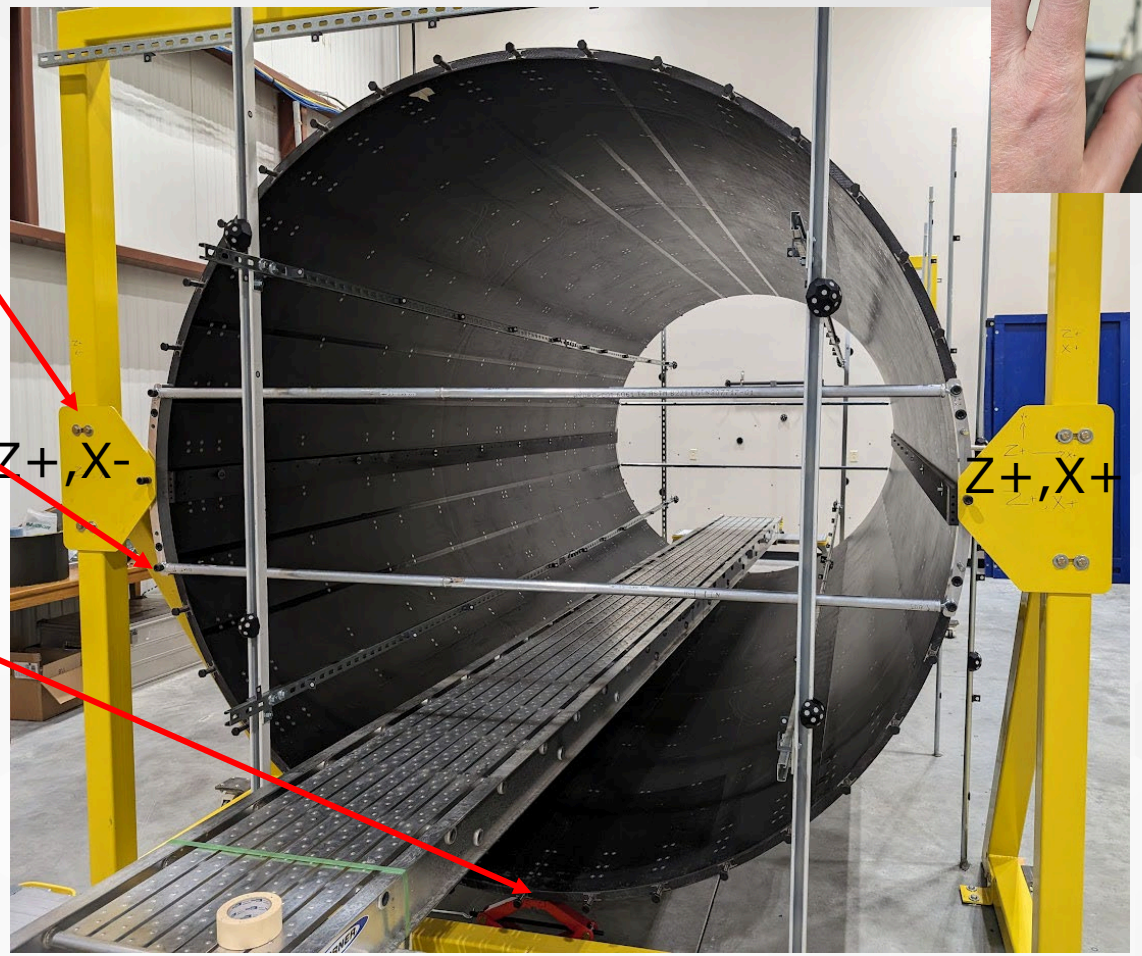
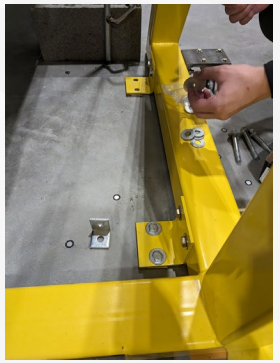
BTST Metrology Setup

- Mounting Brackets and Bolts
  - M16, at 3 and 9 O'Clock
  - Connect to "new" mockup bananas
- Turnbuckle Bars (optional)
  - Adjust bolt-to-bolt distance
- Cradle / Scissor Jack
  - Contoured to tube
  - For support and level
- Reference Targets
  - Everywhere to define measurement space





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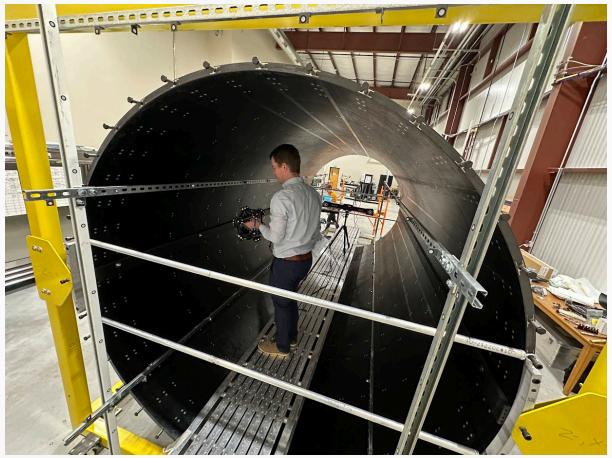
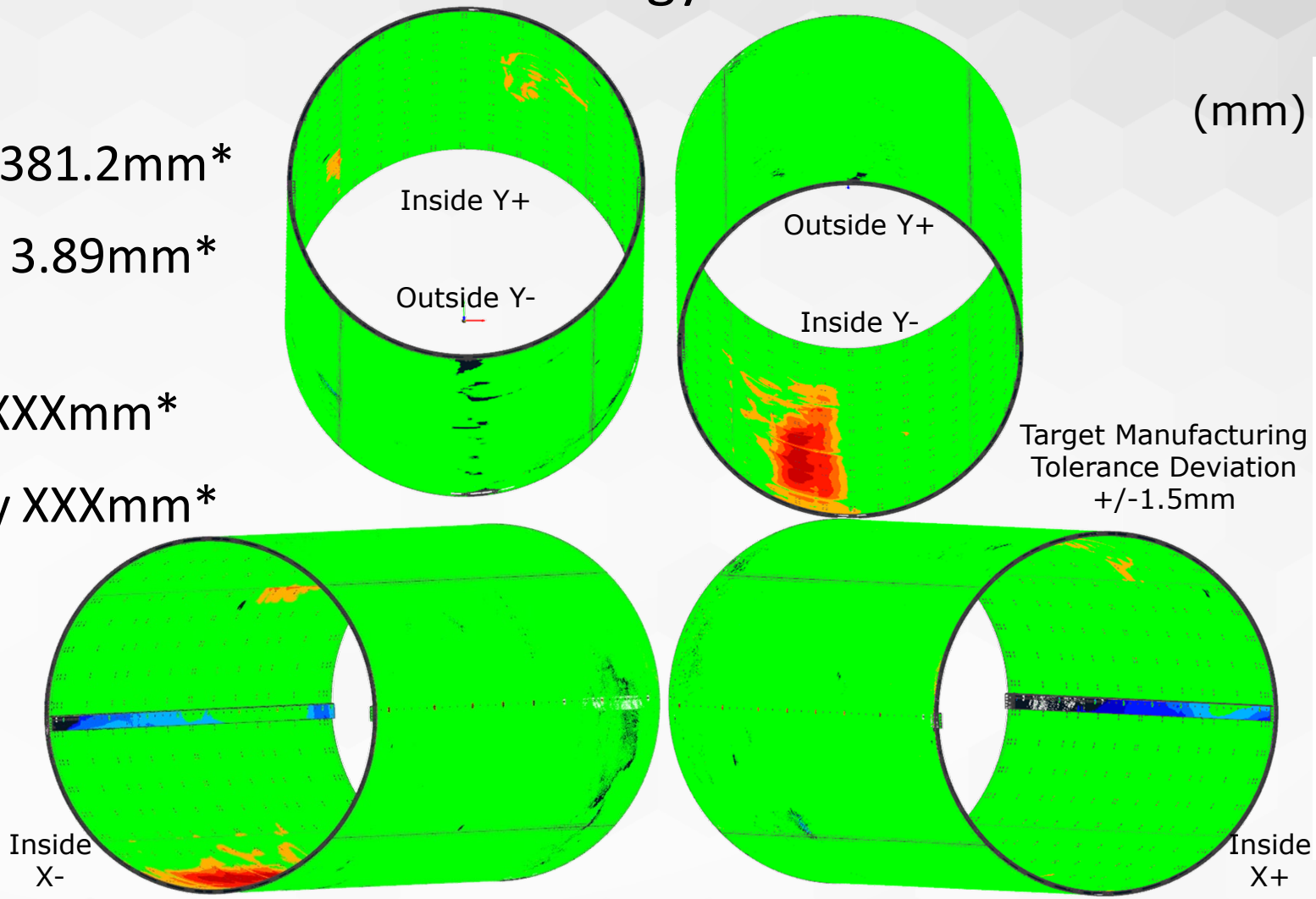
BTST Metrology

- Best Fit Cylinder
  Inner Diameter 2381.2mm*
- Inner Cylindricity 3.89mm*
- Best Fit Cylinder
  Outer Diameter XXXmm*
- Outer Cylindricity XXXmm*





*0.5% of extreme data excluded from calculations

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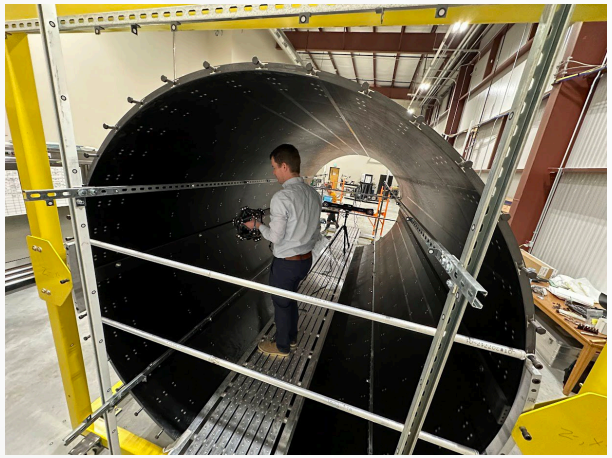

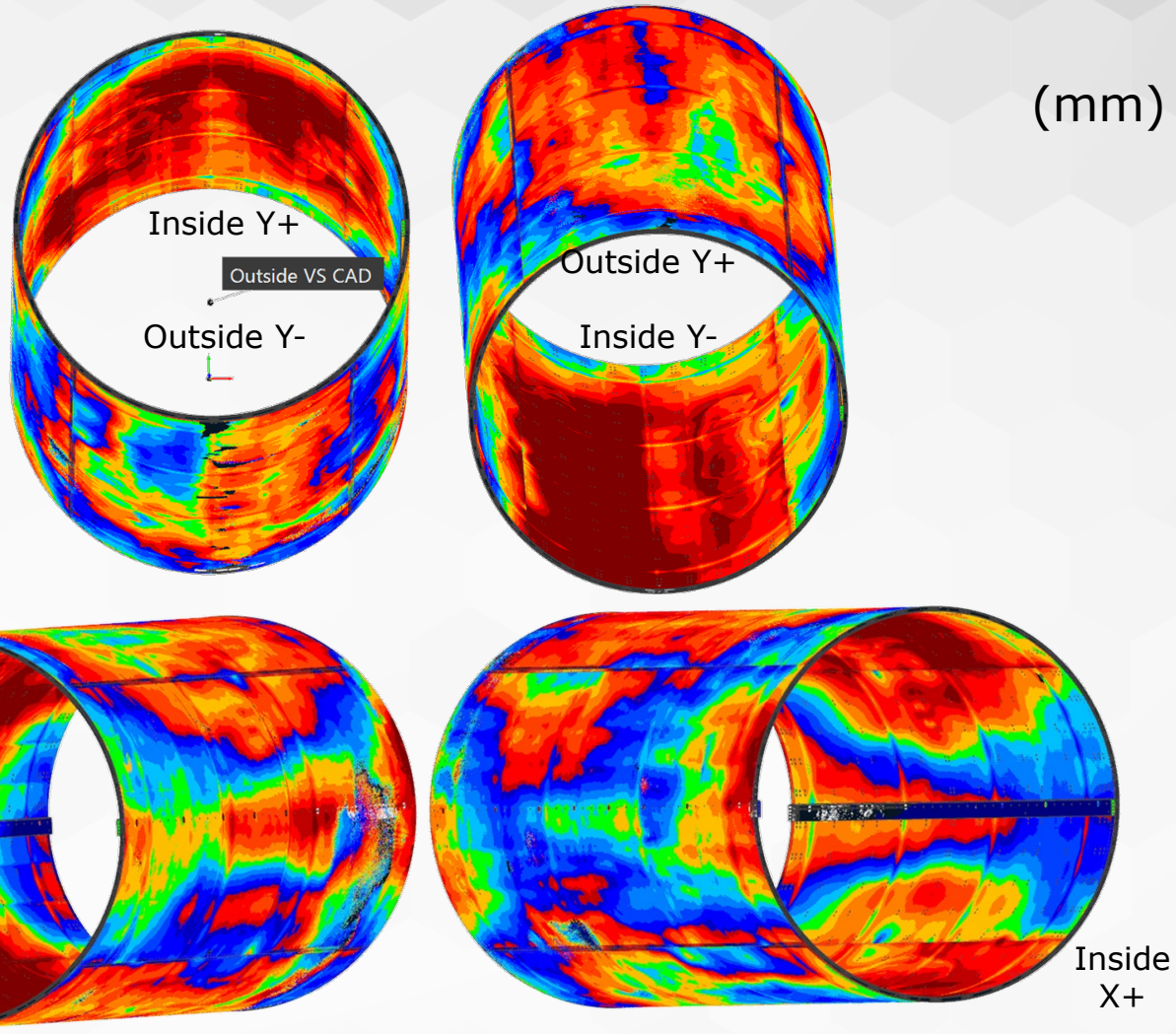

*0.5% of extreme data excluded from calculations

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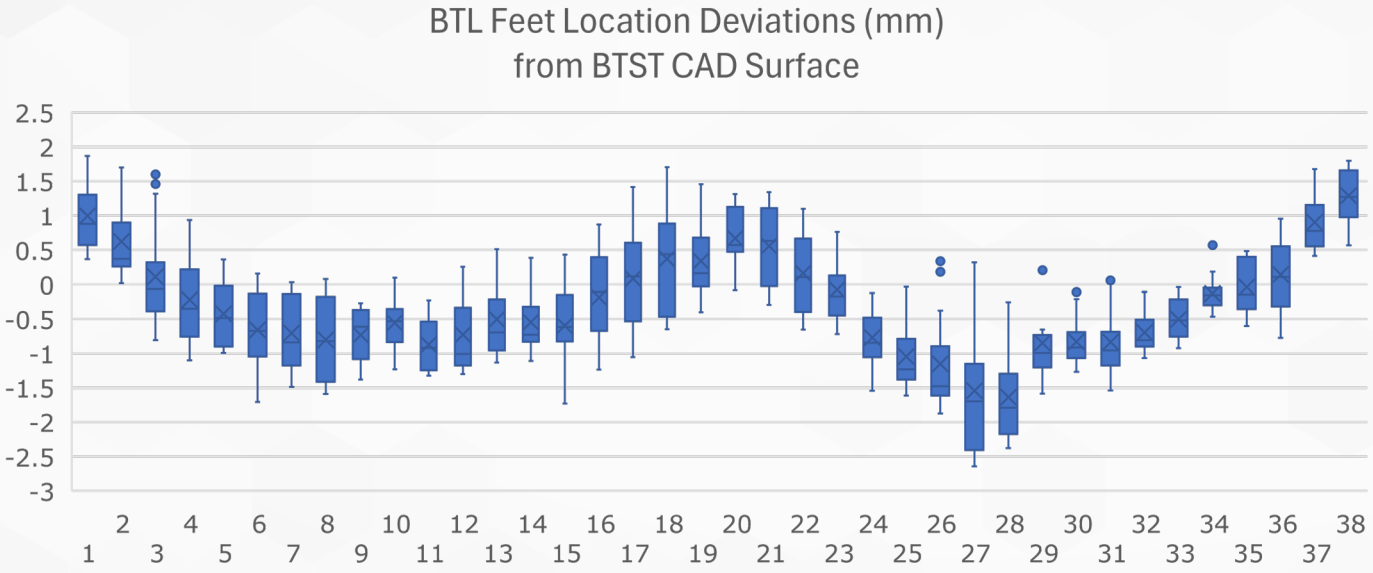
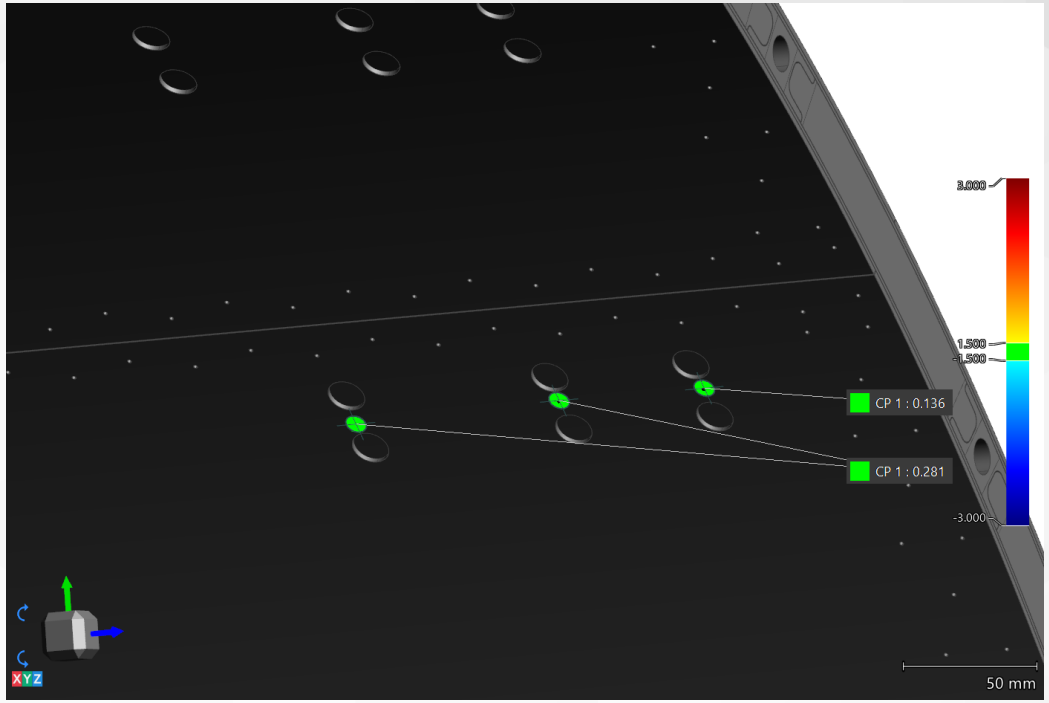
BTST BTL M3 Inserts

- Can extract selected comparison points from full laser scan
  - Only “mouse click” precise selection
  - Deviation from CAD surface still helpful
- Numbered from X+ axis counterclockwise





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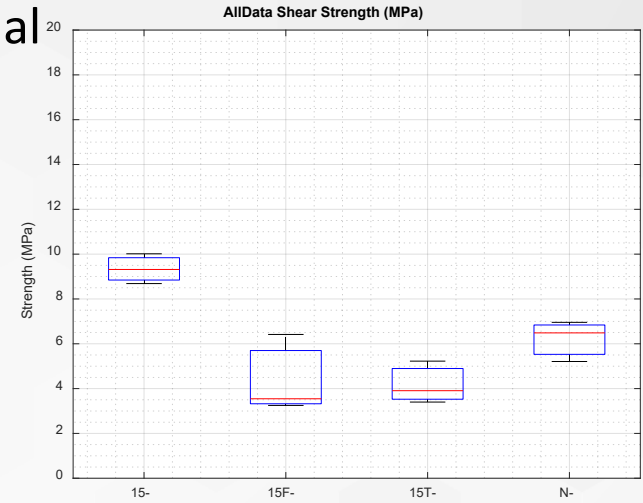
Tracker Rail Adhesive Testing

- Thicken Araldite 2011 to not drip/sag
  - 20% thixotropic silica (Cab-o-sil) to not sag in 3mm gap
  - 1/16” glass fiber for strength
  - 0.45mm max gap expected after shims
- Acrylic sheet injection hole and drip test

- Single lap shear test series, 20x20mm
  - 1.0mm bond cuts strength in half
  - Keep bondline minimal



	Adhesive	Thixotropic Silica (%)	Milled Glass (%)	Bond Thickness (mm)
N-	Araldite 2011	0	0	0.1
15-	Araldite 2011	15	0	0.1
15F-	Araldite 2011	15	5	1.0
15T-	Araldite 2011	15	5	1.0

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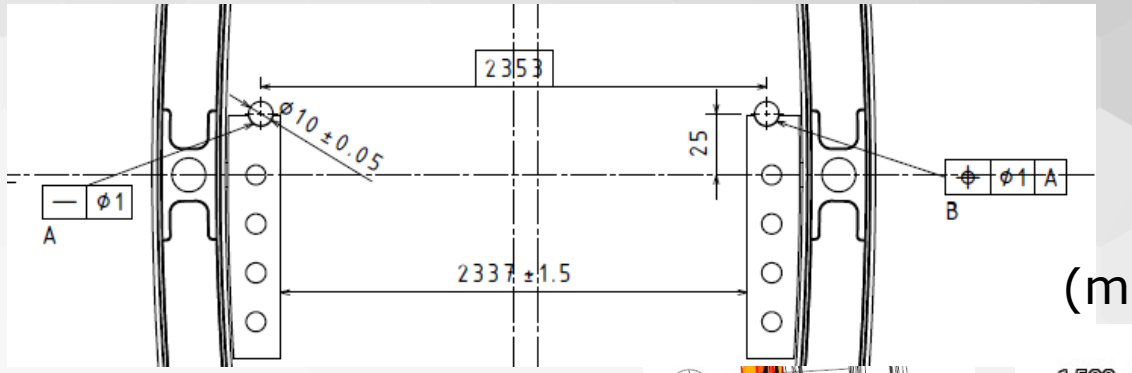
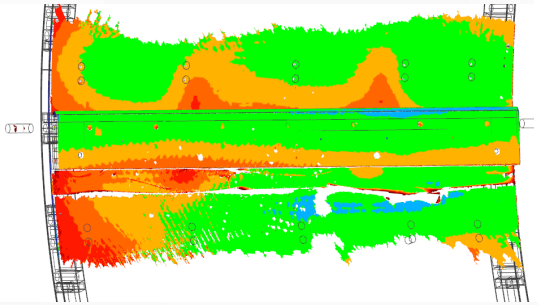
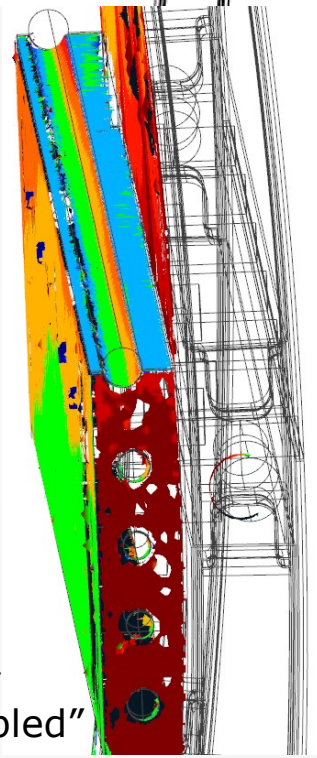
Prototype Tracker Rail Shimming

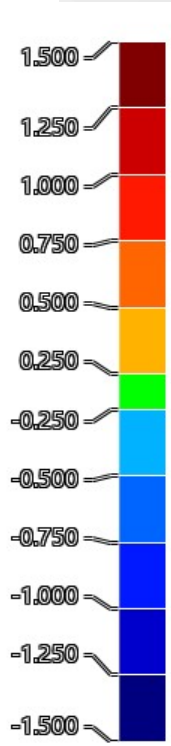
- X+ rod straight [+ 0.25mm,-0.50mm]
- X- Rail at inward position limit
- Rail faces acceptable [-0.25mm,1.00mm]
- Drilled 3mm adhesive injection holes
- Spot bond, bond rod, finish bond with shear pins



(mm)







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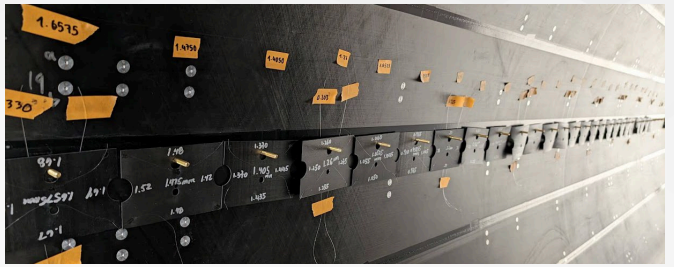
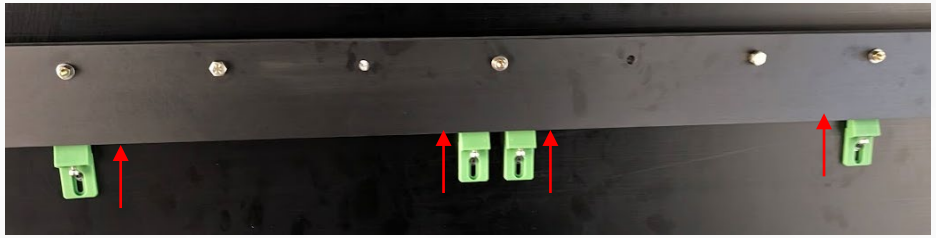
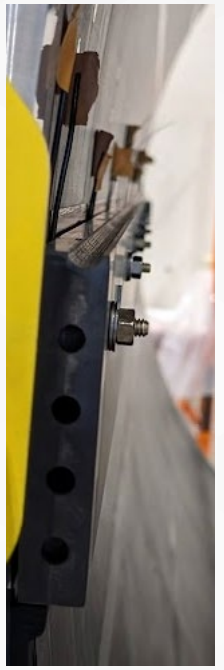
BTST Rail Final Shimming Process

- Only use every third bolt (shear pin hole)
  - # as 6, 5, 4, 3, 2, 1, 0, -1, -2, -3, -4, -5, -6
- Tighten end bolts slightly
- Adjust ends up/down, probe Y, tighten
- Raise center of rail with toe clamps, probe Y
- Tighten remaining bolts with 2.8N-m (25in-lb) torque from center outward







- After adjustment:
  - Pre-bond measure
  - Bond in guide rods
  - Re-measure and small adjustments
  - Spot bond
  - Re-measure
  - Replace bolts with 10mm CFRP rods (bond in)
  - Final gap filling bond
  - Final measure

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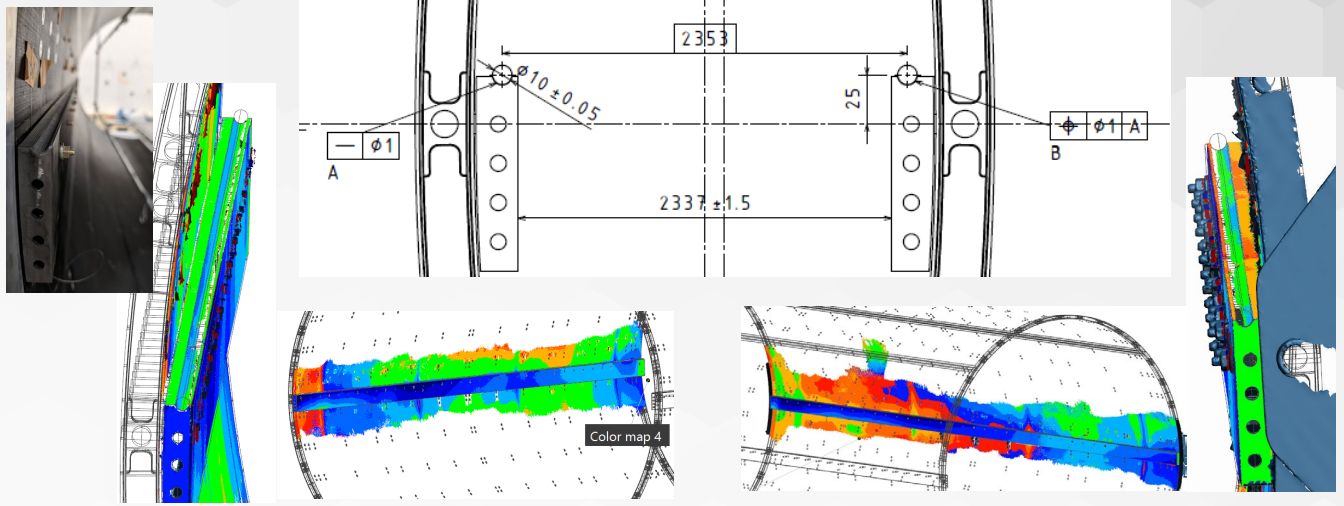
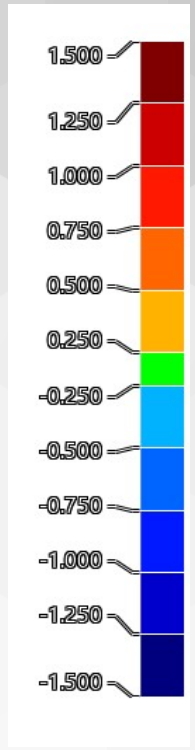
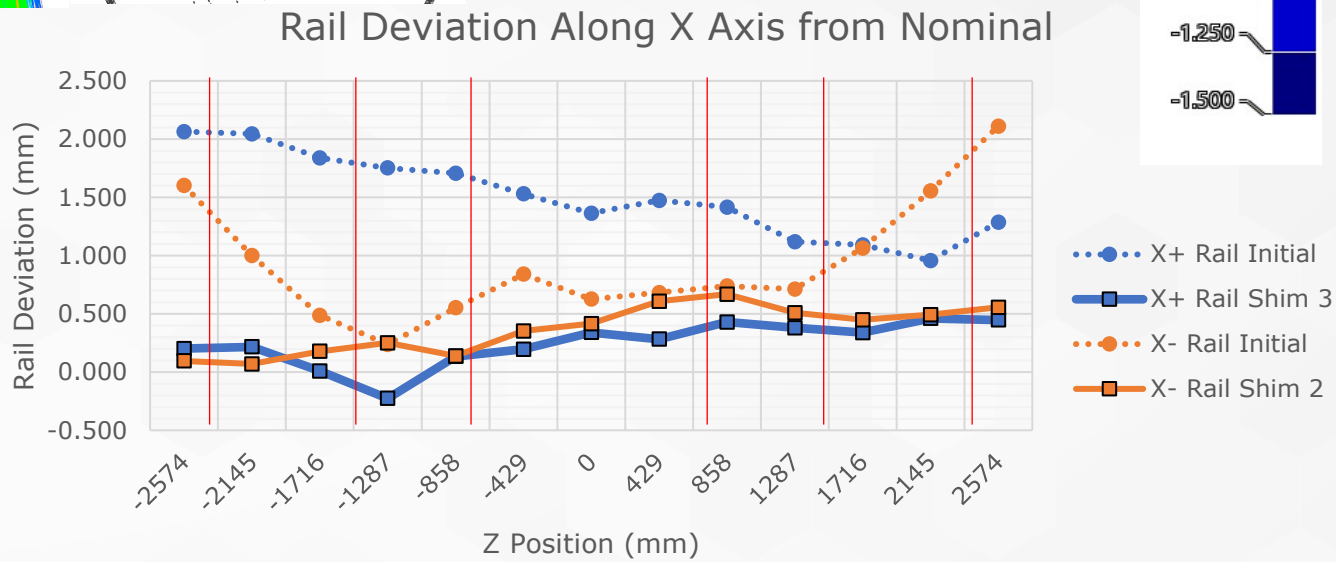
BTST Rail Shimming Result

- Both rails shimmed and “dry assembled” to within
  - [-0.25mm, +0.67mm] X position
  - [-0.25mm, +0.13mm] Y position
- Adhesive bondline thickness
  - [+0.101mm, +0.450mm]
- Rail faces safely within envelope
- Next:
  - Confirm approval to bond
  - Remove rails, drill adhesive holes, bond shim plates
  - Mount, adjust, bond per procedure







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BTST Metrology and Loading Plan

Manufacturing Tolerances	**Finish this week**
- setup completion: volume extension, reference targets, adjust tube to ~~nominal~~ neutral	done
- measure inner and outer surface, confirm cylindricity (~~2mm~~ 3.9mm), best fit radius (+/1.5mm)	done
- measure end ring bolt positions (0.2mm) NOT with "neutral" position sides 1mm off	90%
- measure selected BTL insert positions *across quarters* and map (if time) initial shared	done
Position and Bond Tracker Rails (practice with prototype, report before bond)	**June 5**
- measure direct bolted to tube	done
- measure, shim locally, measure, shim locally, etc – Confirm acceptable position, bond rods, check	Proto 90%, full 50%
- drill and "spot" inject adhesive, measure – ADDED lap shear test for filled adhesive	Strength tests now
- remove bolts, insert shear pins, fill remaining adhesive, measure	
Loading Validation	**June 14**
- design/order cart and wheel hardware, ID water tanks, modify cart	10% done
- measure with loads 100kg, 250kg, 500kg, 1000kg – watch for frame deflections	
- create and compare to simulations	
- adjust simulation properties with 4pt bending sandwich panel test data as justifiable	

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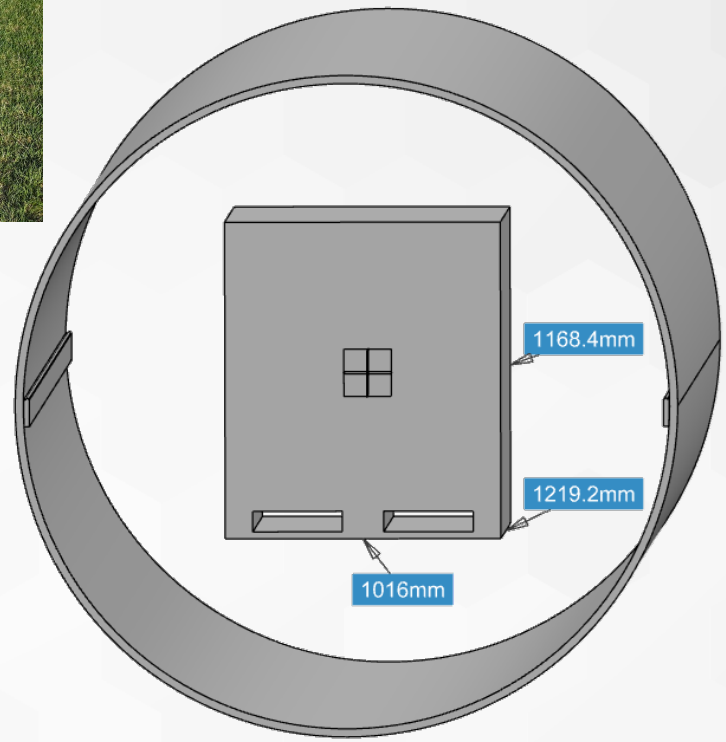
Loading Validation Test Plans

- Load to 1000kg (~2,200lb)
  - Equivalent to loading TB2S+services, TBPS+services, ITST center (empty)
  - Water tank on steel frame
  - Feet on tracker rail at ~ Z = +/- 781mm
- Gather deflection data with surface scan and some points data
- Compare to simulation later
  - Existing simulation, load case 5, no BTL



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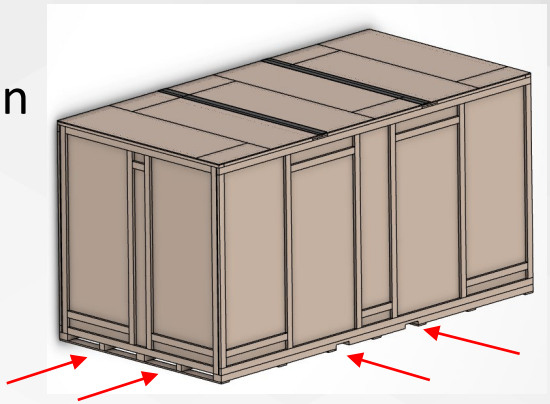
Final shipping info for CERN Carbon Fiber Tube (BTST)

- Crate exterior maximum dimensions
  - **554cm long, 285cm wide, 280cm high** (rounded up from 218x112.25x110inches measured)
- Carbon fiber tube mass: **400kg** (round up from 385kg CAD estimate)
- Wood crate mass: 2.9m^3 wood from CAD model, so 3m^3*~780kg/m^3 = **2340kg estimated**
- **Total Estimated Mass: 2740kg**

- Air Freight: ORD to LUX
  - Mid-June
- Scarbrough has confirmation of fit from



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Backup Slides

On behalf of CMS
Partially supported by NSF

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Simulation of BTST Integration Cases

The following slides contain loads and positions for each of the integration steps for BTST loading of inner and outer tracker components, including services

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BTST Simulation Load History "Complete"

Case	End Ring BCs	Added Loads	Mass (kg) Item + Services (full tube)	"Added" Load Input Locations On BTST
1	- Small Ears	1 Tube Only	384.1	GRAVITY on full model
2	- Small Ears, Bananas*	" "	9.4	
3	" "	BTL	1884.3,18,23.7	Tube inner surface (38 BTL rail lines, distributed)
4	" "	TB2S	520,~~303.7~~ 153.7	Tracker Rails @ Z= +/- 781.3mm, BTL rails (next)
5	" "	TBPS + ITST Center (empty)	175.8, 150	Tracker Rails @ Z= +/- 781.3mm, BTL rails (prev.)
6	" "	TEDD + Seals	535,501,10.8,~~235.6~~	Tracker Rails @ Z= +/- 1474, 2494, 2650, ~~BTL rails~~
7	" "	Bulkhead Disk	327.2 (80%,20%)	Tracker Rail ends, 12 and 6 o'clock M16s (@2800)
8	" "	ITST Ends (empty)	57.4	Bulkhead (tracker rail ends)
9	- Small Ears, Bananas* - Nose Cone Brackets	Nose Cones	340	Nose cone corner brackets, offset mass to…3500?
10	" "	Services moved to cones	1452.6	Cone brackets during lift/lower, offset to…3500?
11	- Bananas* - Big Ears Z- - Eiffel+Nose Brackets Z+	Big ears* REMOVE SMALL EARS*	73.4* Z- only -31.2*	*if modeled explicitly Eiffel "reaches through" and supports Z+ nose cone
12	- Support Bracket	REMOVE NOSE CONES, EARS	120*,-1452.6, - 340	Banana support post, nose cone corner brackets
13	" "	Service Cylinder w/ TBPX	172, 67.9	Tracker Rails @ +/- 781.3mm, Bulkhead (rail ends)
14	" "	TEPX	117.0	Bulkhead via rail ends
15	" "	Cool to -5°C, +10°C outside		Outer face sheets (quarter, joint, end), end ring at +10°C

BTST_HalfSymm_2023-03-03_highMod_HM63_F6_K13916_F6rail.inp

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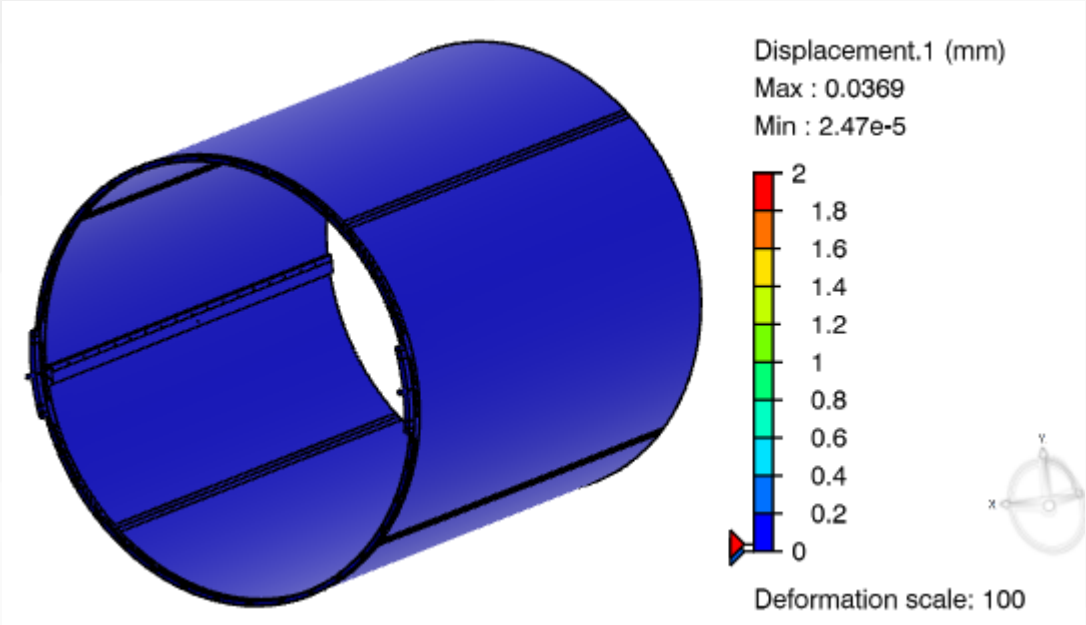
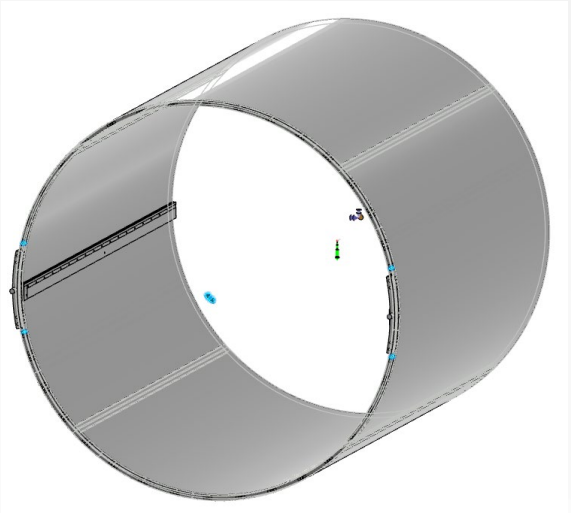
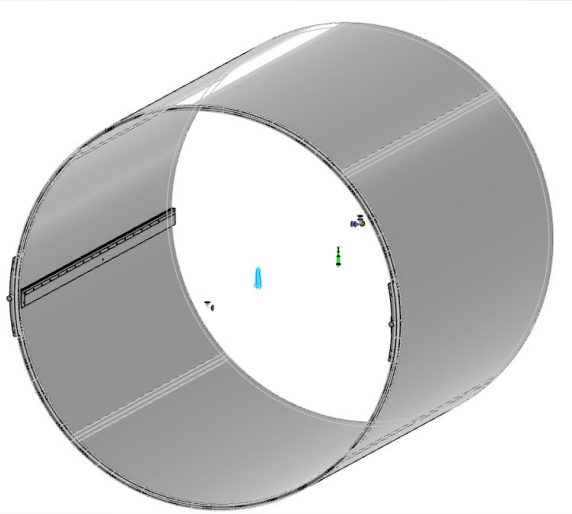
Small Ears + Tube Only + Bananas Installed

BTST_HalfSymm_2023-03-03_highMod_HM63_F6_K13916_F6rail.inp

BTST_HalfSymm_2023-02-23_highMod_HM63_F6_K13916_F6rail







Case		BCs	Additions	Masses of Additions (kg)	Locations of Masses
1	-	**Small Ears**	**1 Tube Only**	**384.1**	
2	-	Small Ears, Bananas*	" "	9.4	GRAVITY on full model

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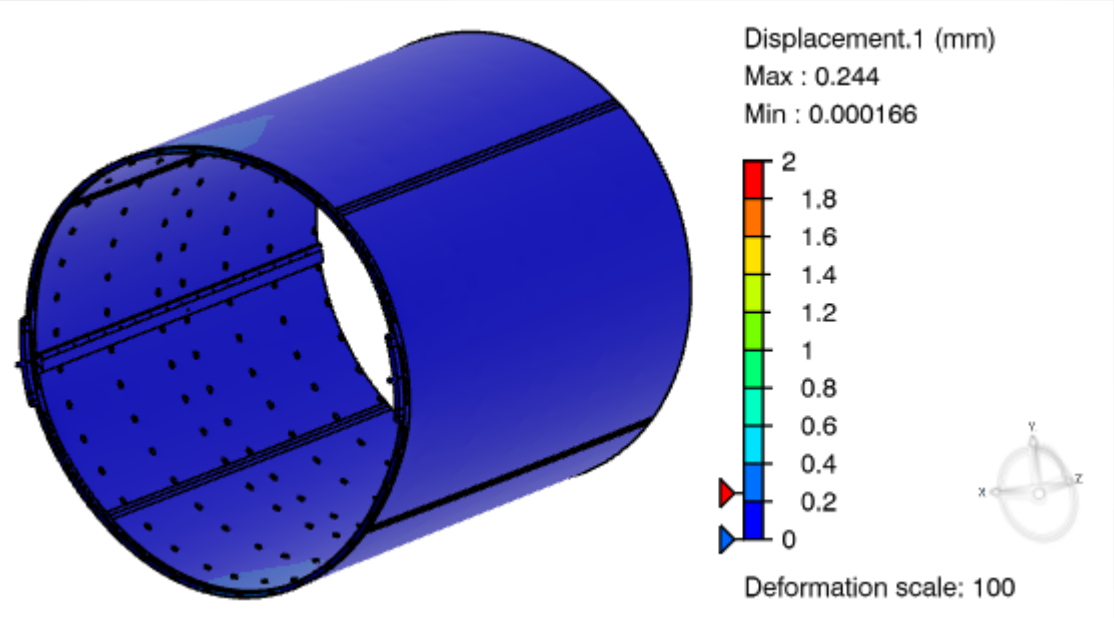
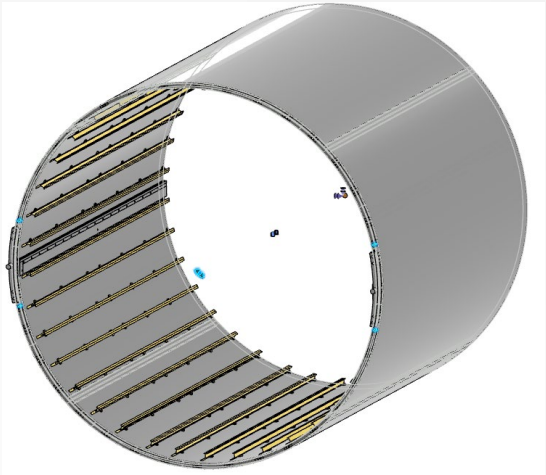
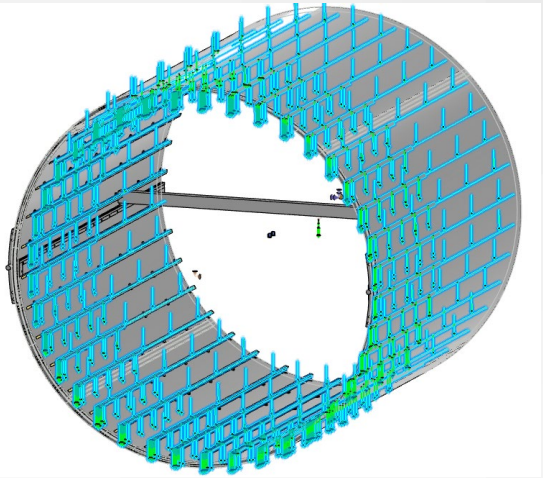
+ BTL rails, trays, services







Case	BCs	Additions	Masses of Additions (kg)	Locations of Masses
3	**" "**	**BTL**	**1884.3,18,23.7**	**Tube inner surface (38 BTL rail lines, distributed)**

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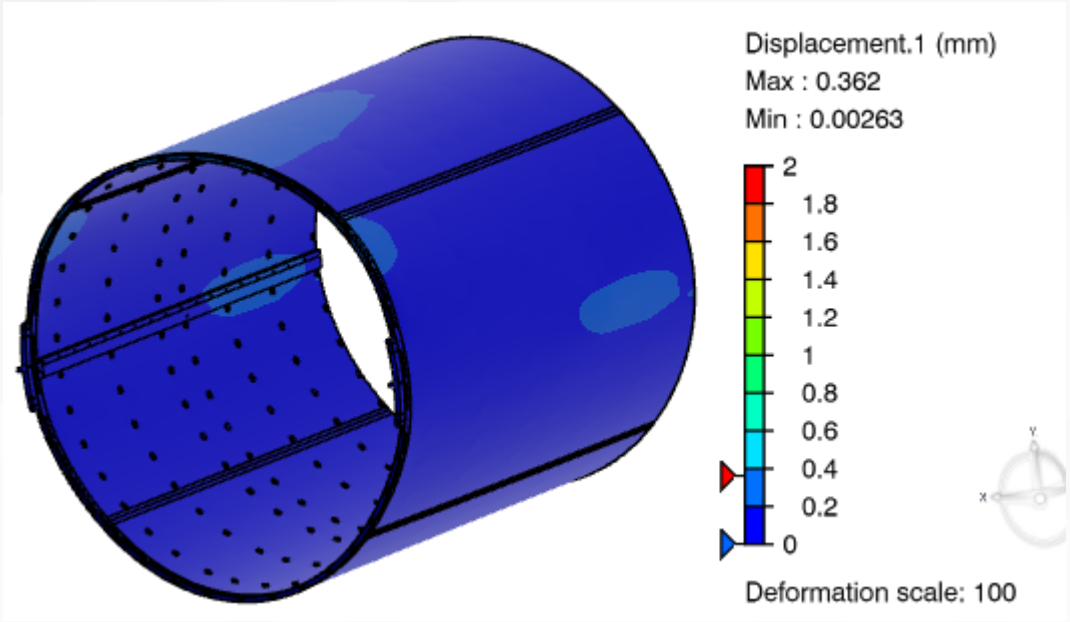
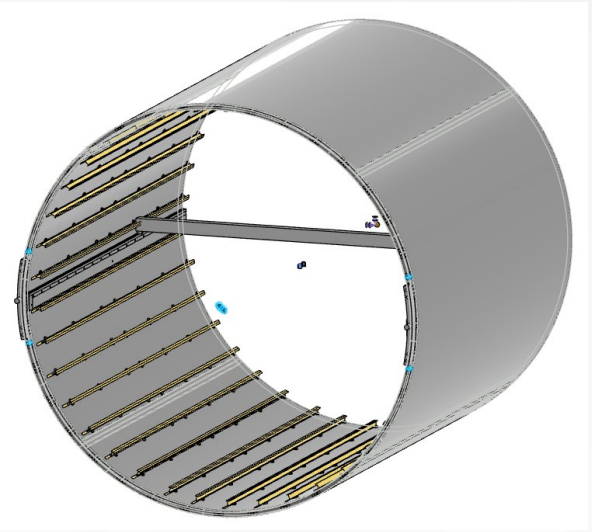
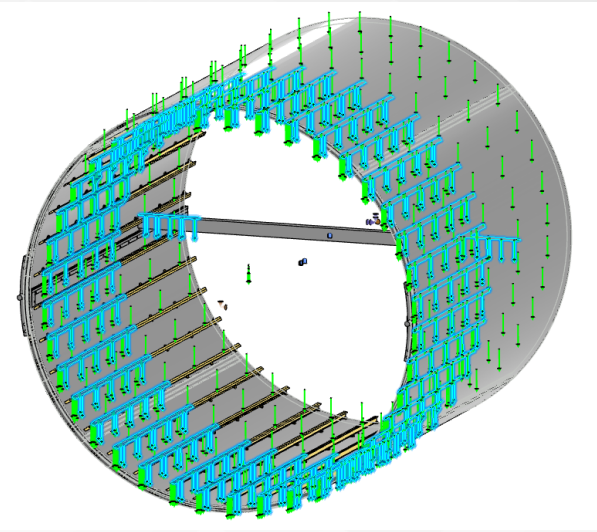
+ TB2S, services







Case	BCs	Additions	Masses of Additions (kg)	Locations of Masses
4	**" "**	**TB2S**	**520,~~303.7~~ 153.7**	**Tracker Rails @ Z= +/- 781.3mm, BTL rails (next)**

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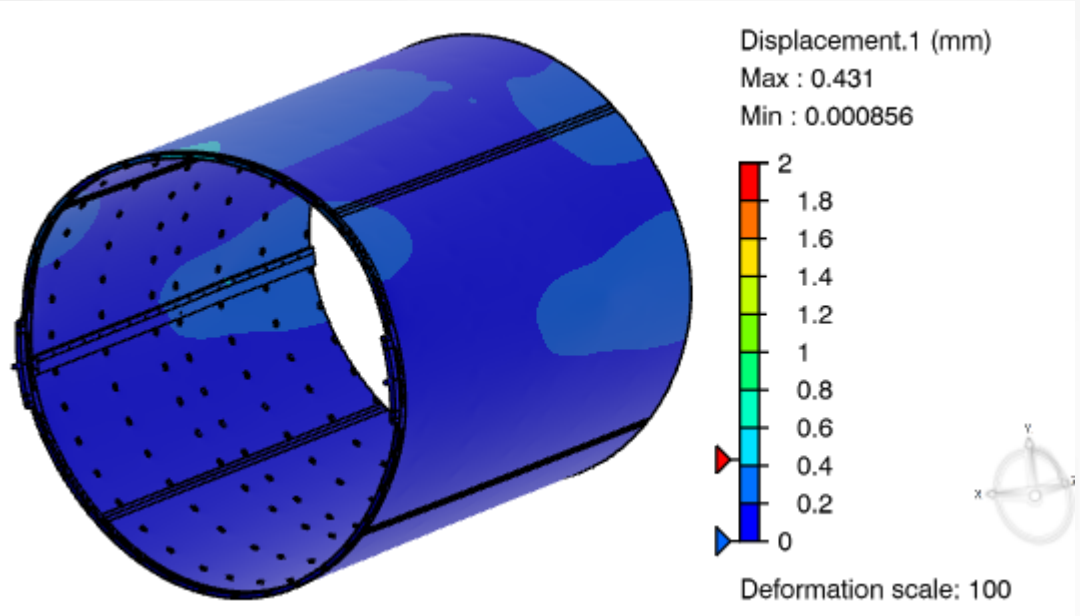
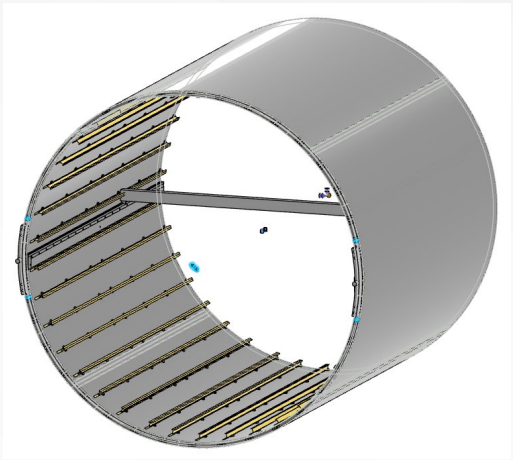
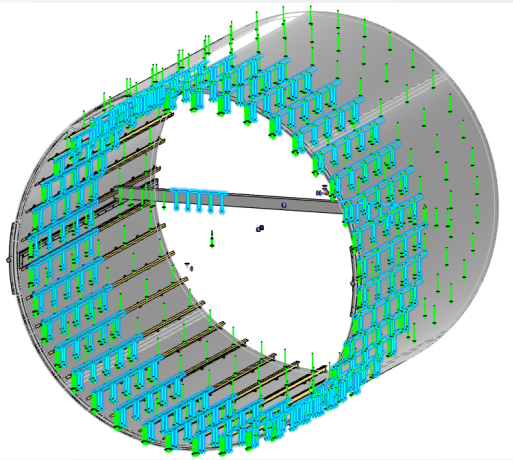
+ TBPS, services, ITST center







Case	BCs	Additions	Masses of Additions (kg)	Locations of Masses
5	**" "**	**TBPS + ITST Center (empty)**	**175.8, 150**	**Tracker Rails @ Z= +/- 781.3mm, BTL rails (prev.)**

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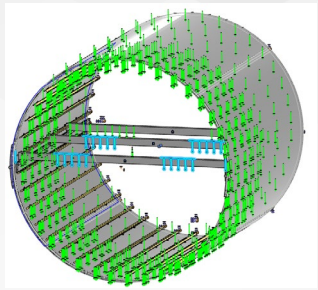
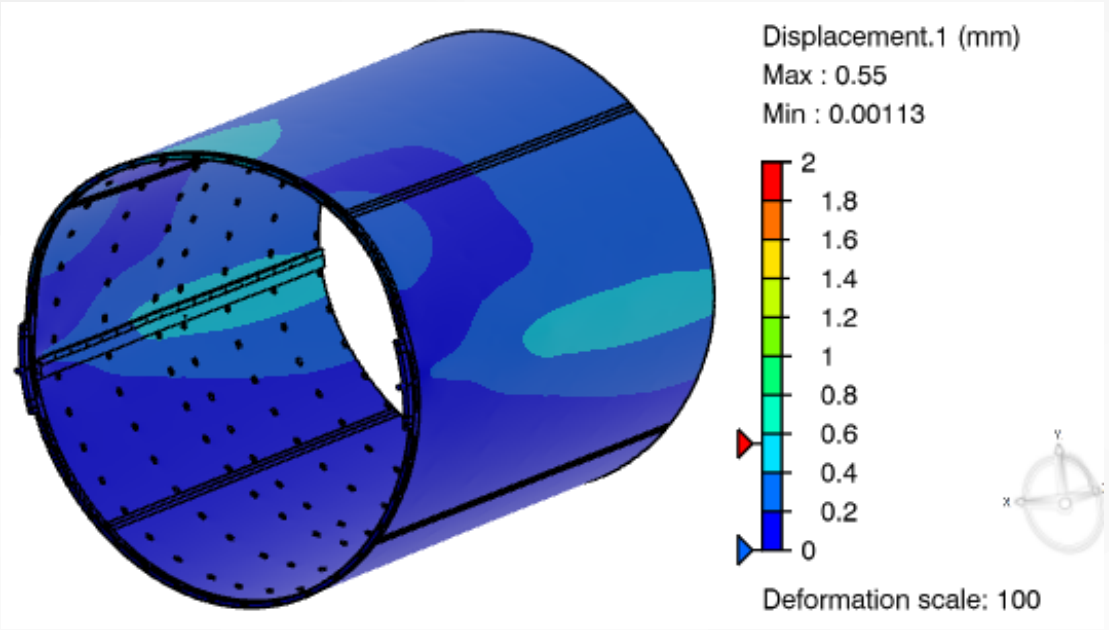
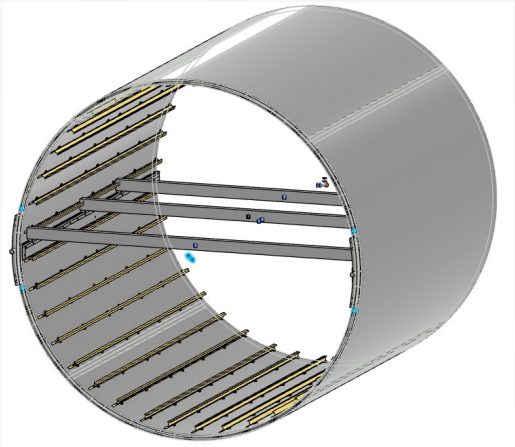
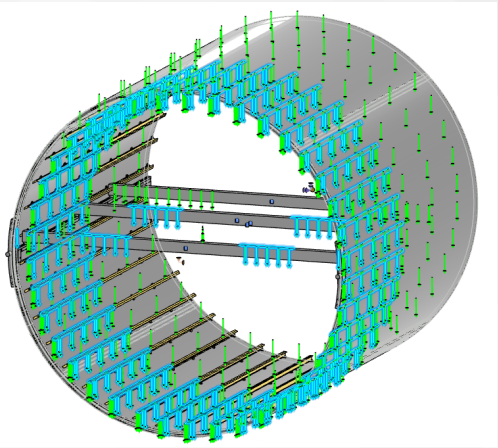
+ TEDD, periphery seals

- Move TEDD Services to rail









Case	BCs	Additions	Masses of Additions (kg)	Locations of Masses
6	" "	TEDD + Seals	400,400,10.8,235.6	Tracker Rails @ Z= +/- 1474, 2494, 2650, BTL rails

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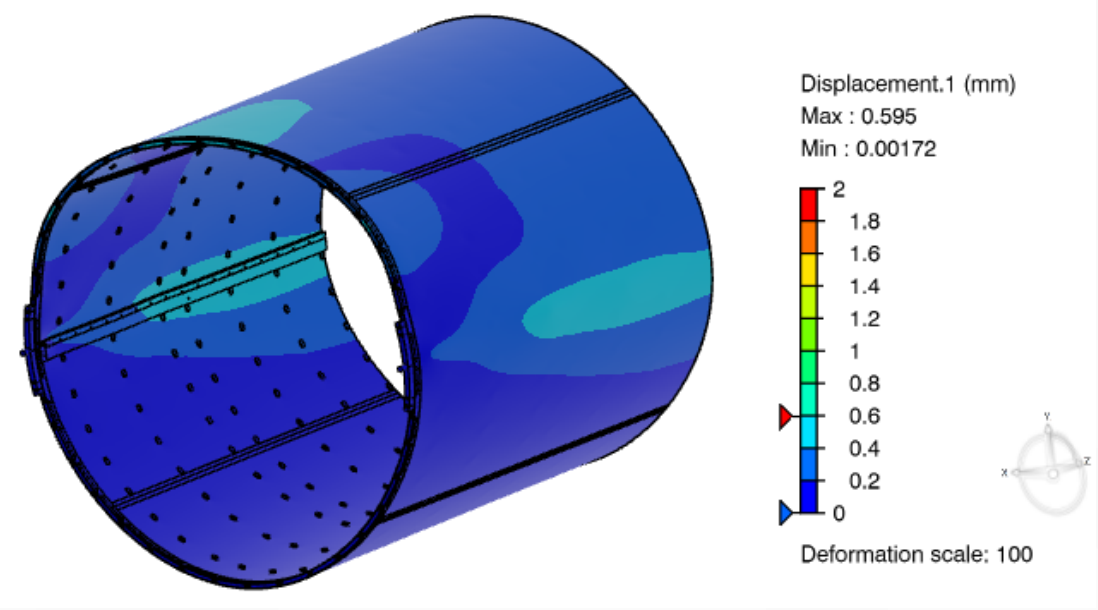
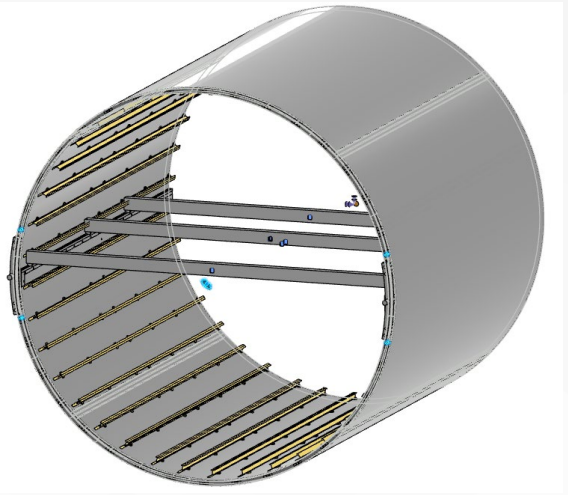
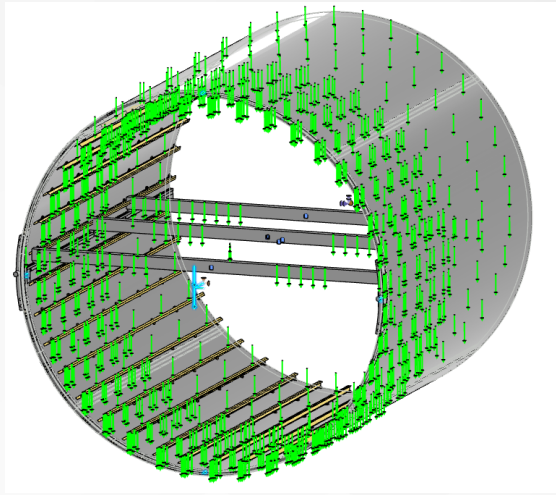
+ Bulkhead disk

- Move TEDD Services







Case	BCs	Additions	Masses of Additions (kg)	Locations of Masses
7	**" "**	**Bulkhead Disk**	**327.2 (80%,20%)**	**Tracker Rail ends, 12 and 6 o'clock M16s (@2800)**

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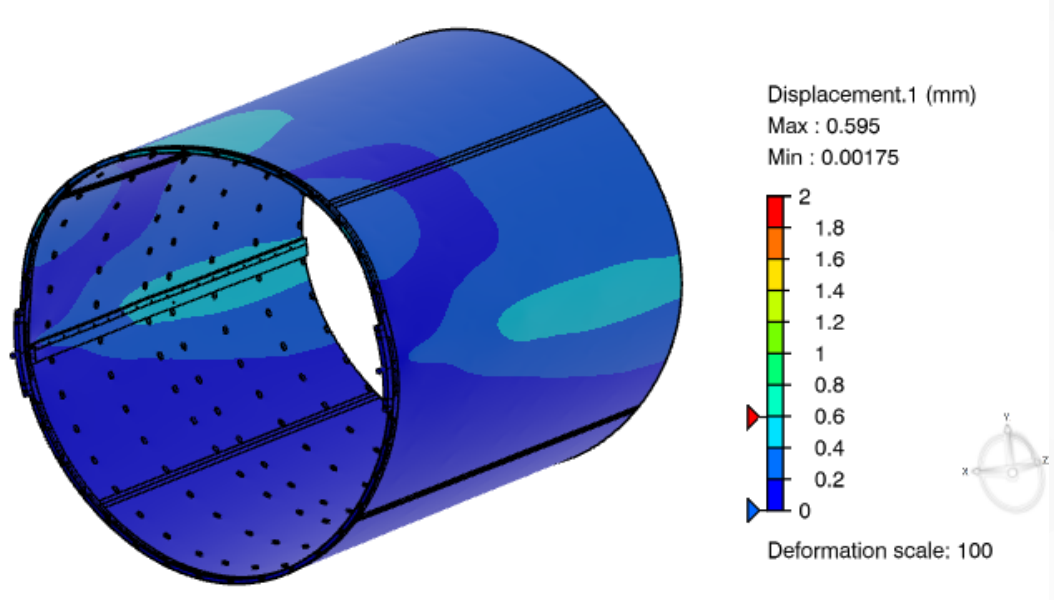
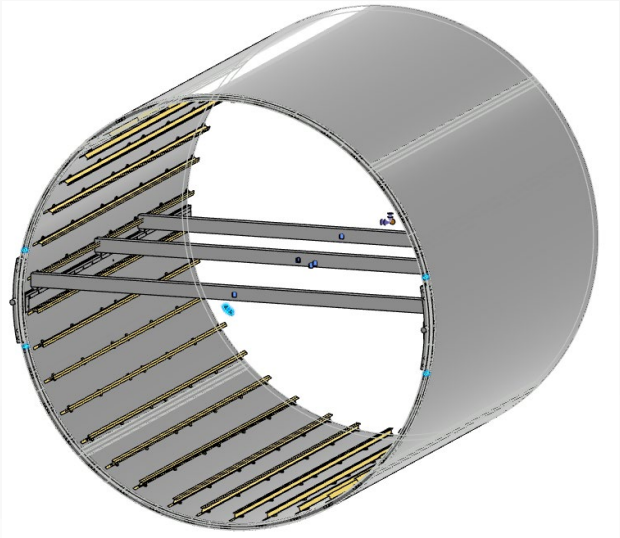
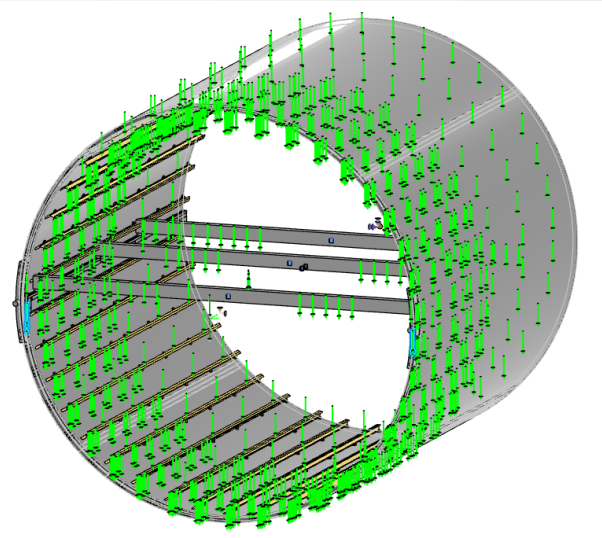
+ ITST Ends

- Move TEDD Services







8	" "	ITST Ends (empty)	57.4	Bulkhead (tracker rail ends)

Case	BCs	Additions	Masses of Additions (kg)	Locations of Masses

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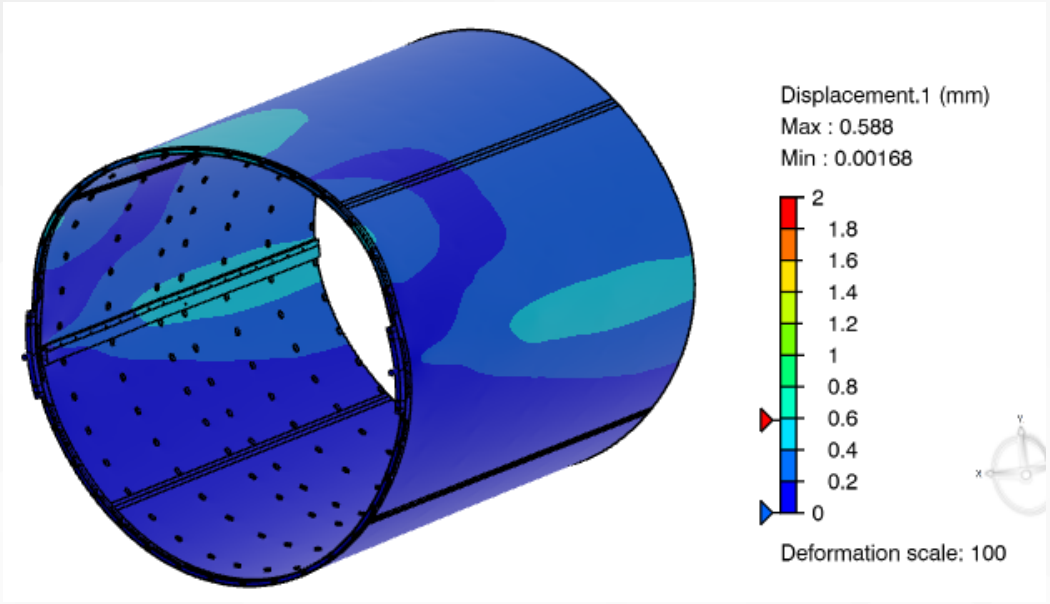
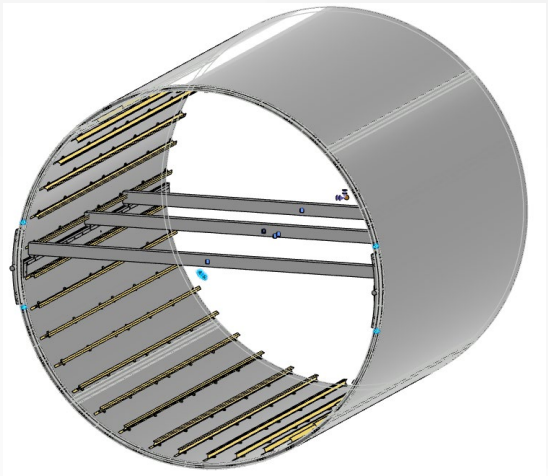
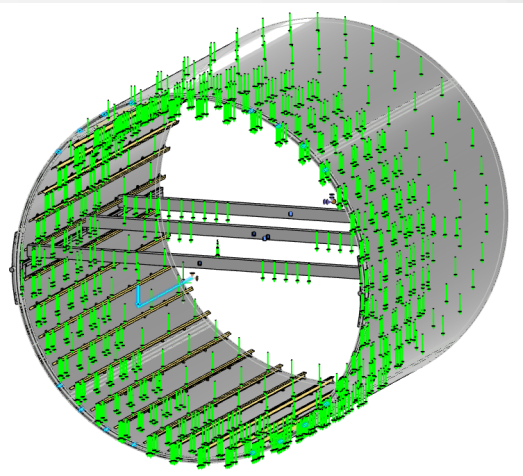
+ Nose Cones

- Move TEDD Services







Case	BCs	Additions	Masses of Additions (kg)	Locations of Masses
9	**- Small Ears, Bananas* - Nose Cone Brackets**	**Nose Cones**	**340**	**Nose cone corner brackets, offset mass to…3500?**

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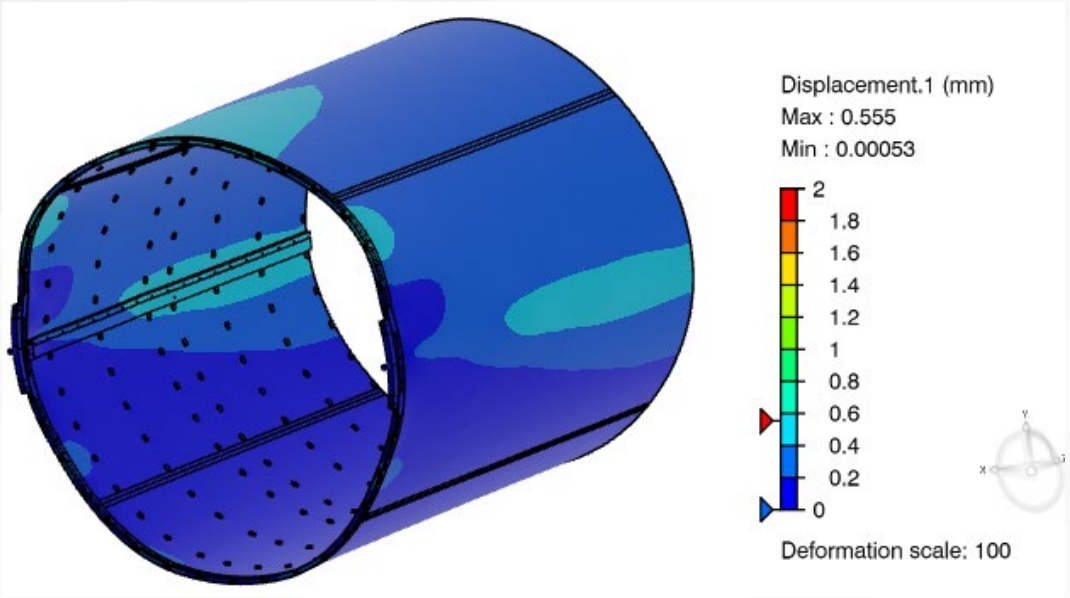
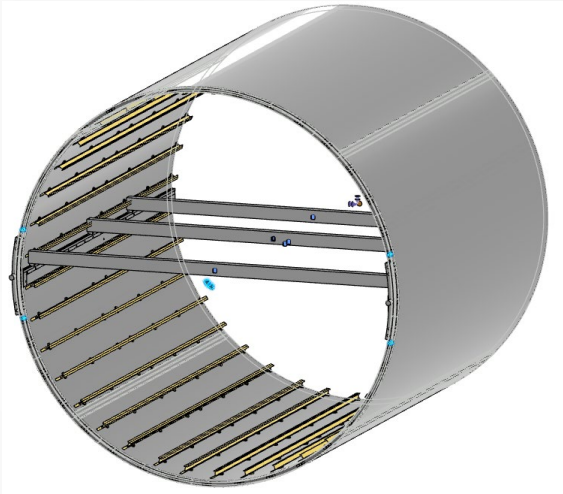
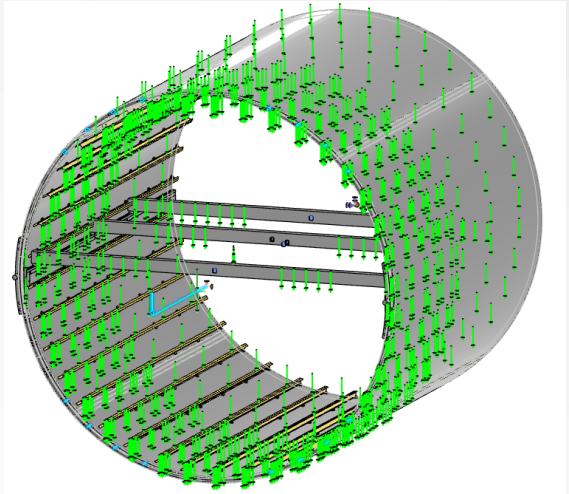
+ Move Services to Nose Cones

- Move TEDD Services







10	" "	Services moved to cones	1452.6	Cone brackets during lift/lower, offset to...3500?
Case	BCs	Additions	Masses of Additions (kg)	Locations of Masses

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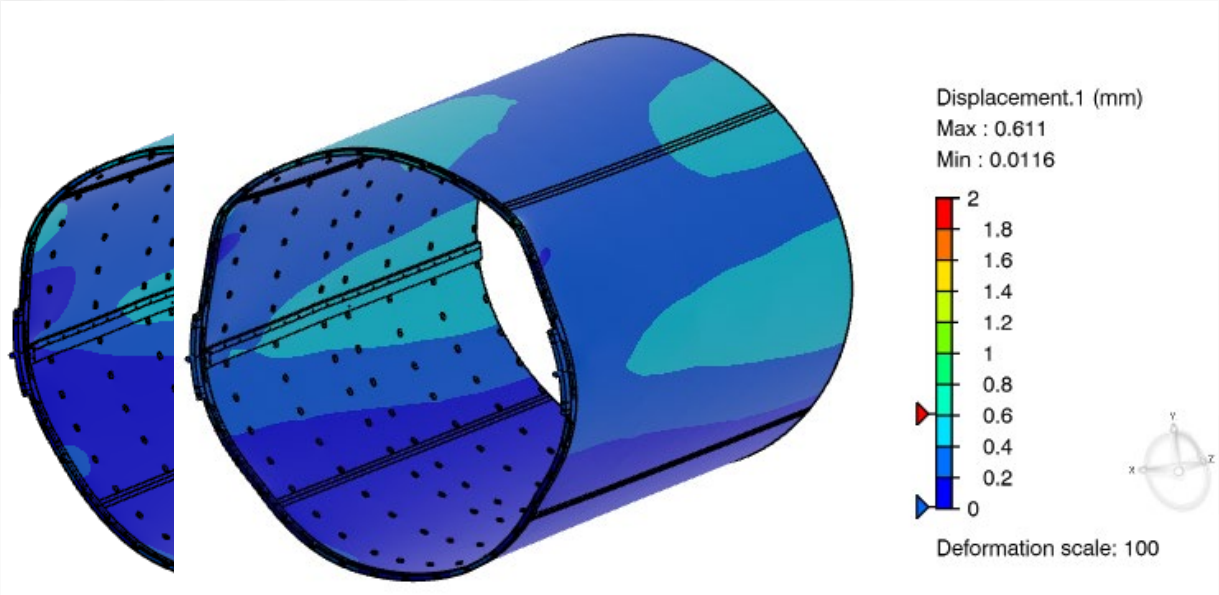
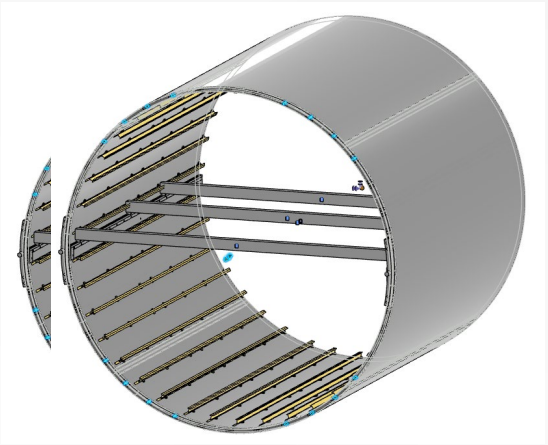
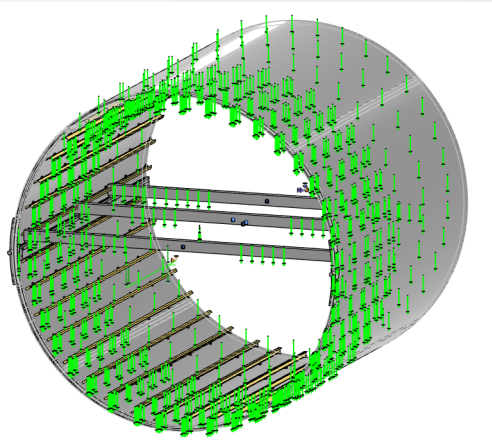
+ Switch support from small ears to big ears

- Move TEDD Services







Case	BCs	Additions	Masses of Additions (kg)	Locations of Masses
11	- **Bananas*** - **Big Ears Z+** - **Eiffel+Nose Brckts Z-**	**Big ears* REMOVE SMALL EARS***	**73.4* Z+ only -31.2***	***if modeled explicitly Eiffel "reaches through" and supports Z- nose cone**

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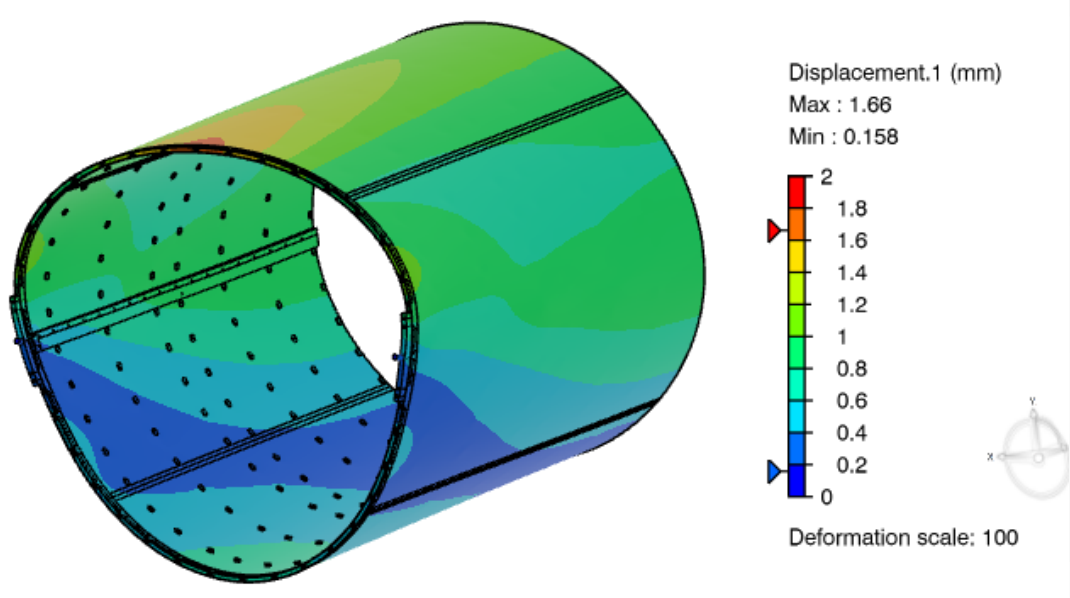
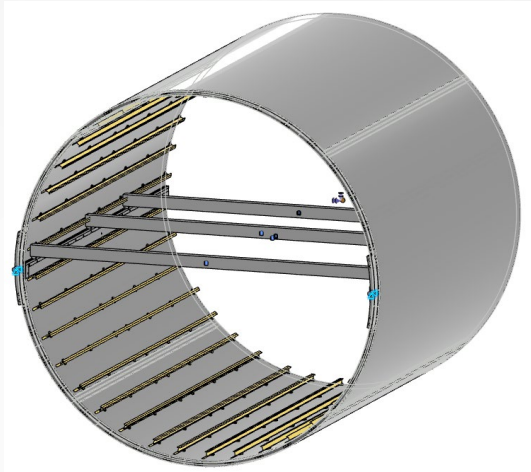
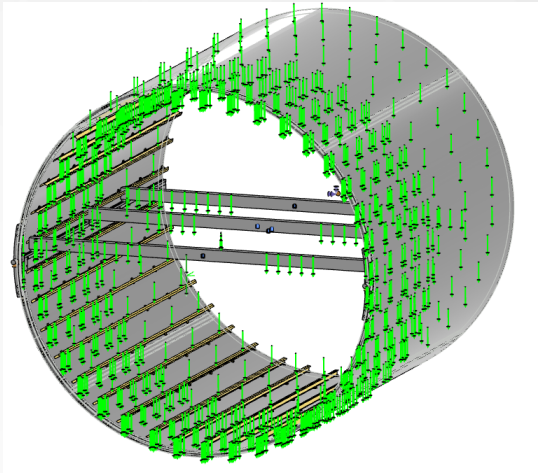
+ Brackets, Remove Nose Cones, Remove Big Ears

- Move TEDD Services







Case	BCs	Additions	Masses of Additions (kg)	Locations of Masses
12	**- Support Bracket**	**REMOVE NOSE CONES, EARS**	**120*,-1452.6, -340**	**Banana support post, nose cone corner brackets**

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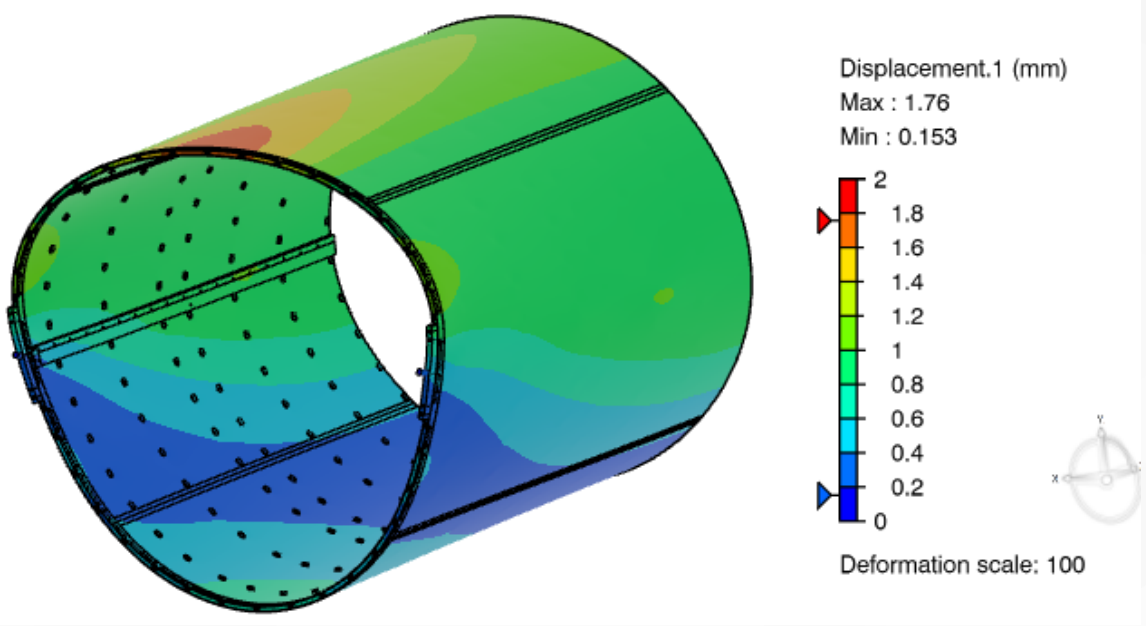
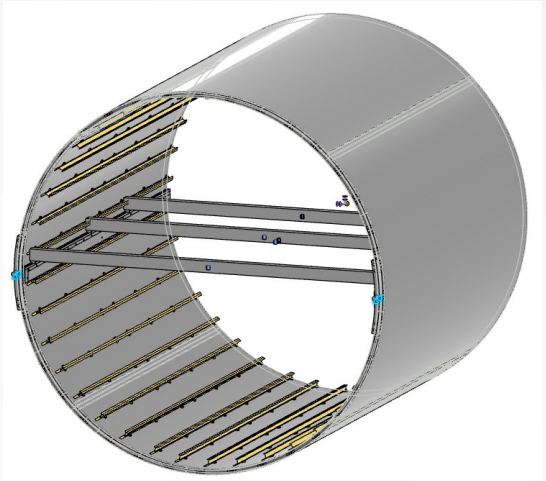
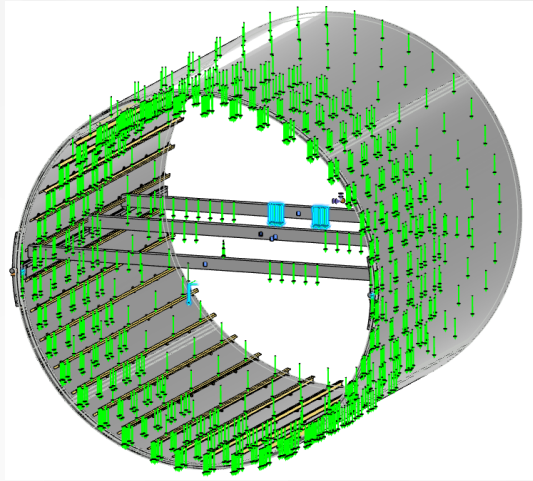
+ Service Cylinders

- Move TEDD Services







Case	BCs	Additions	Masses of Additions (kg)	Locations of Masses
13	**" "**	**Service Cylinder w/ TBPX**	**172, 67.9**	**Tracker Rails @ +/- 781.3mm, Bulkhead (rail ends)**

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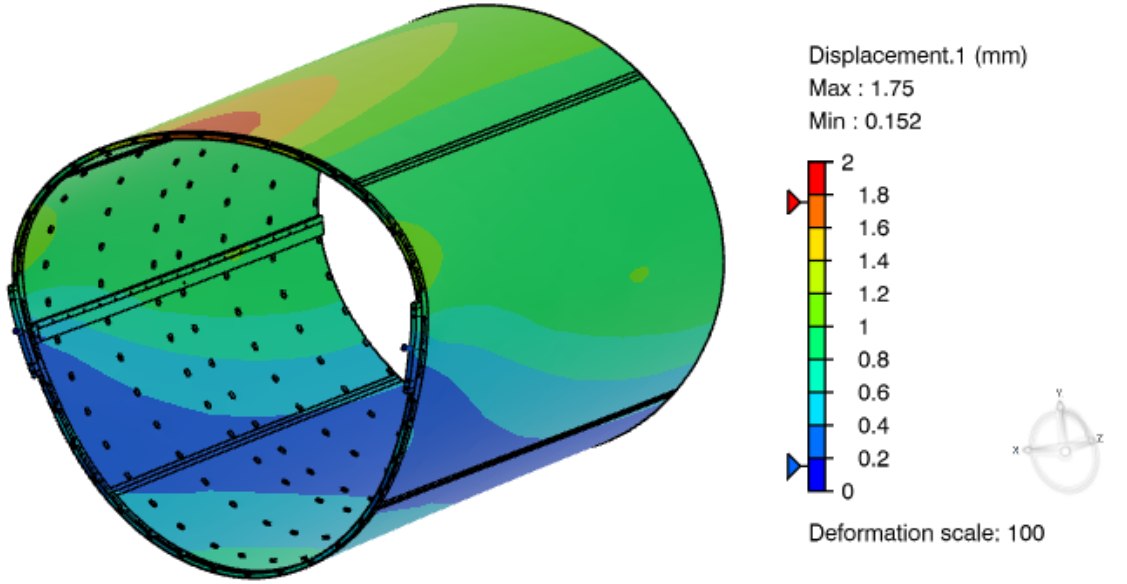
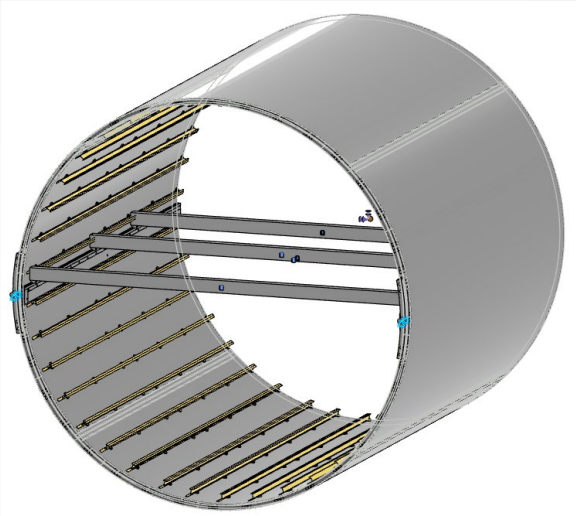
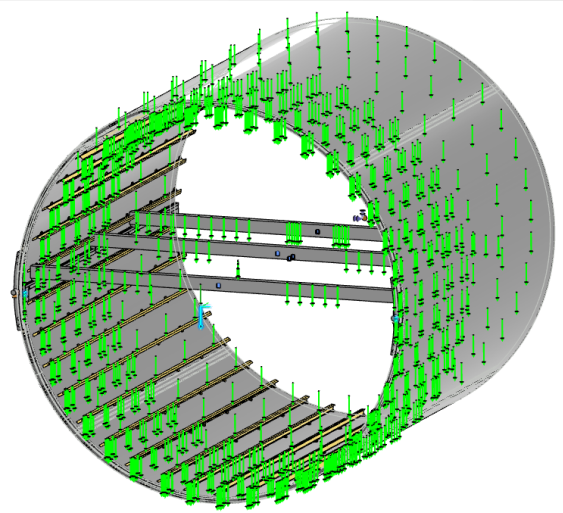
+ TEPX

- Move TEDD Services







14	**" "**	**TEPX**	**117.0**	**Bulkhead via rail ends**

Case	BCs	Additions	Masses of Additions (kg)	Locations of Masses

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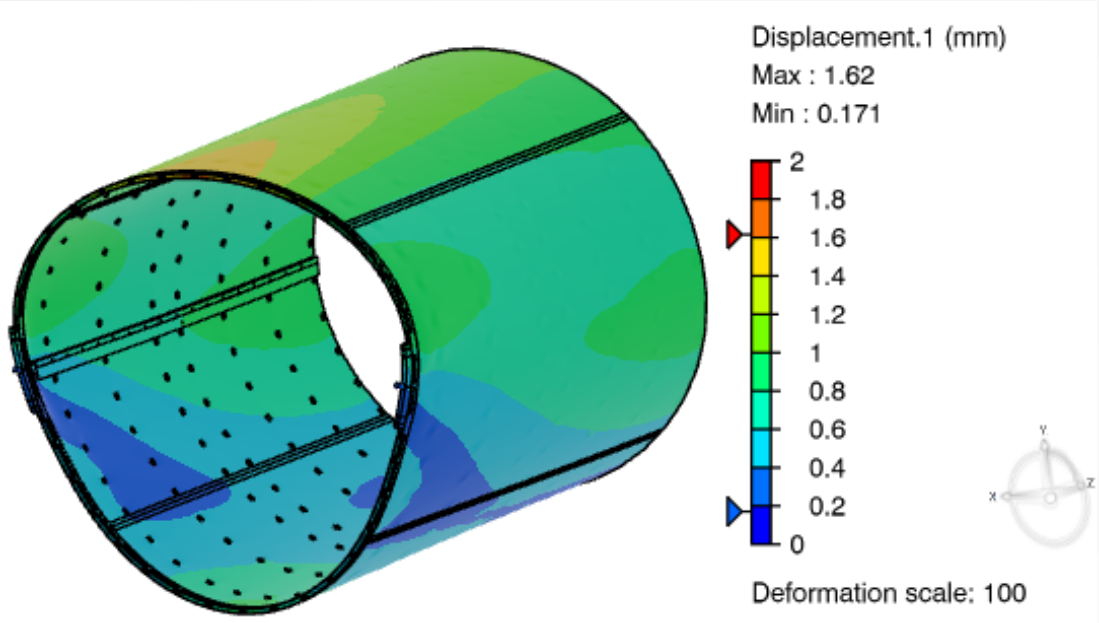
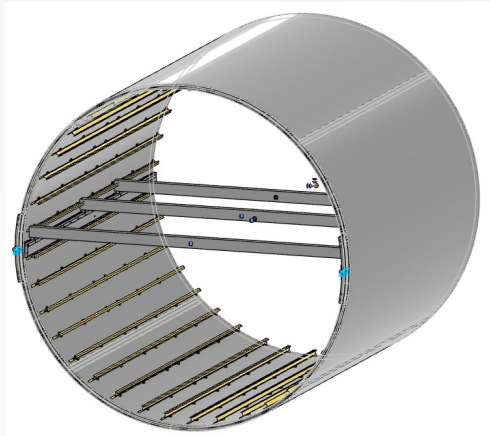
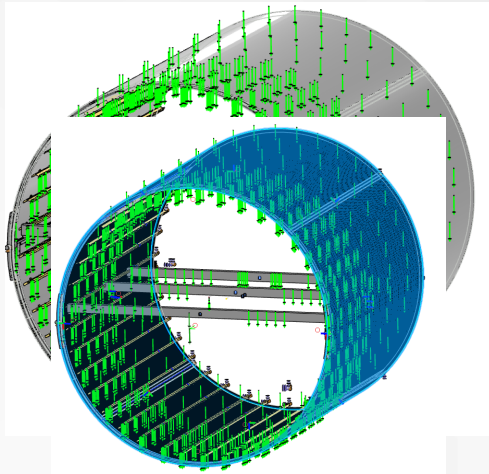
+ Cool to ~~-20°C~~ -5°C

- Move TEDD Services
- Outer face sheets and end ring at +10°C per Guillermo's models on next slide







15	" "	Cool to -20°C, +10°C out		Outer face sheets at +10°C

Case	BCs	Additions	Masses of Additions (kg)	Locations of Masses

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