Field Period Assembly

T. Brown

Princeton Plasma Physics Laboratory
Oak Ridge National Laboratory

External Peer Review
Princeton Plasma Physics Laboratory
Princeton, NJ
October 11-12, 2006

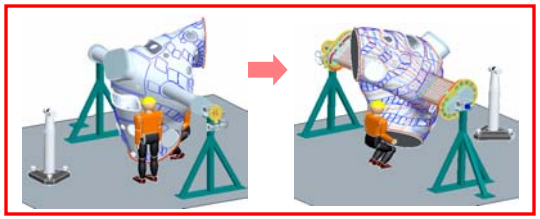
Field Period Assembly (FPA)

NCSX
National Compact Stellarator Experiment

- What is involved with FPA
- How does the “As-Built” modular coil and vacuum vessel compare with their original CAD data.
- What activities have been used to develop the design approach and reduce assembly risk

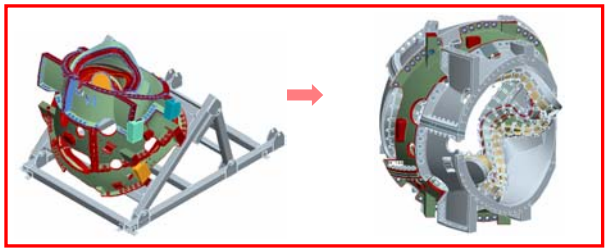
FPA is accomplished in five Stages

Stage 1



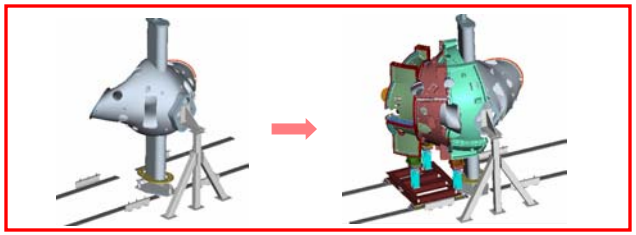
VV Prep

Stage 2



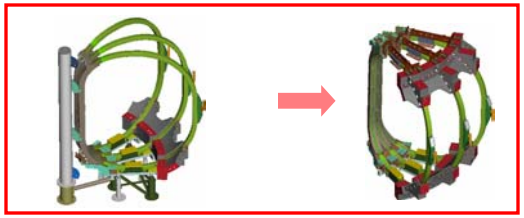
MC Half Period Assembly

Stage 3



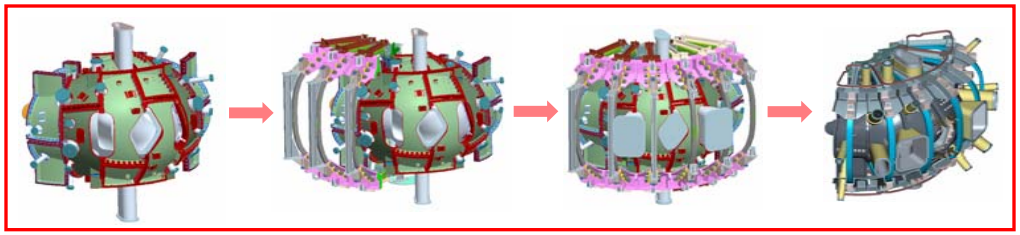
MCHP installation over VV Period

Stage 4



TF Half Period Assembly

Stage 5

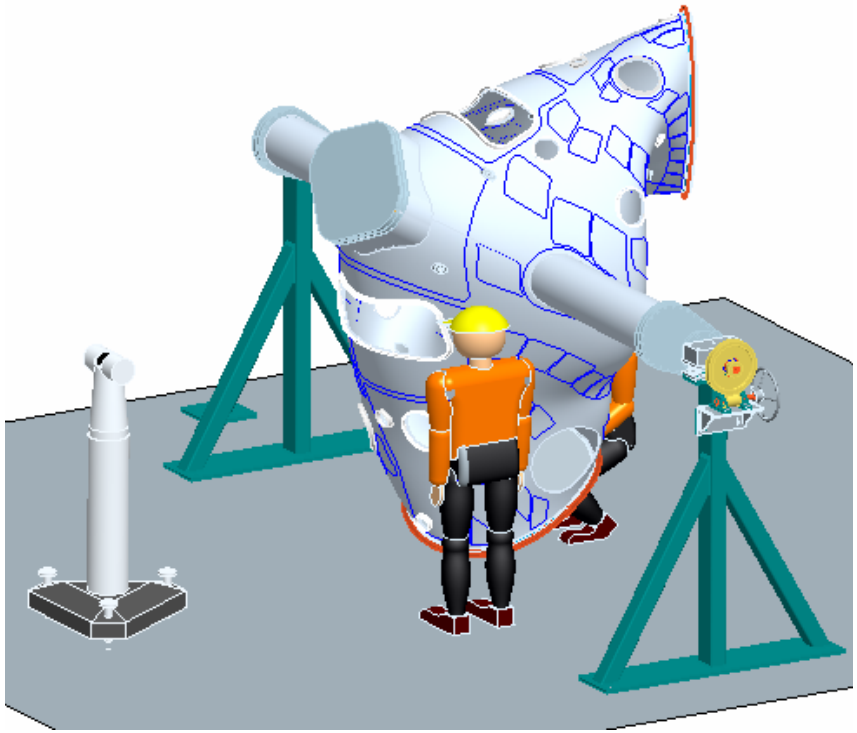


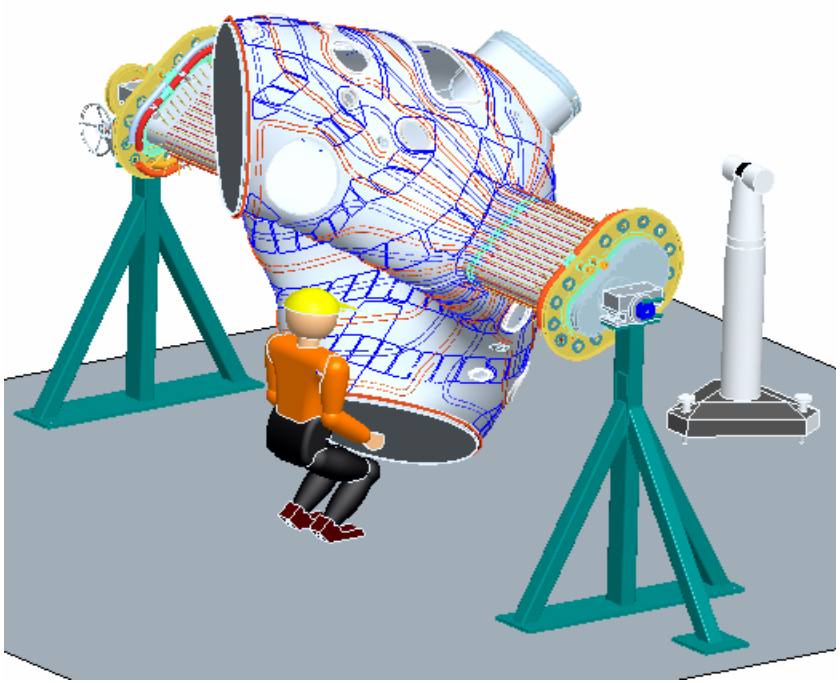
Final FP Assembly

VV Prep Station

NCSX National Compact Stellarator Experiment

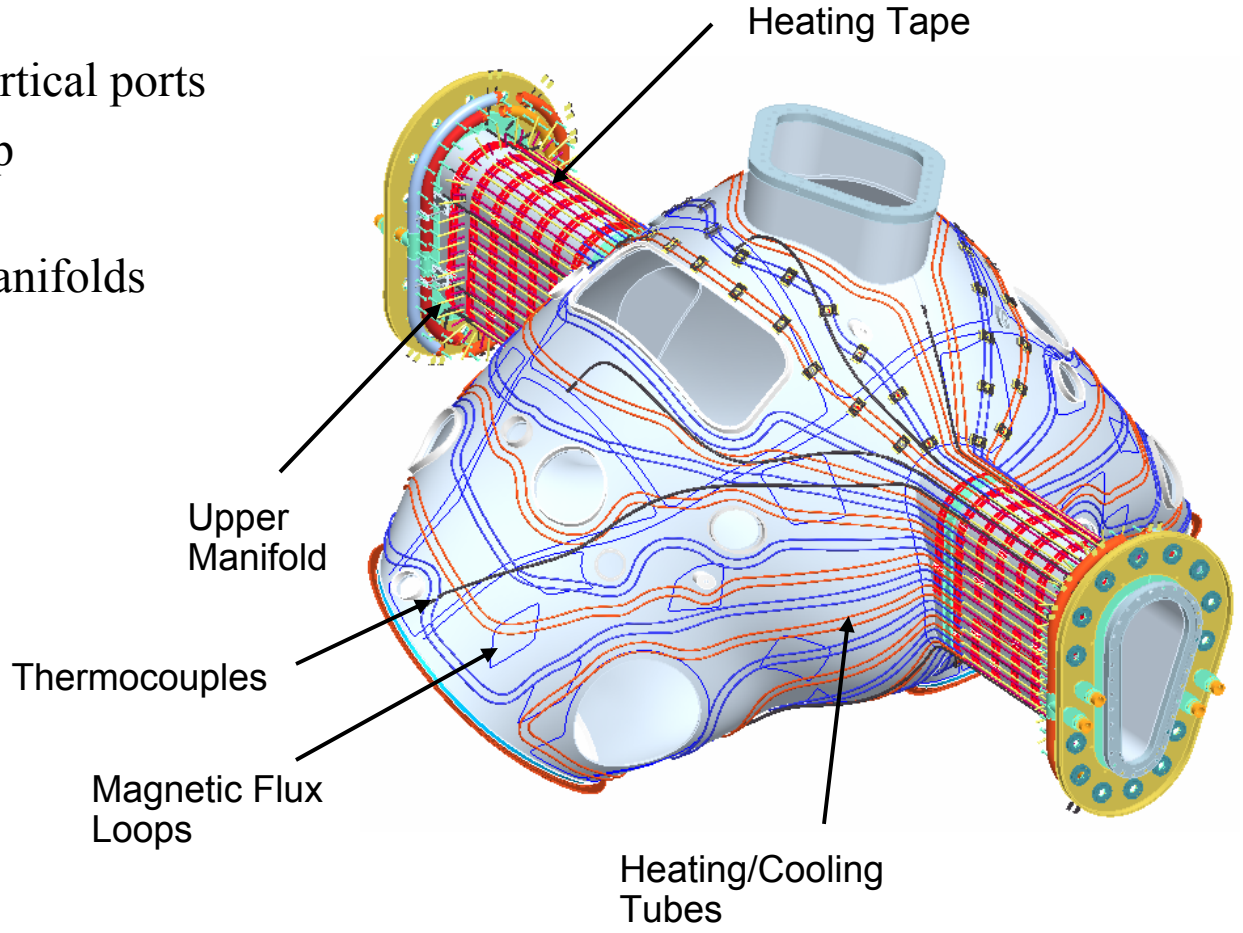
Stage 1 is used to install ~ 70 magnetic loops with metrology alignment on each of the three VV Field Periods along with ~ 800 studs, 32 coolant tubes and 58 thermocouples.





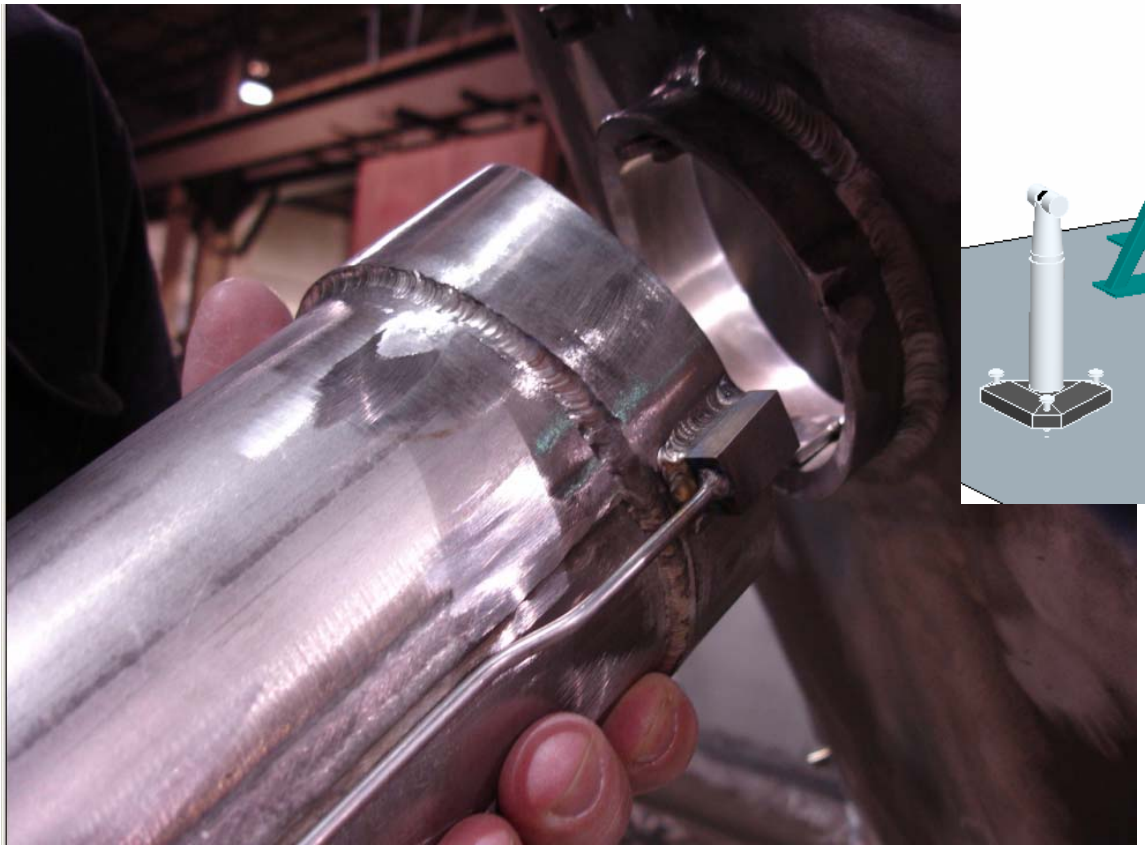
Vertical port installation details.

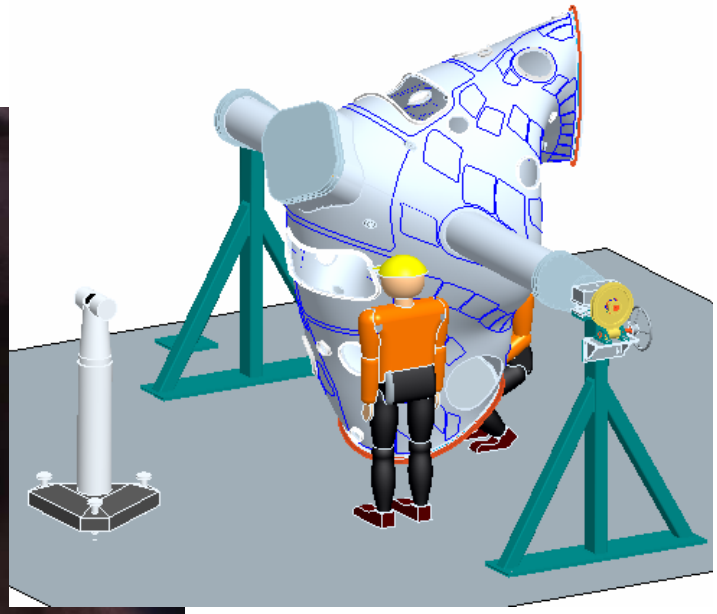
- Heating tapes on vertical ports
- Magnetic Flux Loop termination
- Upper and lower manifolds
- Termination of TC Instrumentation



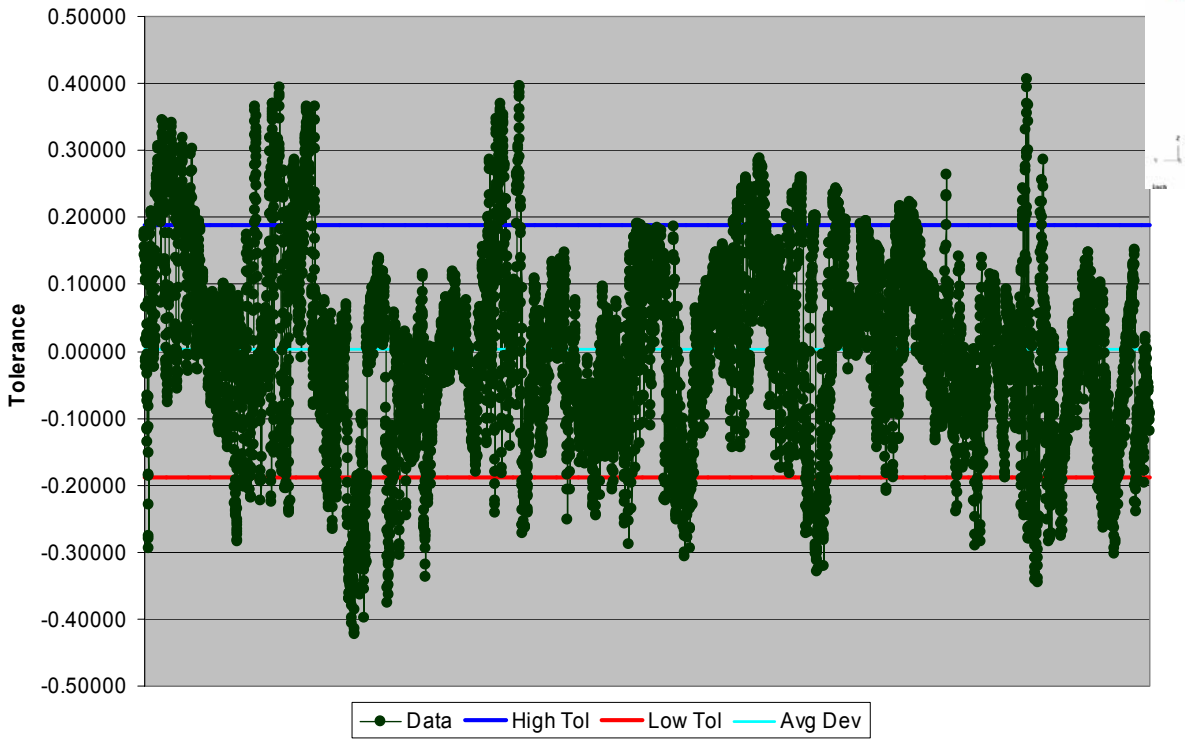
Station 1 is also being used to test port fit-up for welding purposes

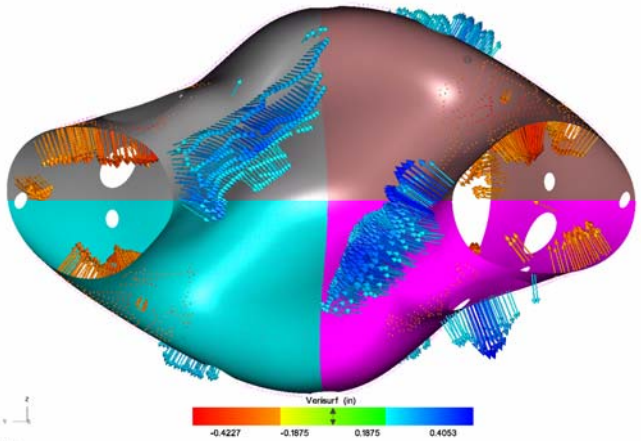
NCSX
National Compact Stellarator Experiment



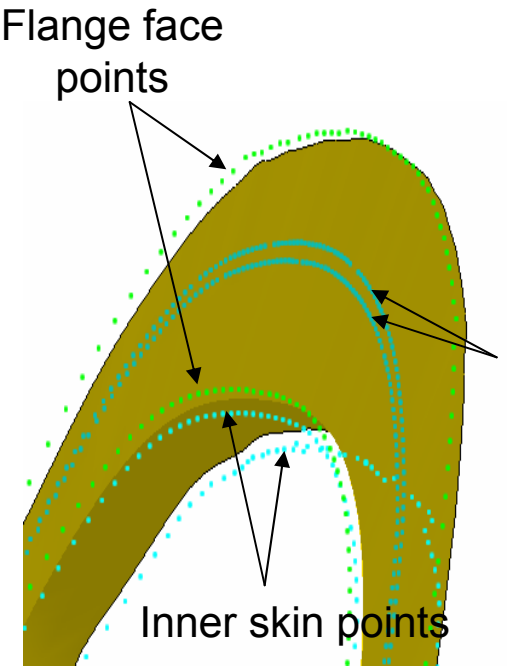


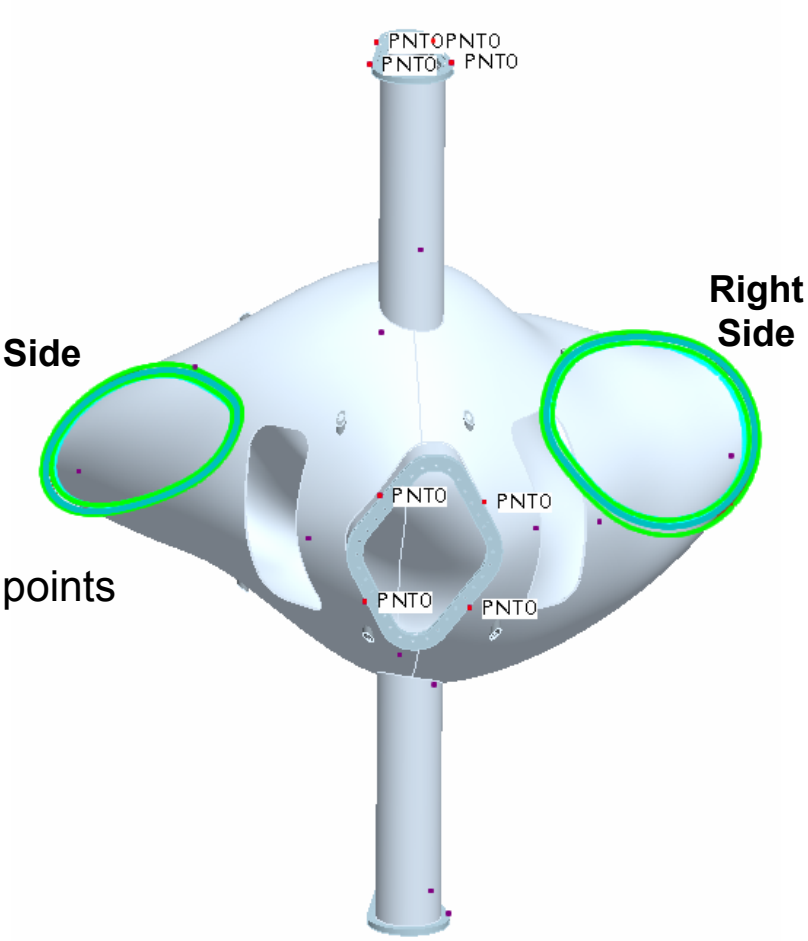
VV is best-fit to surface data and out-of-tolerance regions identified



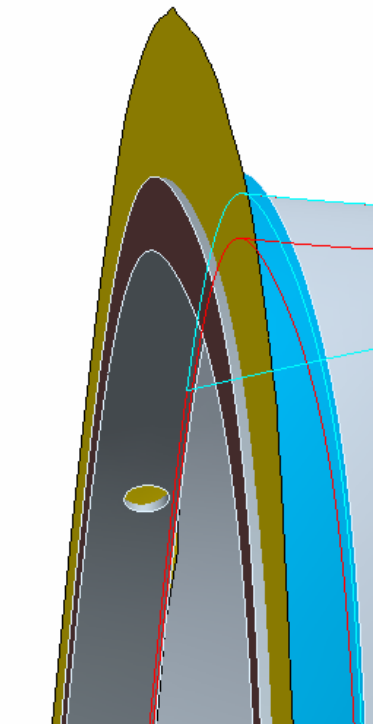


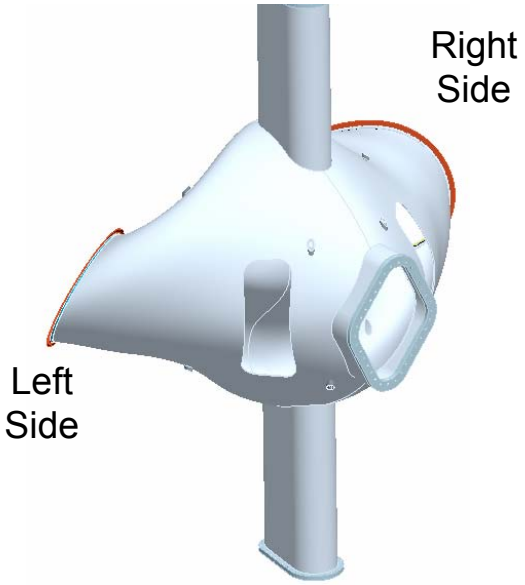
After shell best-fit, 3-mm probe measurement used to establish vessel flange geometry

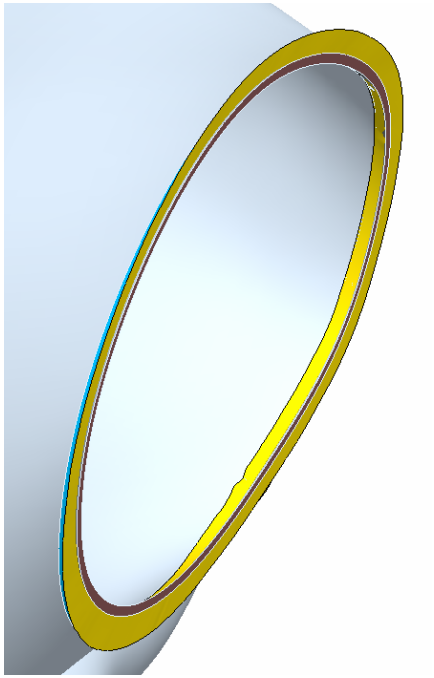




Typical as-built vessel flange geometry



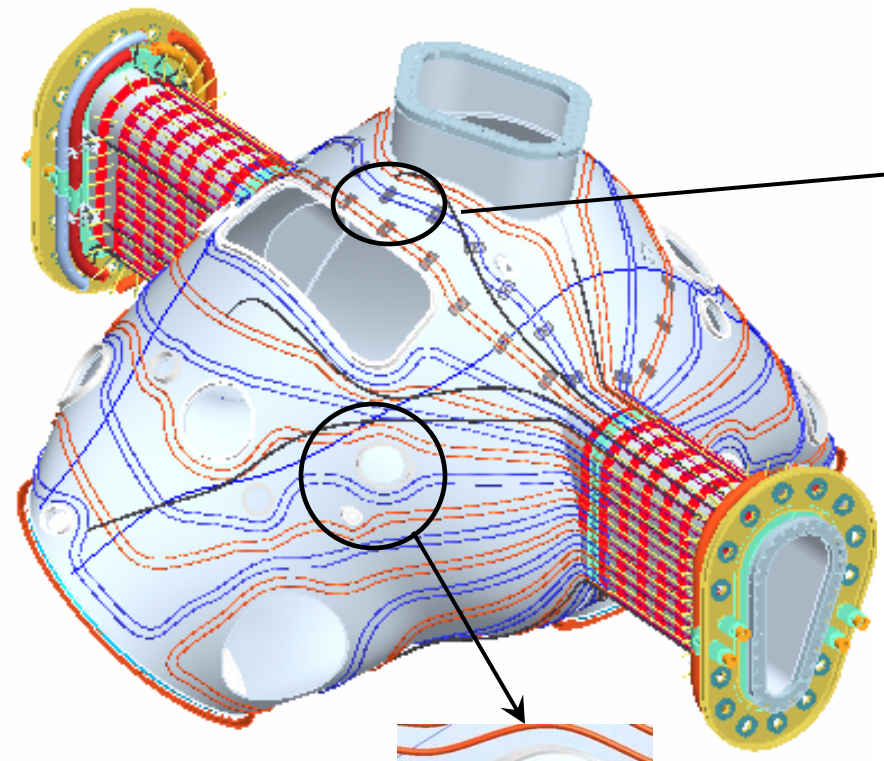




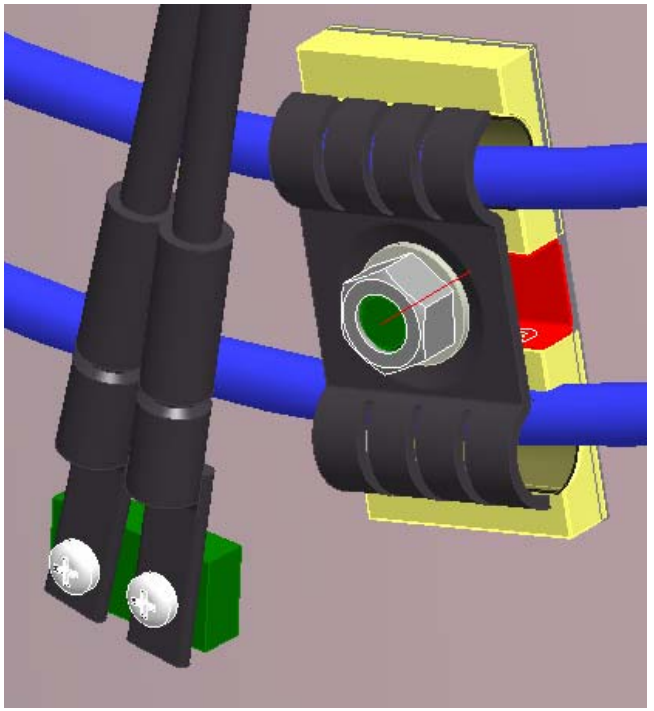
Left Side flange surface located -0.060” to - 0.090” into the nominal flange surface

Right Side flange surface located -0.020” to – 0.070” into the nominal flange surface

Measurements will also be taken to define location and size of critical surface offsets.



VV support boss and port stubs

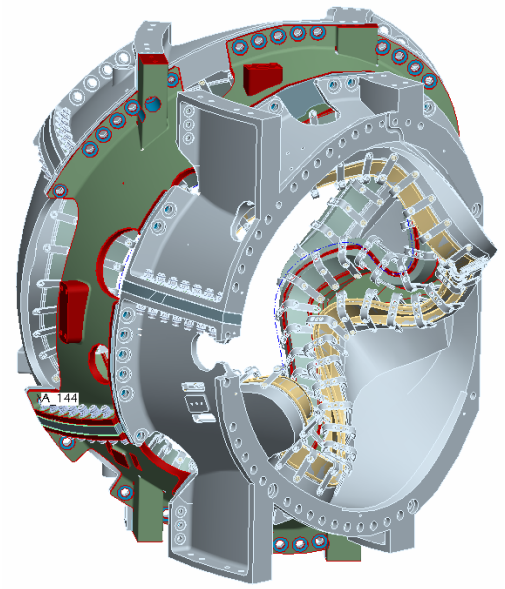


0.77” maximum offset from off VV measured on CAD model

MC Half Period Assembly – Stage 2

NCSX
National Compact Stellarator Experiment

BASIC REQUIREMENTS:



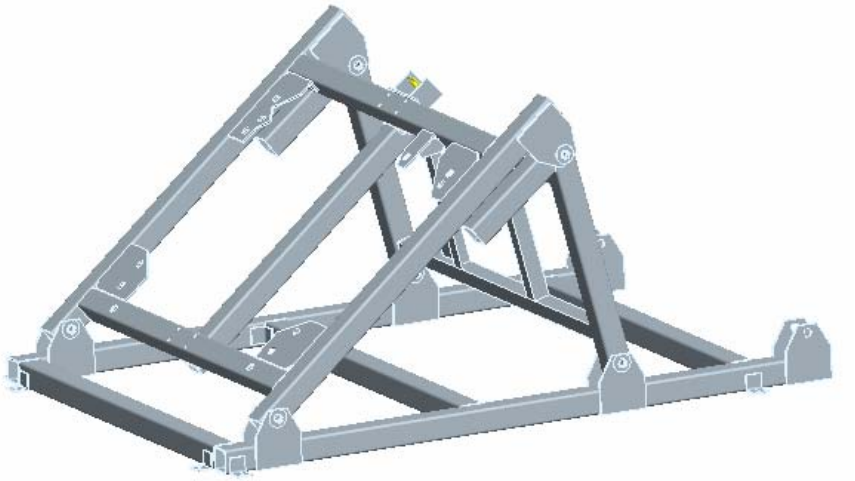
- Assemble Type A, B and C module coils.
- The assembly fixture must support the MC components and allow access to complete the flange fit-up and hardware installation.
- The final assemble tolerance for the completed MCHP is ± 0.010”.

MC Half Period Assembly – Stage 2

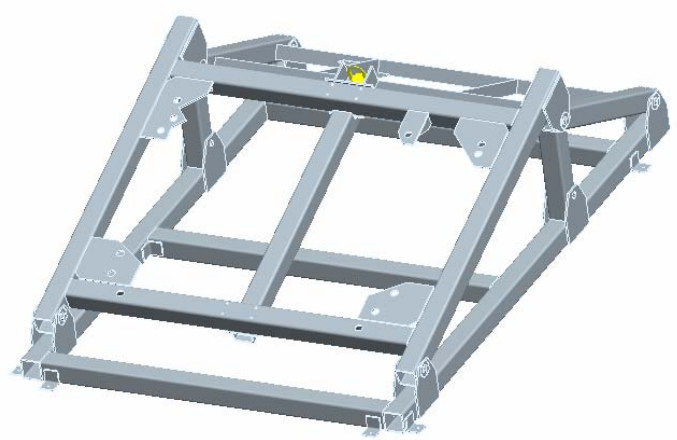
NCSX National Compact Stellarator Experiment

An adjustable support stand is used to support the Modular Coil Half Periods (Type A, B and C) as the individual coil windings are set on three precision adjusted spherical seats.

Structural weight: 4,000 lbs

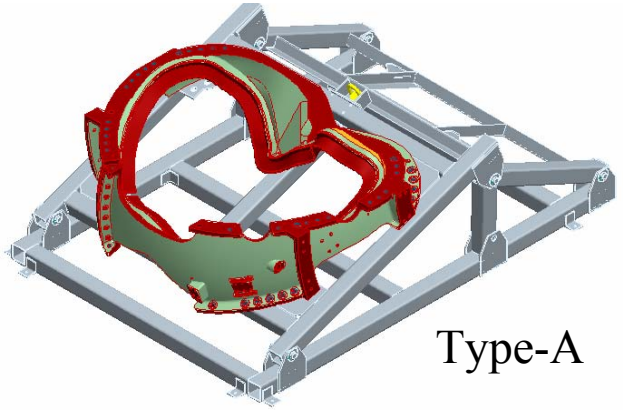


40° set-up to install Type-C

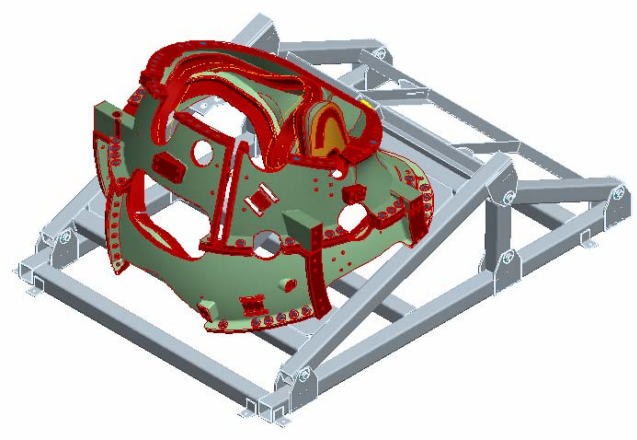


20° set-up to install Type-B

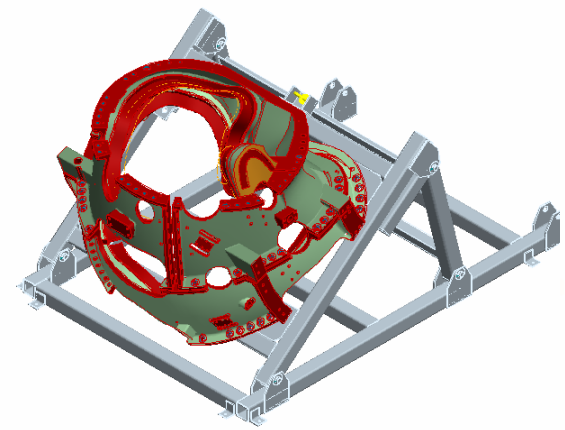
MCHP Assembly Sequence



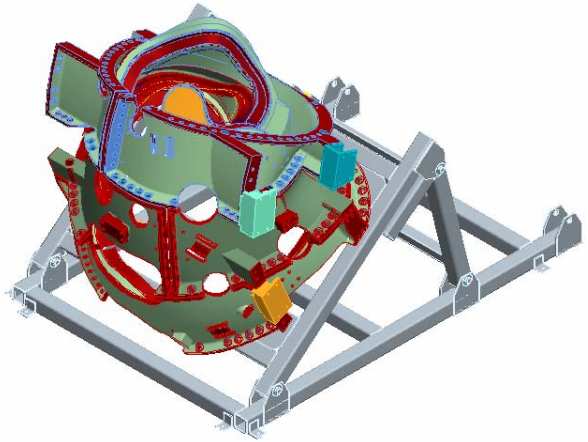
Type-A



Type-B on A

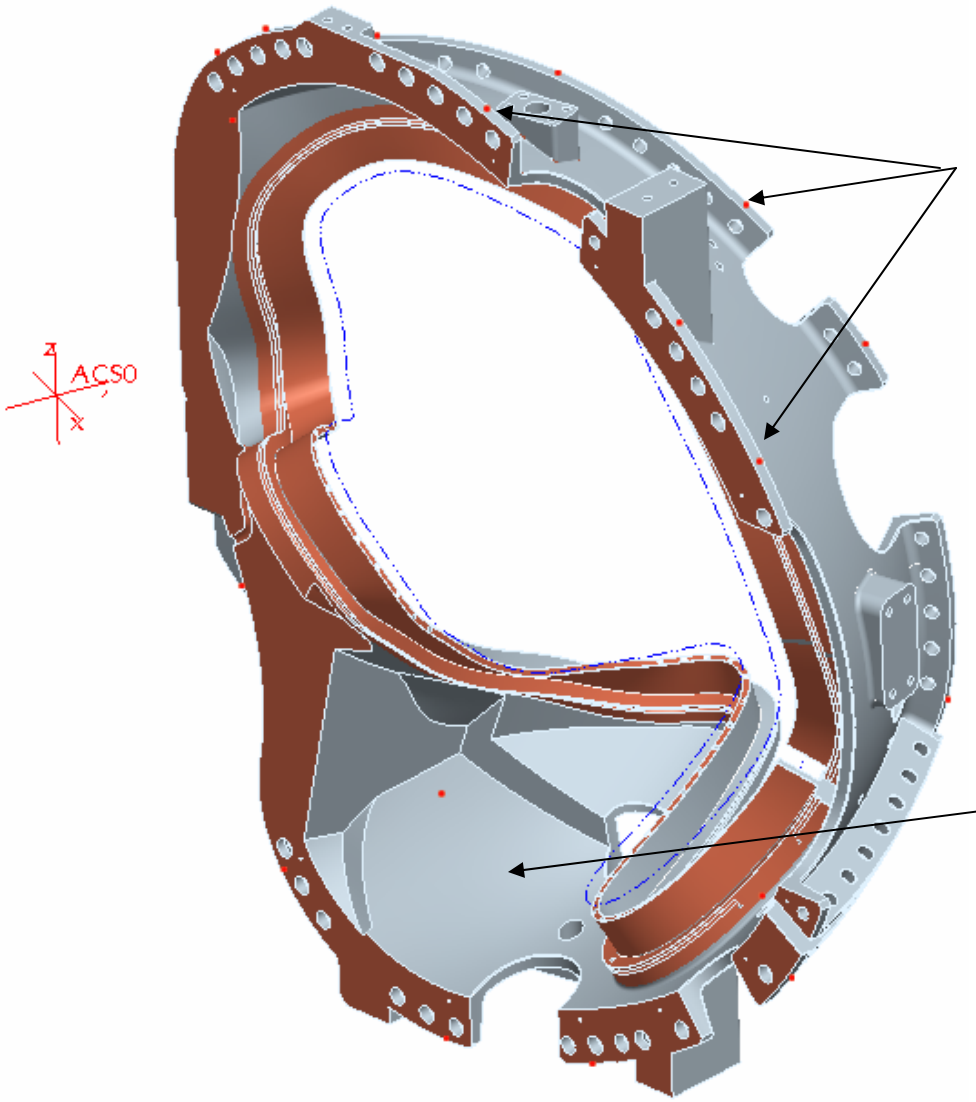


Stand repositioned to receive Type-C



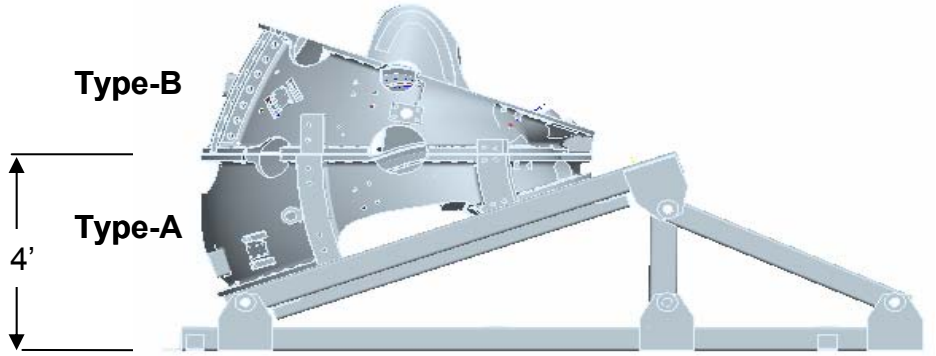
Type-C added along with supports

Metrology datum's locations

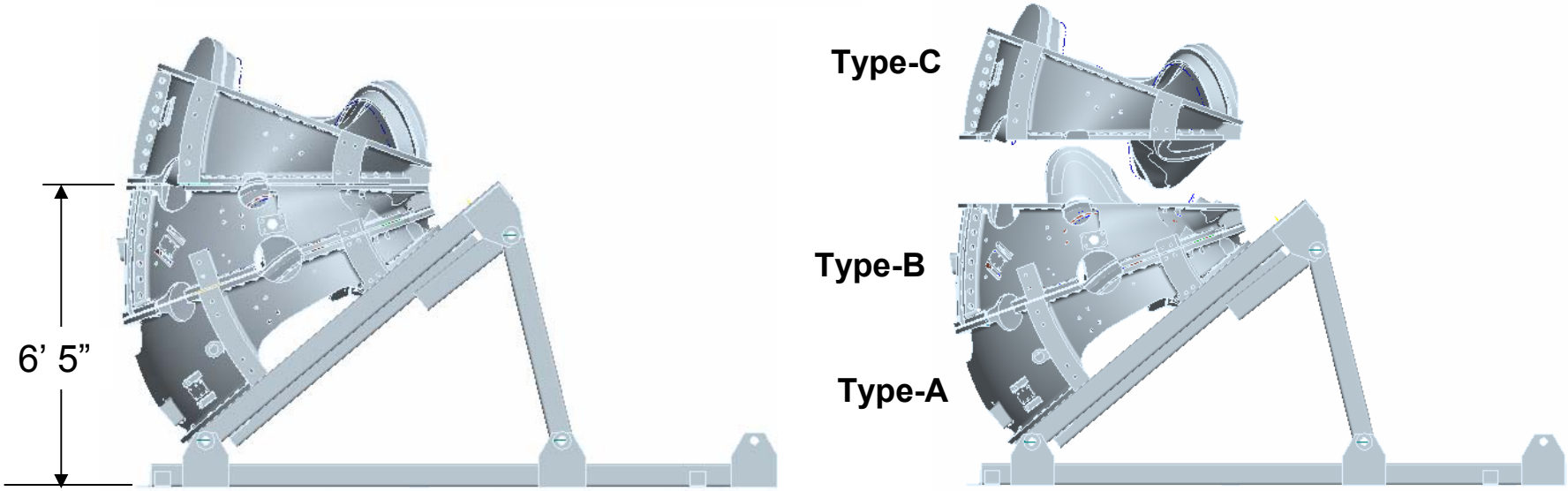


- 18 fiducial datum points are spaced around each MC flange
- Interior datum's were added on the inner surface for use in winding the modular coil

MCHP Installation



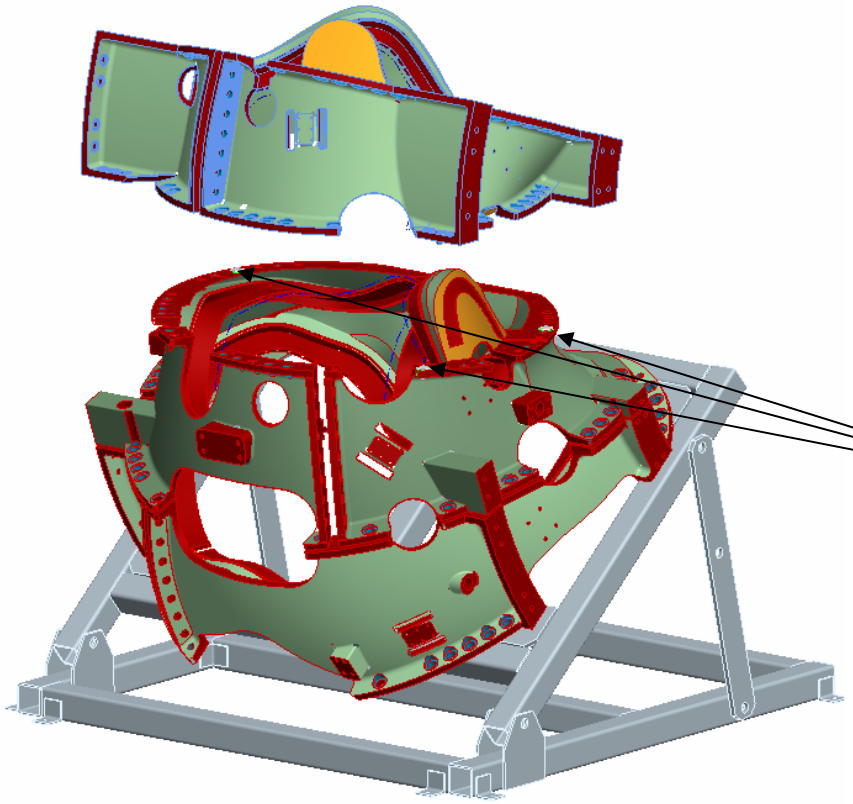
20° set-up to install Type-B

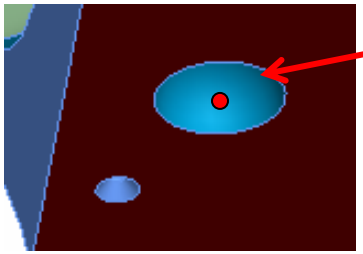


40° set-up to install Type-C

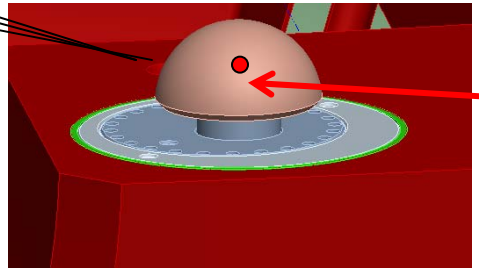
The MC position is set using a concentric spherical seat assembly

Three spherical seats are pre-adjusted for each Modular Coil based on metrology measurements of the winding and then manipulation of a CAD model assembly.



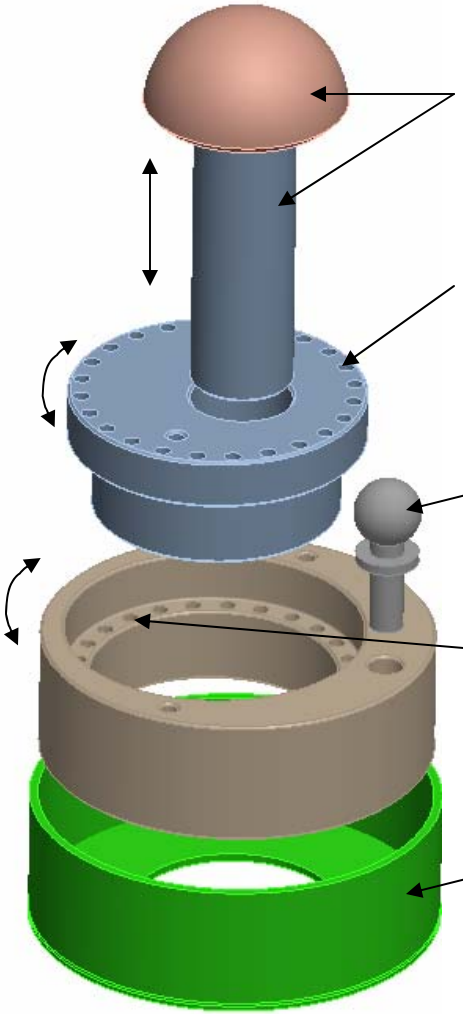


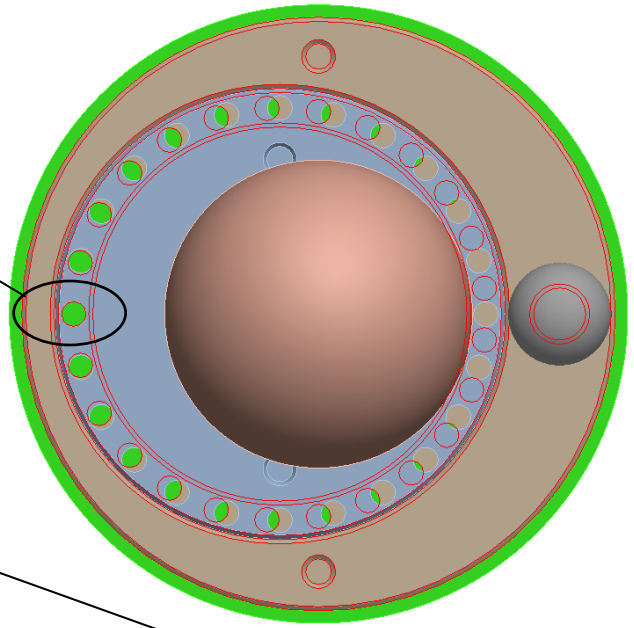
Female side spherical seat.

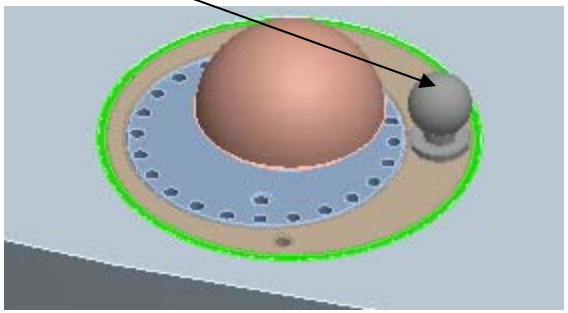


Adjustable male spherical seat

Spherical seat assembly details

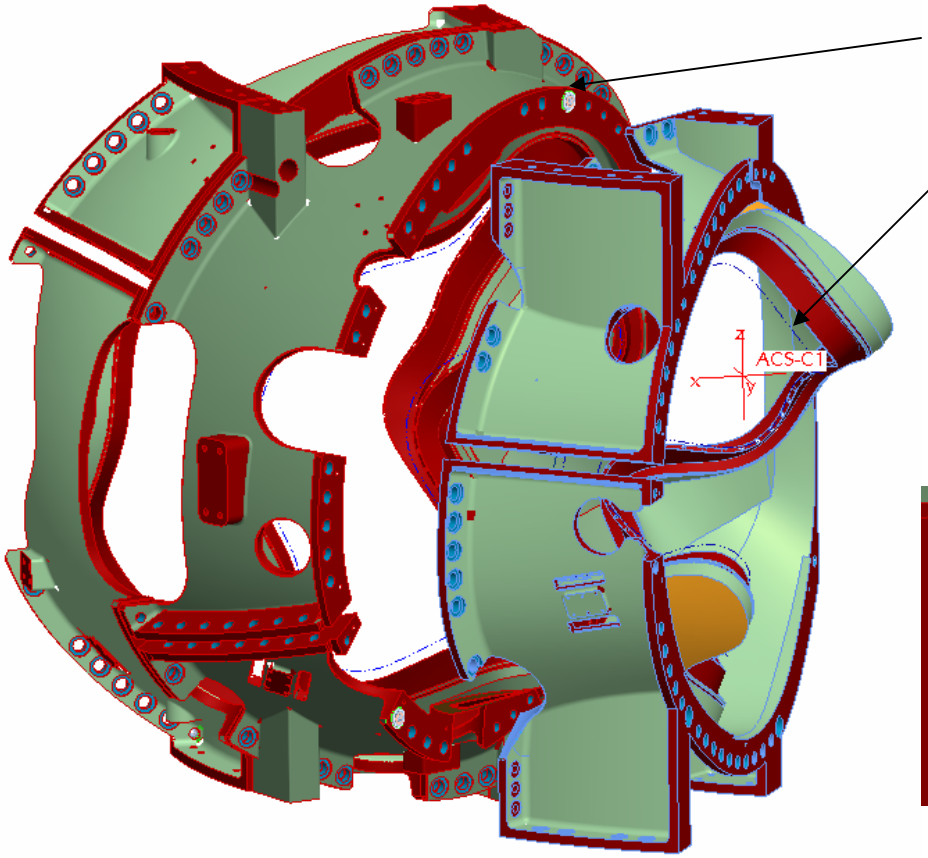




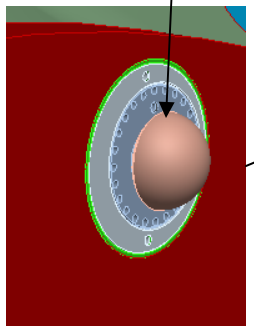


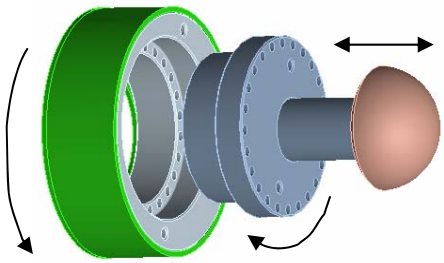
FPA CAD model used in the assembly process

All 18 MC's will be set to match the measured metrology data and spherical seats will automatically adjust in the CAD model to the correct position to align male and female interfaces.



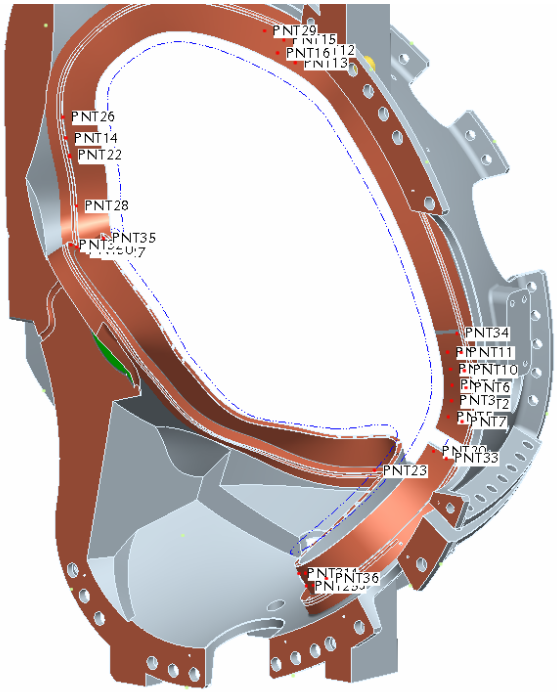
Setting the individual coordinates system results in spherical seat motion which defines pin location and position of outer cylinder and ball/stud assembly.





How accurate are the fabricated MC's

MC geometry is set by best-fit of Tee data

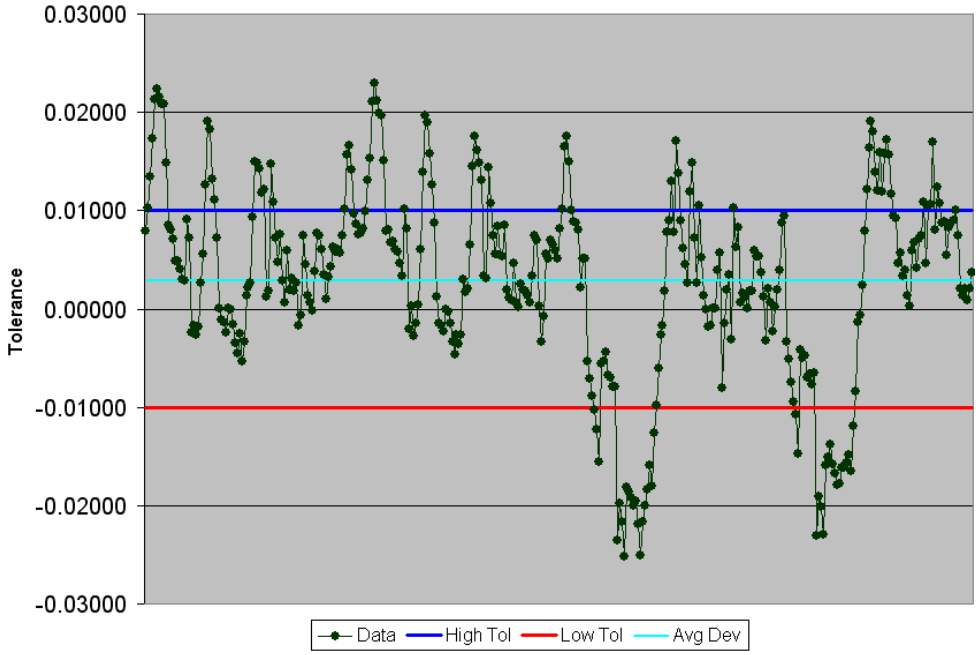


MC B1 Inspection

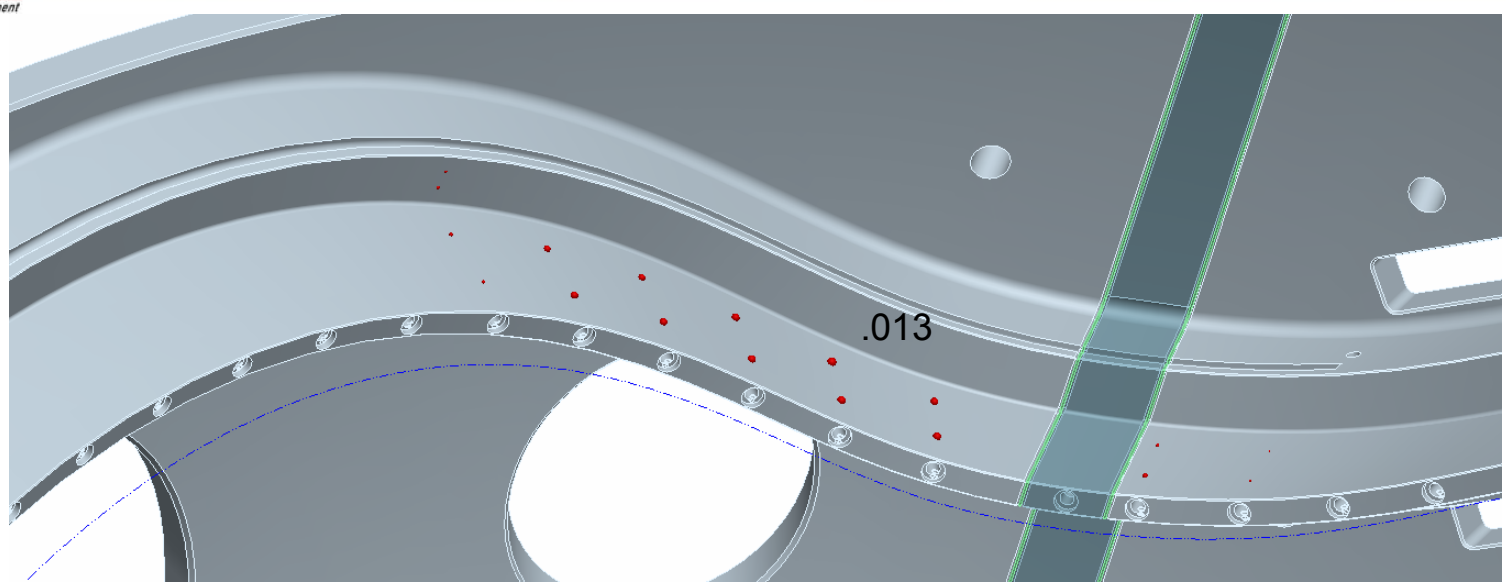
Profile of M to MI: 114 point are OOT out of 362 sample points.

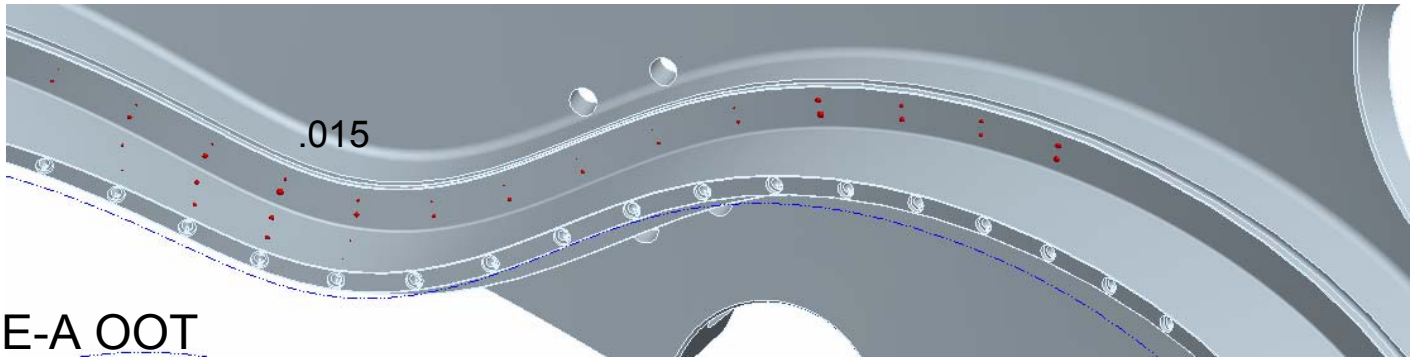
Max + = 0.0129" OOT

Max - = -0.0152" OOT



Local detail of B1 Tee area OOT points



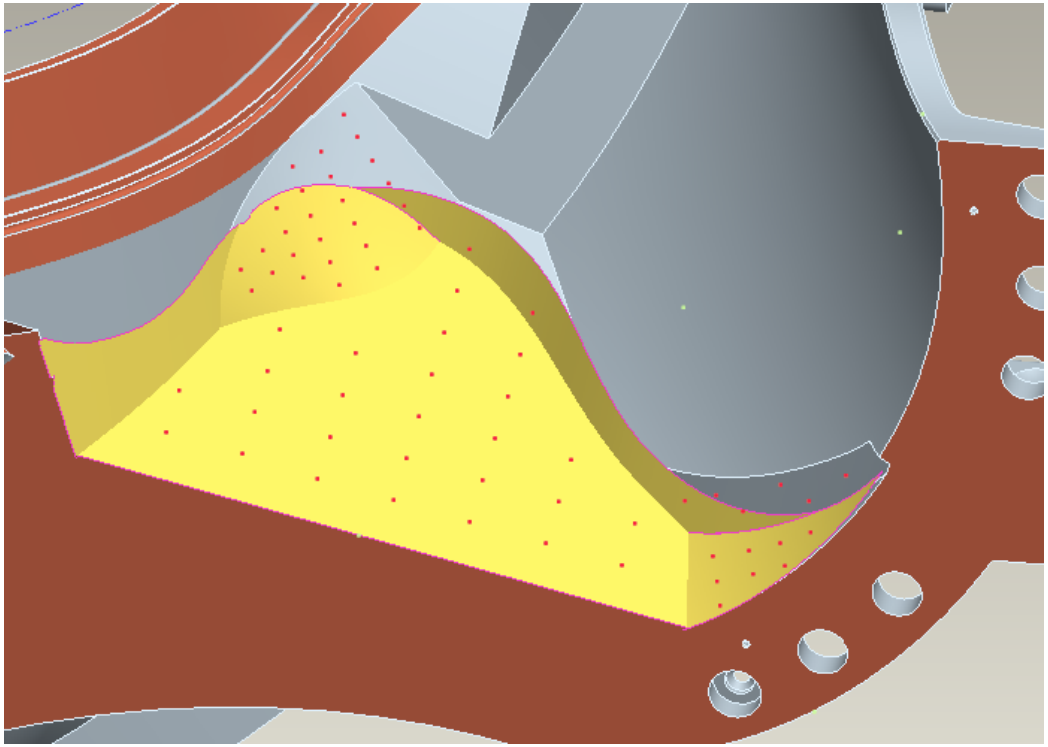


M-M1 SIDE-A OOT

Once a best fit of the Tee is made all interfacing surfaces are evaluated

NCSX
National Compact Stellarator Experiment

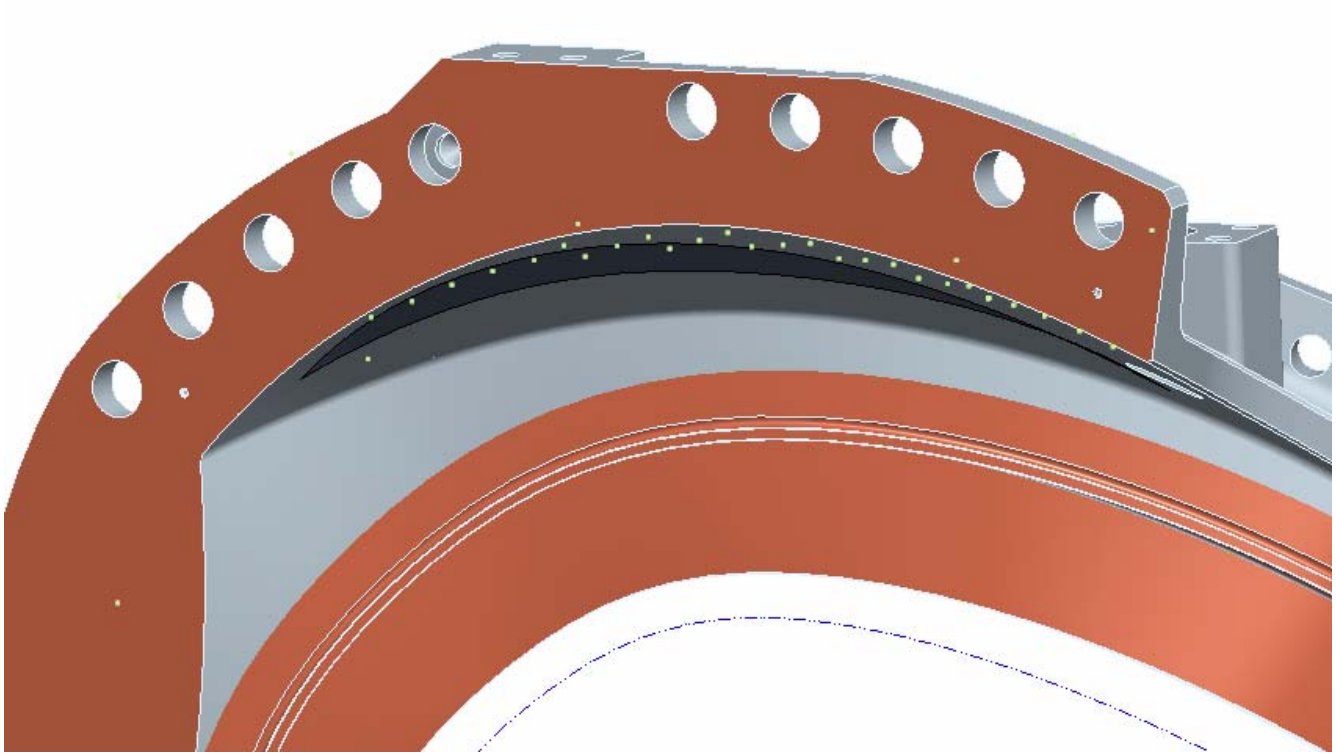
SIDE-A INNER POCKET +0 / -.12



MC Type-A to Type-B large wing pocket interface clearance is 0.358” in the CAD model.

MC Type-A to Type-B small wing pocket interface clearance is 0.445” in the CAD model.

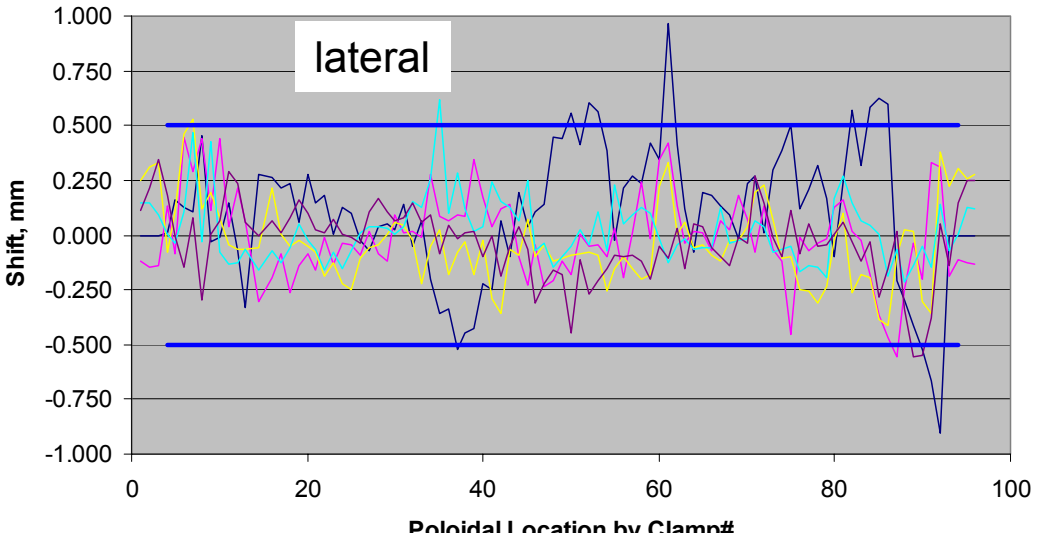
NCSX
National Compact Stellarator Experiment

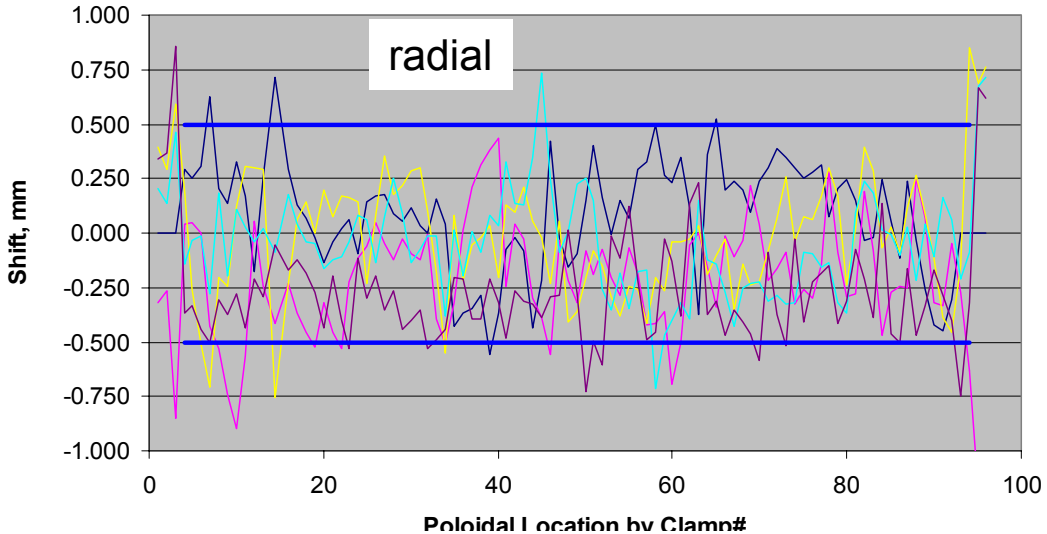


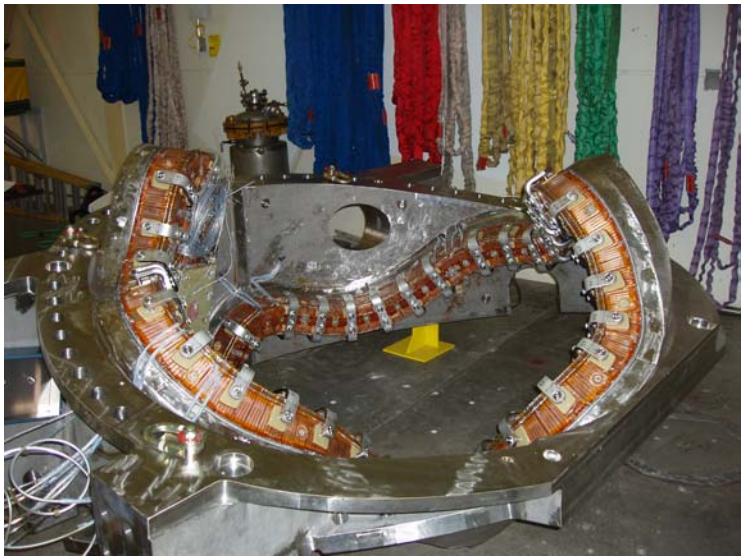
Coil Construction Achieves ±0.5 mm Accuracy

NCSX National Compact Stellarator Experiment

Current Center Position Error (5 Coils)







5 Coils Have Been Completed

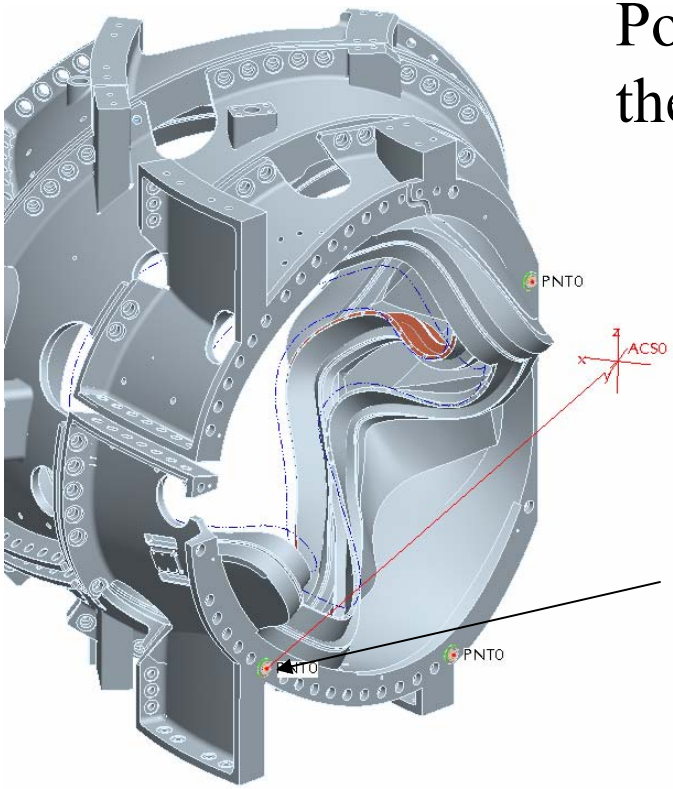
Coordinate system realignment

NCSX
National Compact Stellarator Experiment

Coils are realigned as a group to minimize field errors

	Origin (inches)			Orientation (degrees)		
	X	Y	Z	About X	About Y	About Z
C1r2	0.00496570	-0.00337040	0.00488230	0.00337396	-0.00057835	-0.00167491
C2r2	-0.00302021	-0.00392354	-0.00412903	0.00786915	-0.00057131	-0.00144236
C3r2	0.00090761	0.00435469	-0.00327171	0.00310577	0.00302650	-0.00194060
C4r2	0.00389920	-0.00001208	-0.01071775	-0.00124067	0.00979748	-0.00195675

Impacted of coil realigment



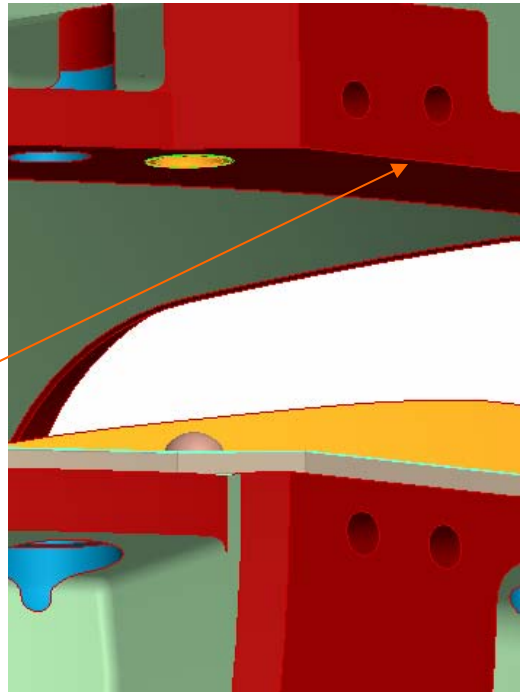
Positional change of a spherical seat on the Type-C coil from coil realignment.

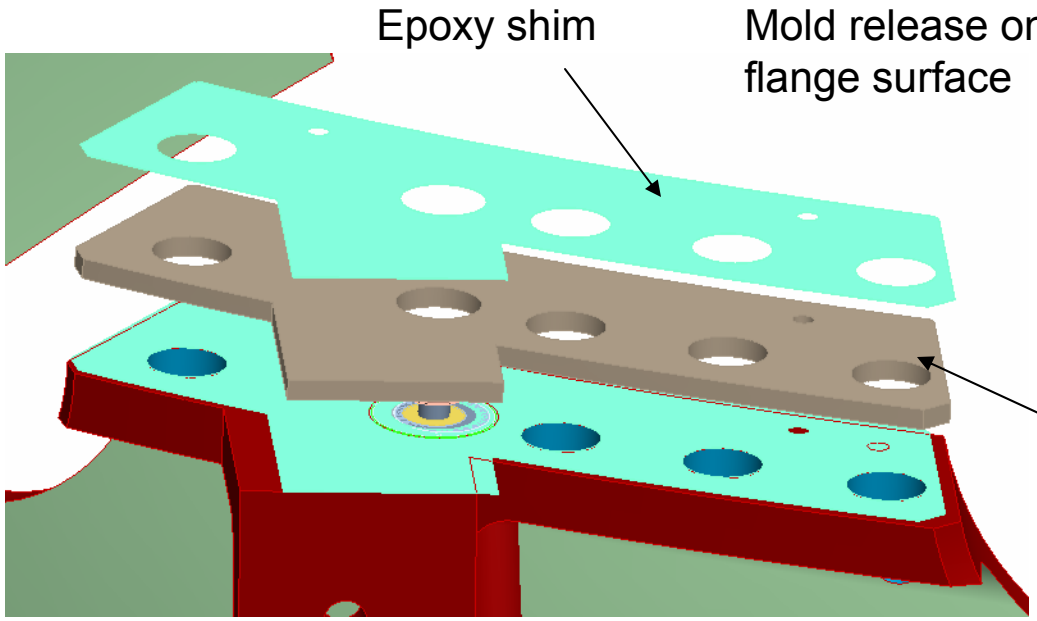
C4 coils realigned as a group

	X	Y	Z
C4 – reference	37.9221	66.1831	-29.0206
C4 – realigned	37.9234	66.1812	-29.0393
▲	0.0013	0.0019	0.0187

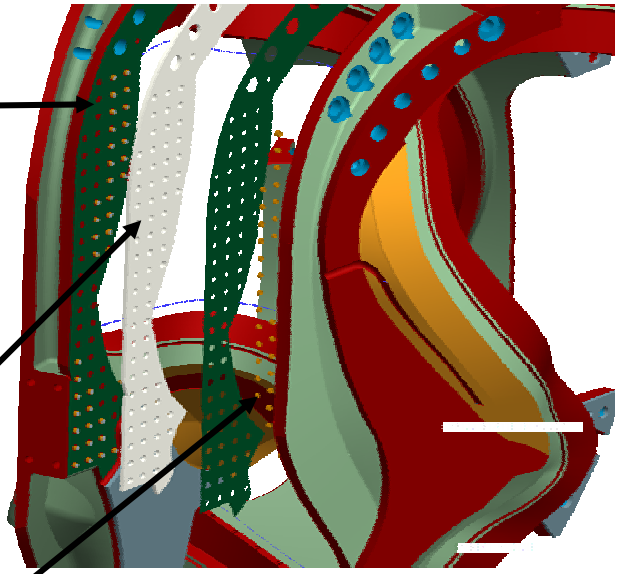
MCHP Flange Interface

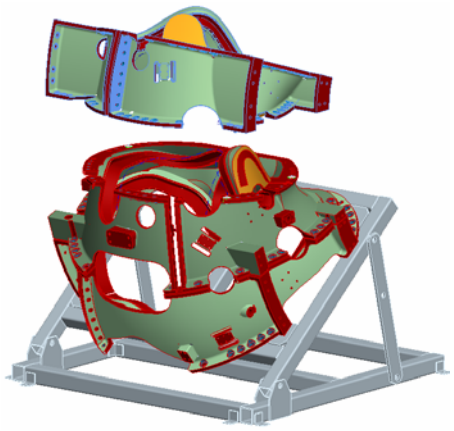
The flange interface requires accurately mated spherical seats with a nominal ½" flange gap that is closed by shim material. A liquid shim option is being considered.

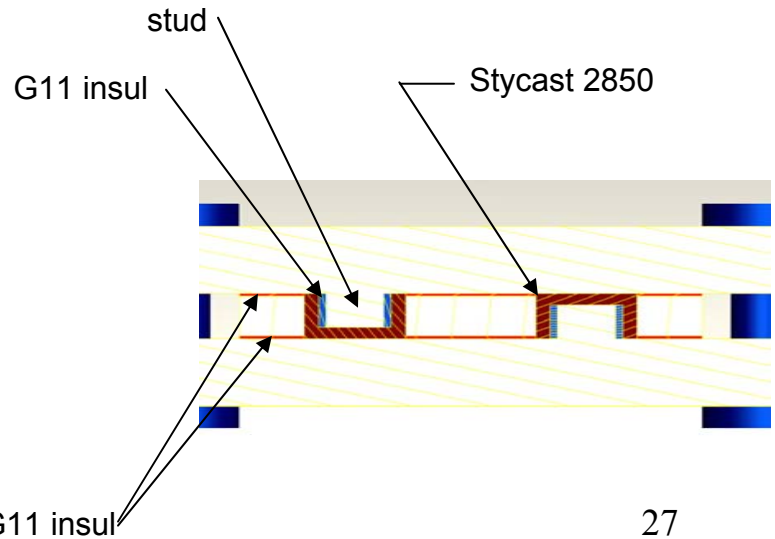




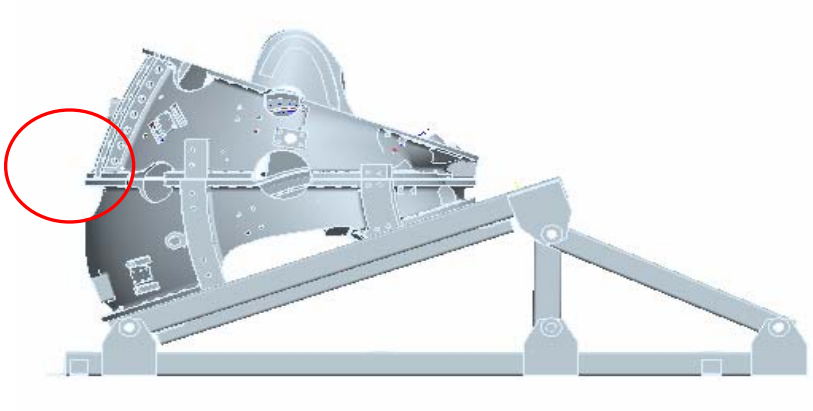
Inboard shims provide shear path for loads on the coil flange where bolting is not practical.



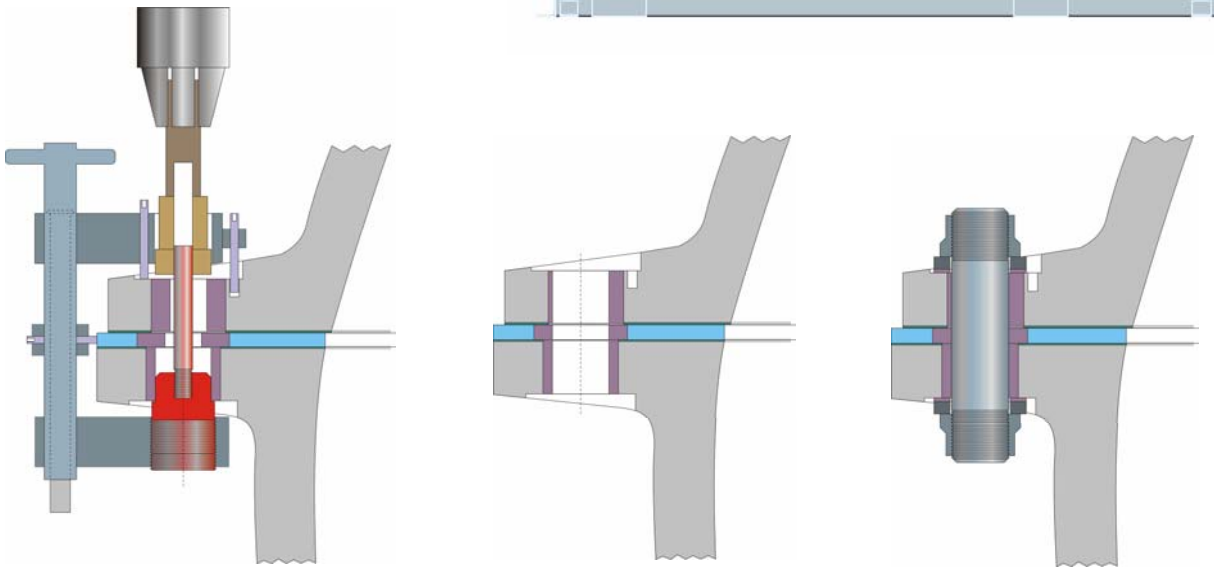




Stage 2 will facilitate hole reaming operation

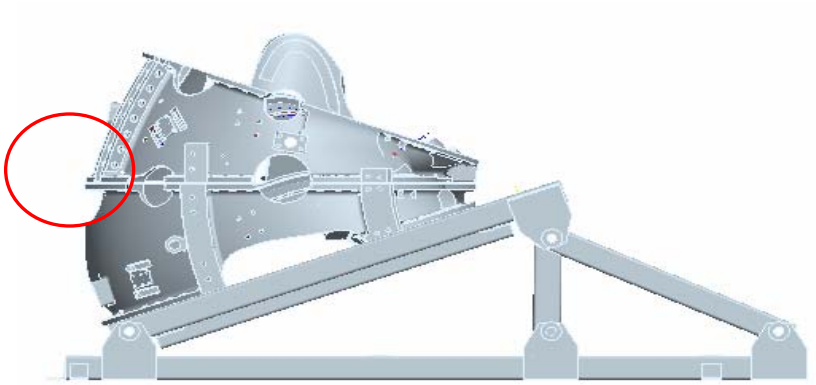


Thru bolt configuration

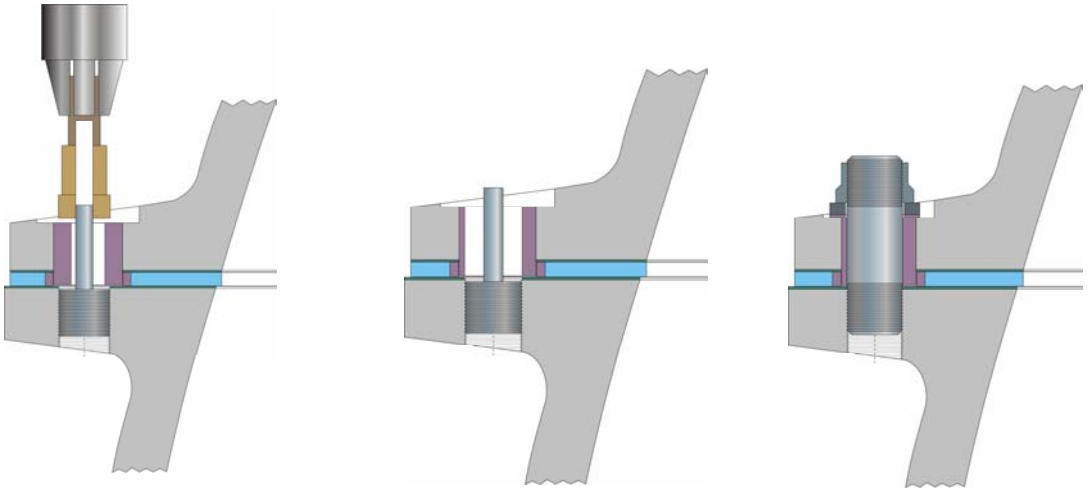


Stage 2 will facilitate hole reaming operation

Temporary fasteners at spherical seat locations will be used to fix flange surfaces.



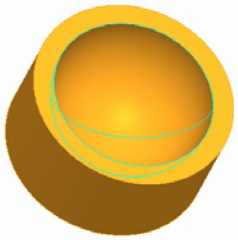
Tapped hole configuration

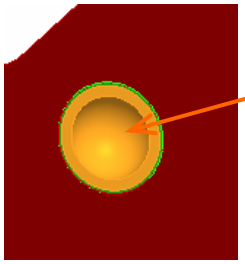


Coil alignment is being considered using a sphere, flat and Vee

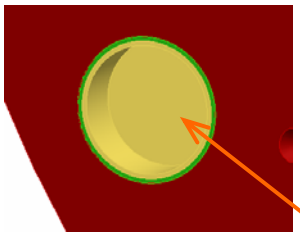
NCSX
National Compact Stellarator Experiment

Sphere



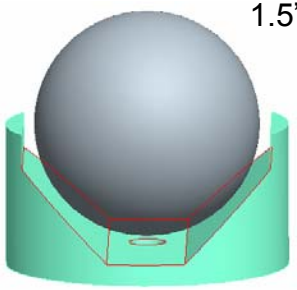


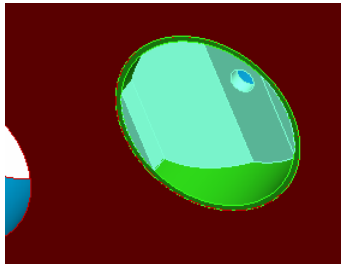
Flat

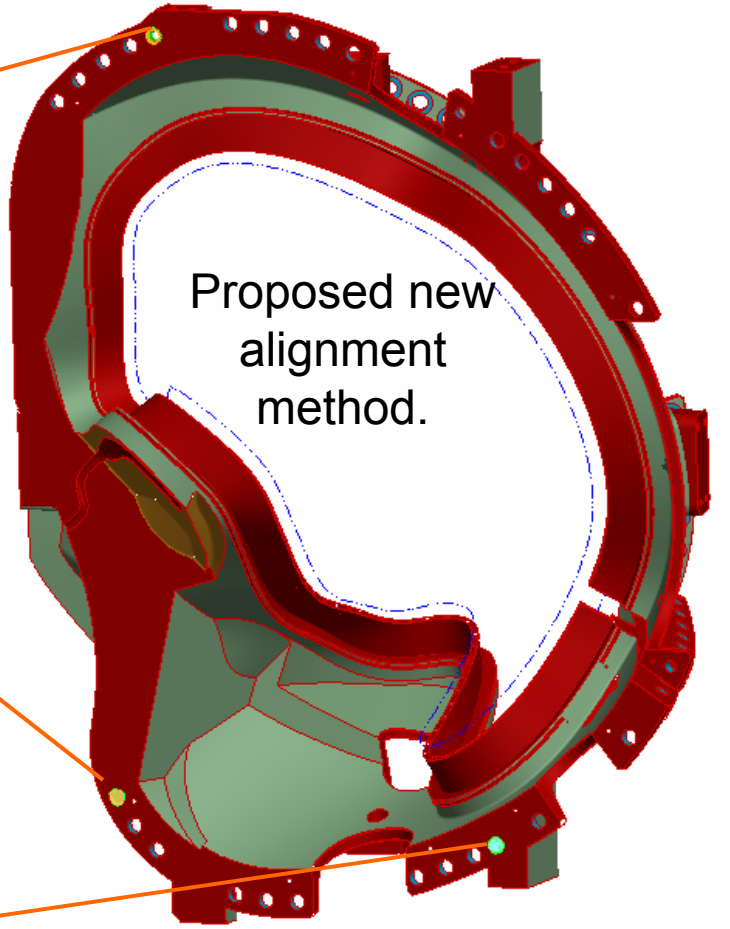


"V"

1.5" Ø

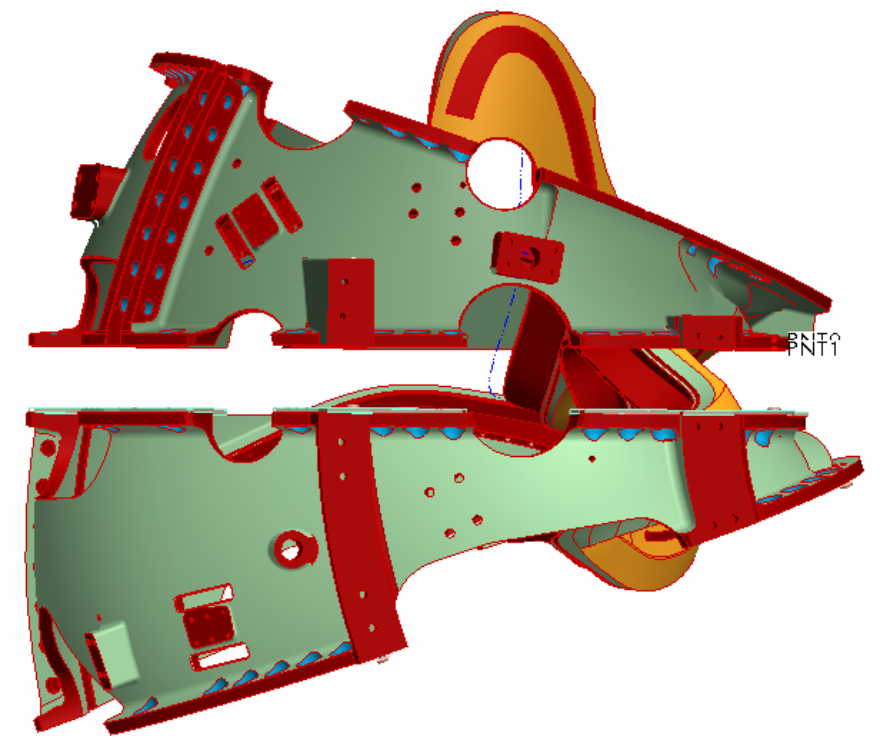


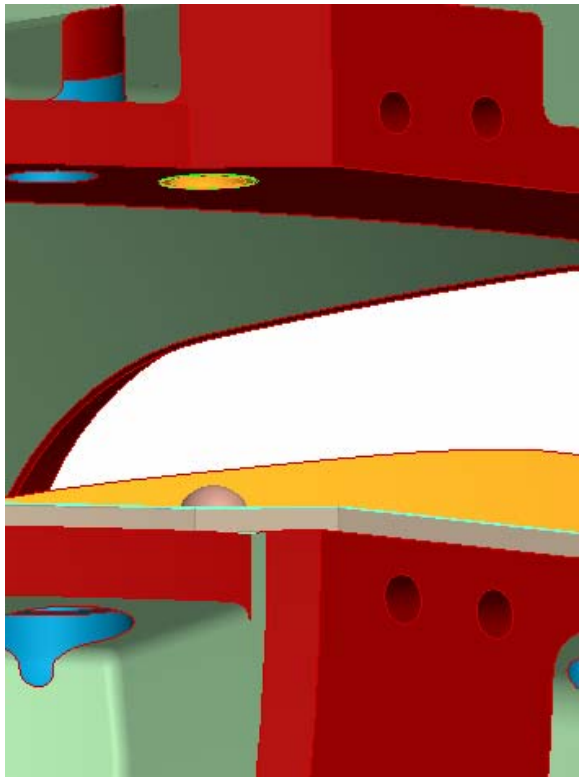




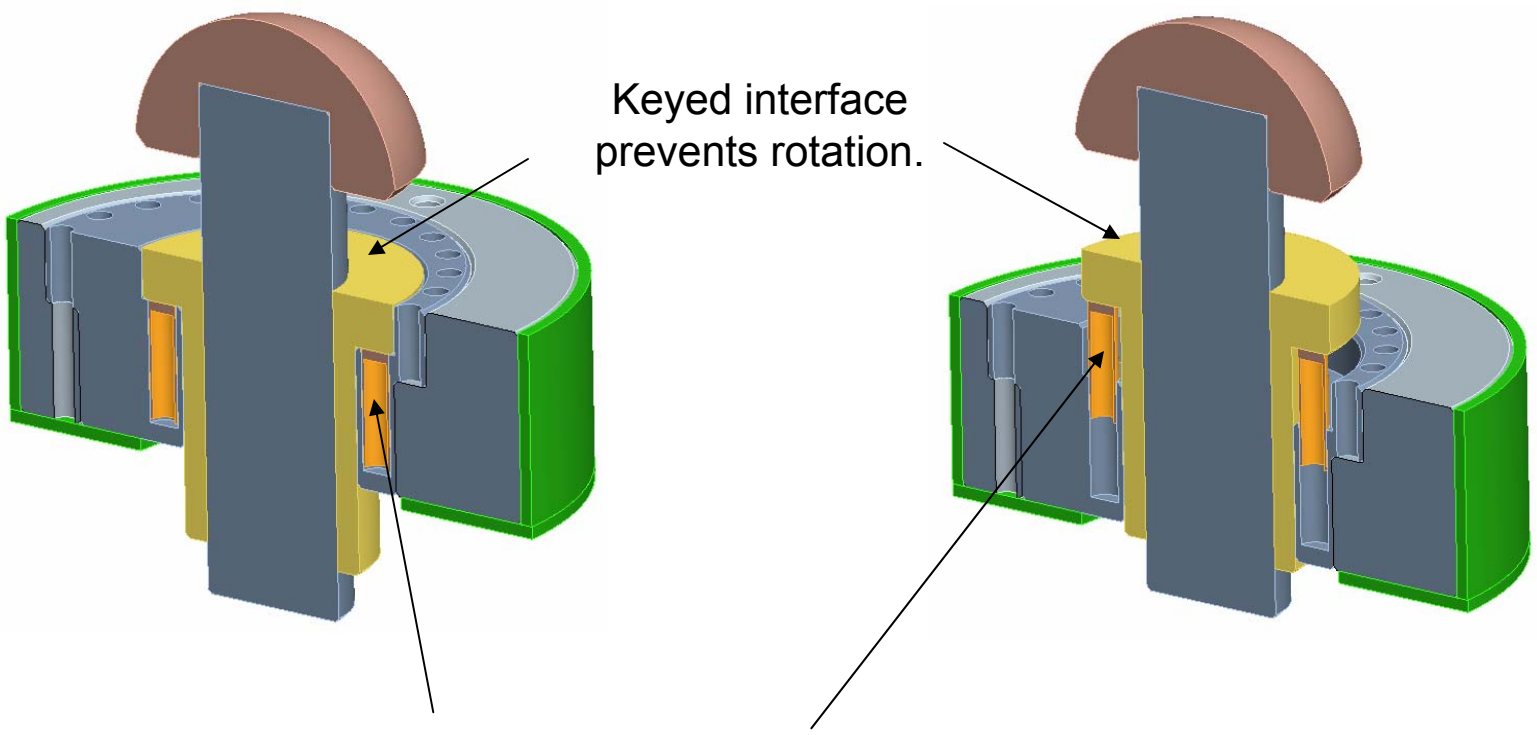
Spherical seats must interface without shim interferences

NCSX
National Compact Stellarator Experiment



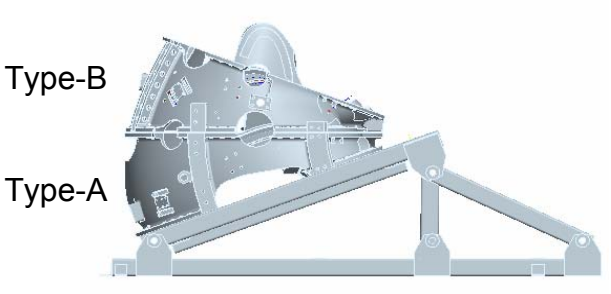


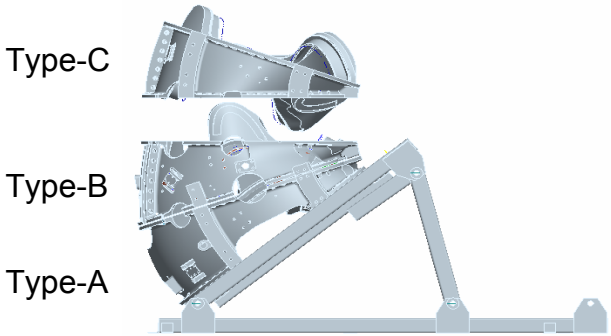
Spherical seats spring loaded interface



Captured precision compression springs provides an additional 3/8” extension above flange shims to aid alignment.

MCHP installation sequence summary

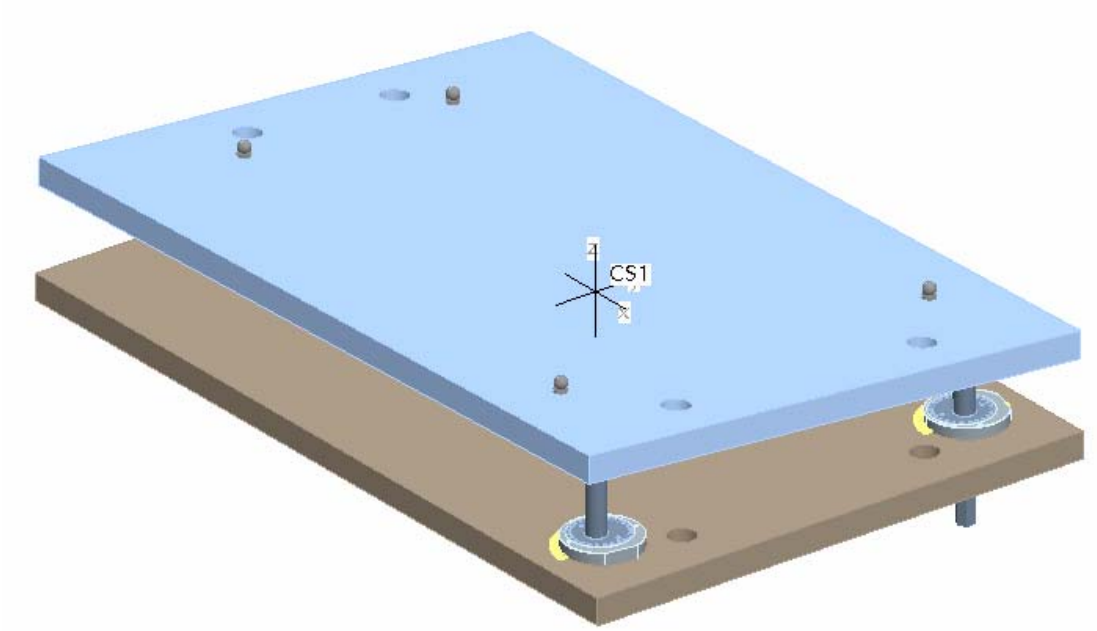




- Set stand at 40° position
- Attach Type-A MC to stand
- Take metrology measurements of Type-A using flange fiducials
- Set spherical seats based on CAD model with spring locked in place (solid)
- Set Type-B on spherical seats & measure position
- Measure flange gap to check shim machine cut
- Remove Type-B modular coil and unlock spherical seats on Type-A
- Place flange shim assemblies on Type-A flange
- Reinstall Type-B and verify position is correct.
- Ream holes, bolt flanges and inject epoxy at inner shims.

MC HP Assembly – R&D Activity

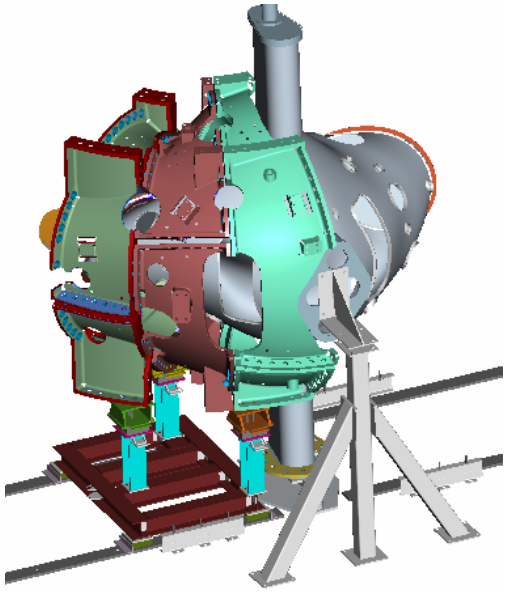
A pair of 20” x 30” plates with three spherical seat assemblies have been fabricated. They will be used to test our ability to set the alignment of the plates and accuracy measure their position using our Leica laser metrology system.



MCHP installation over VV period – Stage 3

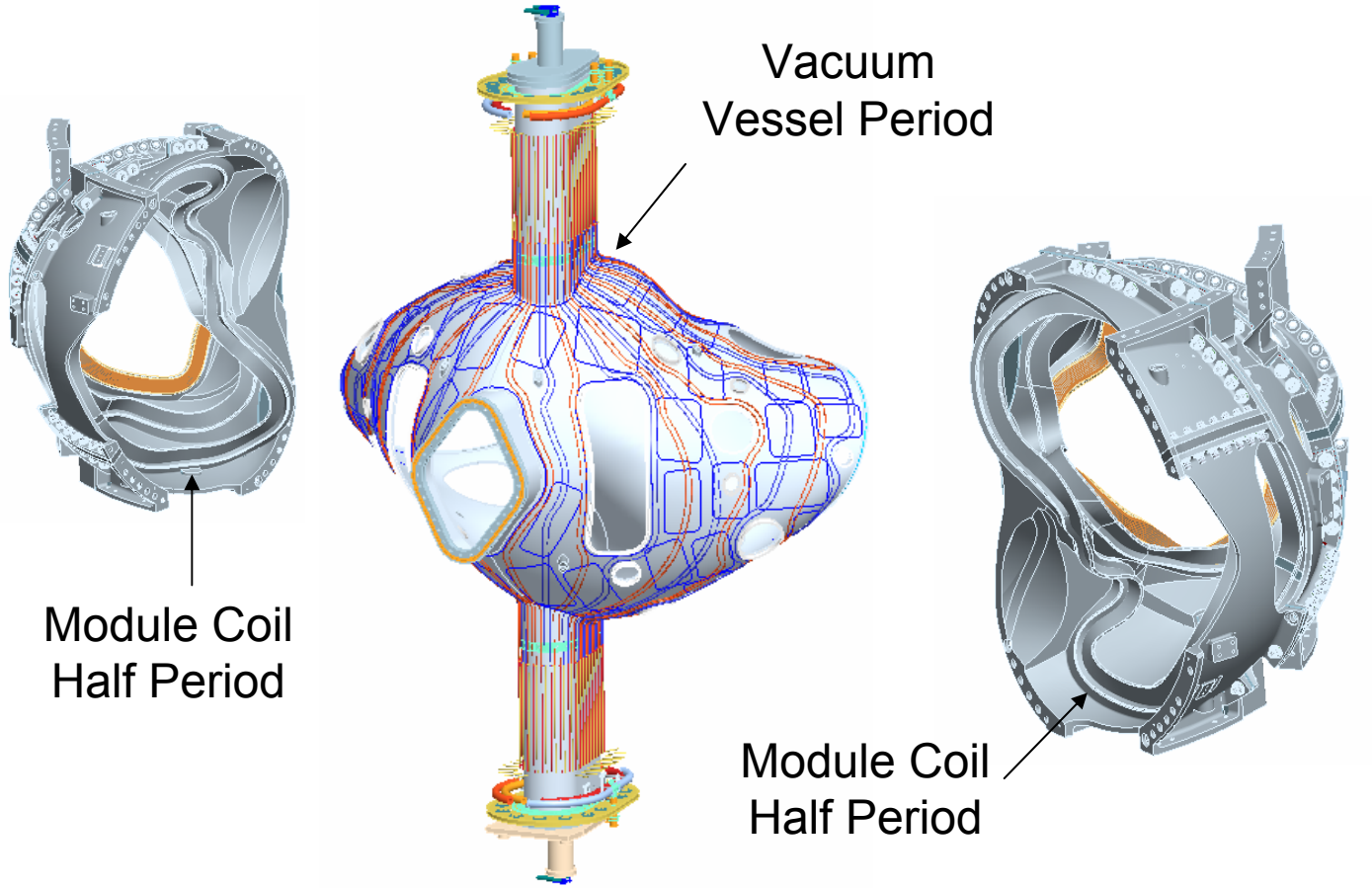
NCSX National Compact Stellarator Experiment

BASIC REQUIREMENTS:



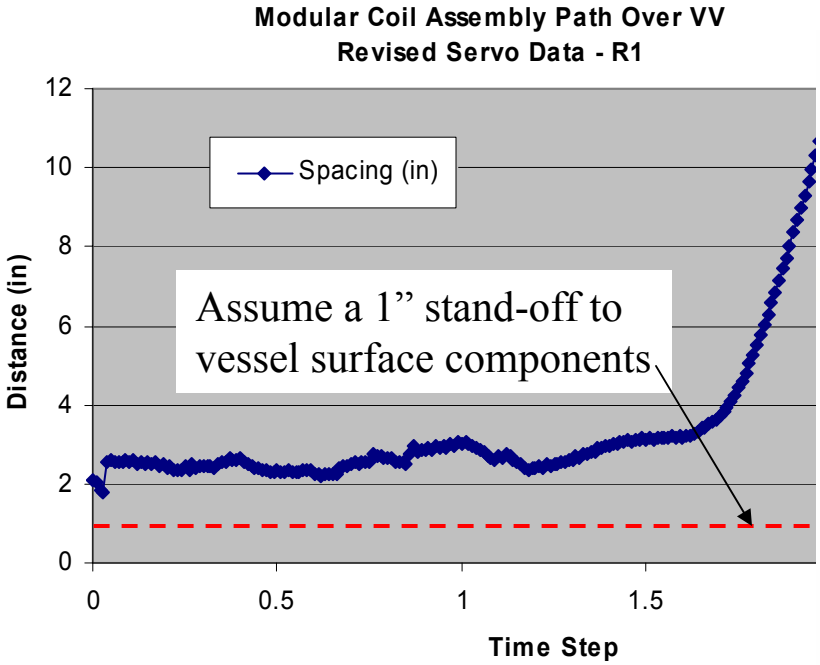
- Provide a stable VV support system.
- Provide a method for rotating a MCHP over the VV without interferences.
- Provide for temporary support for each MCHP to set Type-A flange interfacing components.
- The final tolerance for the completed assembled MC period is ± 0.020”.

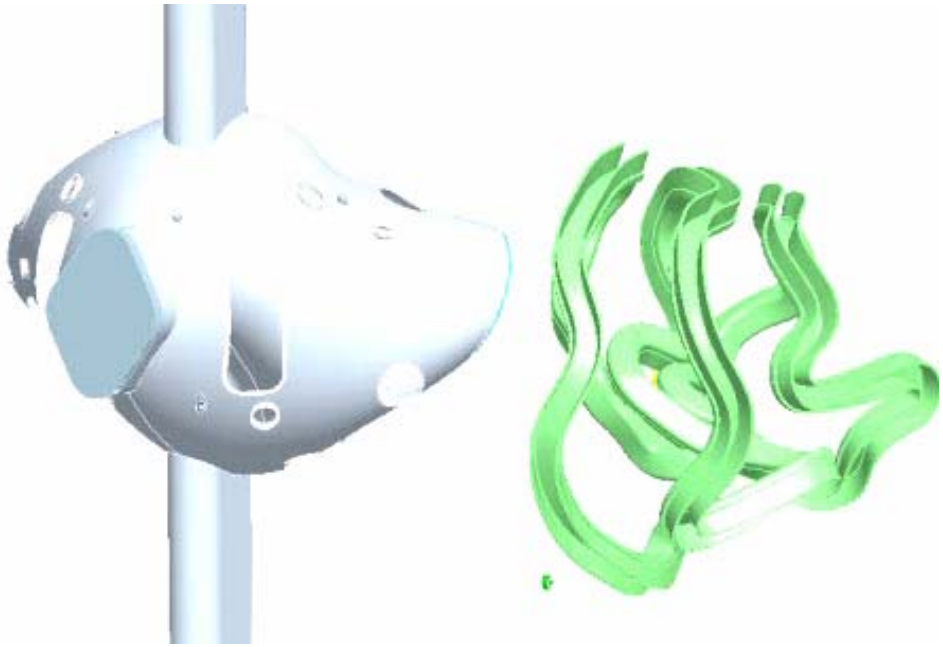
The design intent for Stage 2 is pass two modular coil half period assemblies over the VV and accurately position mating flanges…without hitting the VV.



The MCHP must follow a prescribed path

The 24,000 lb MCHP must move over the VV field period within a prescribed assembly path.

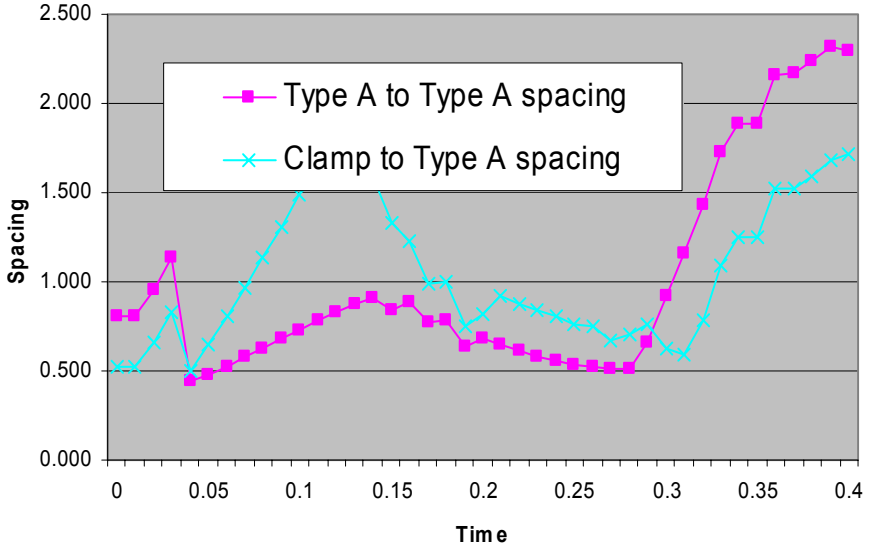




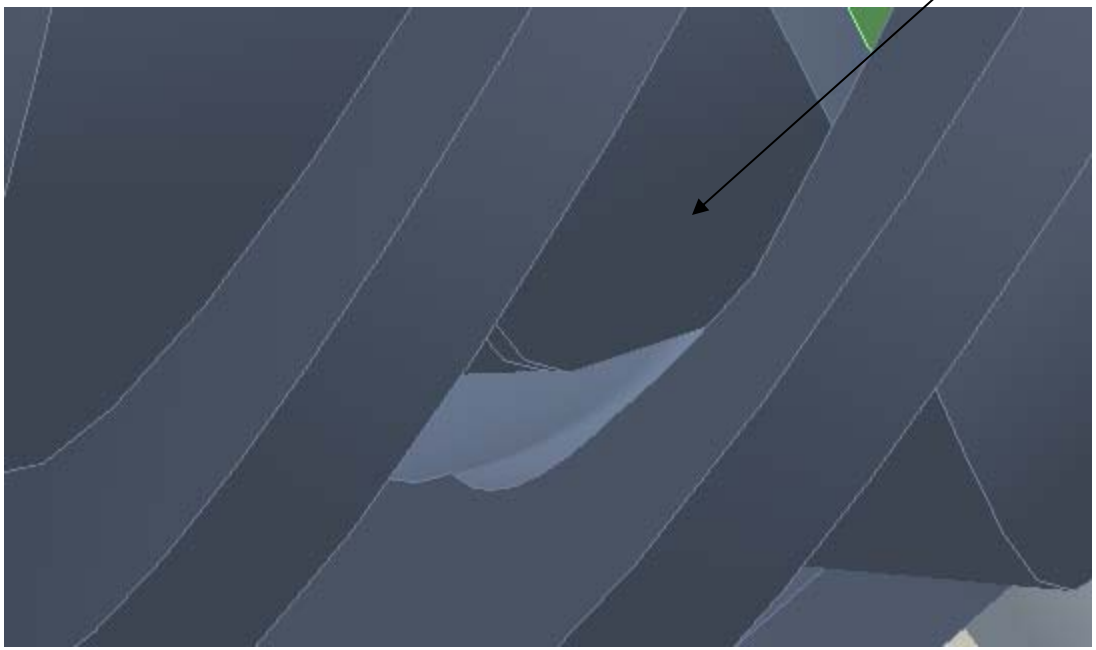
An assembly path has been established that maximizes the VV/MCHP distance.

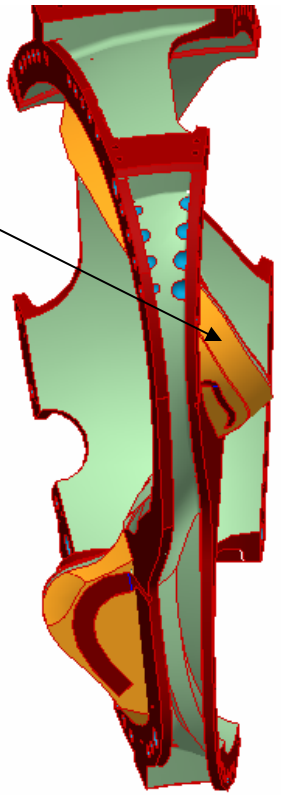
MC to MC Clearance

A 0.45” minimum clearance exists between wing region of Type A’s as the two half period MC shells comes together.

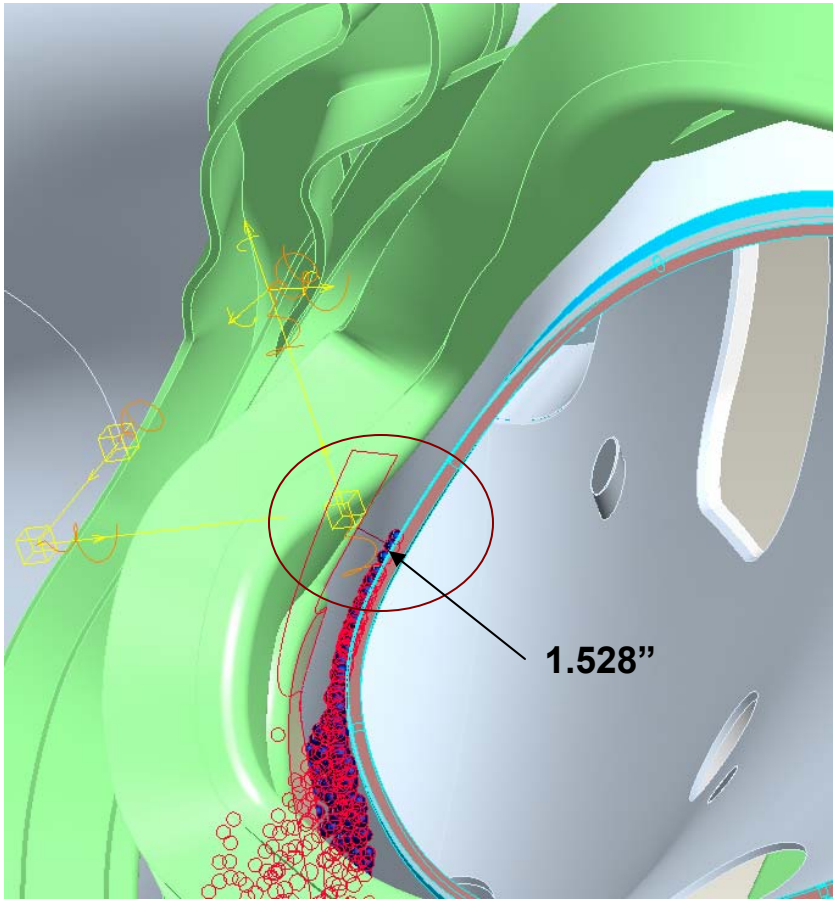


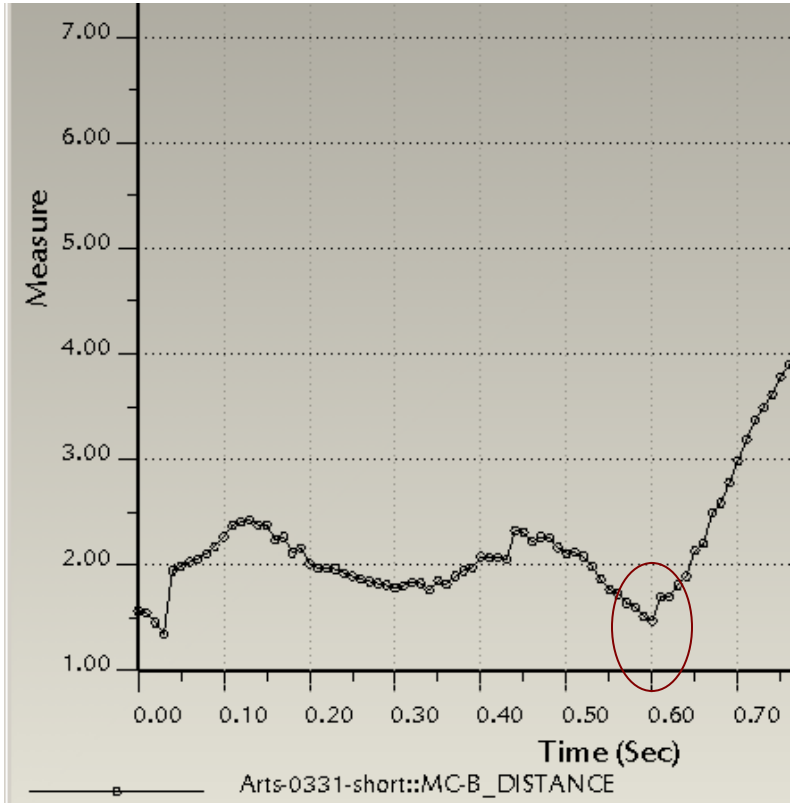
Wing region



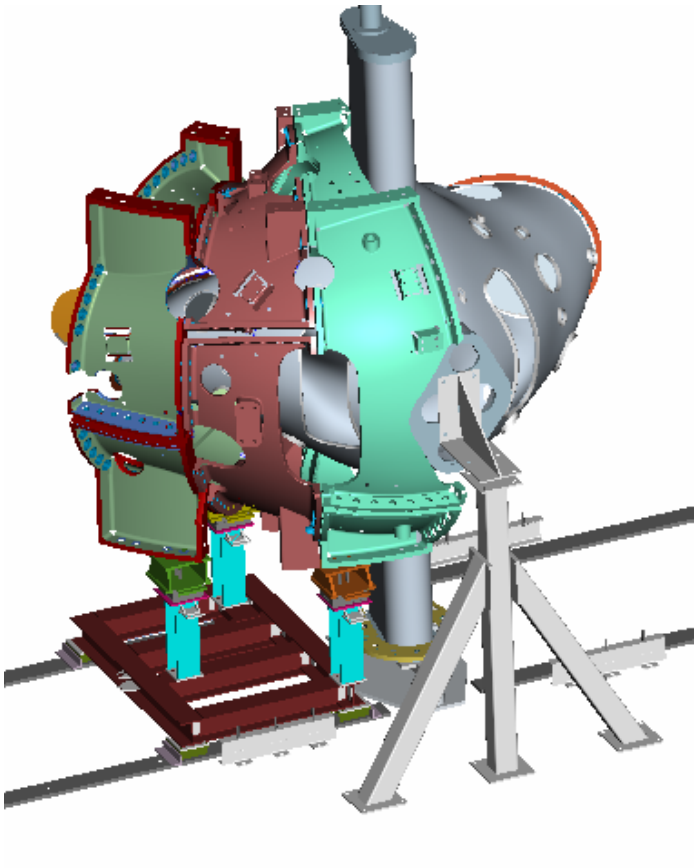


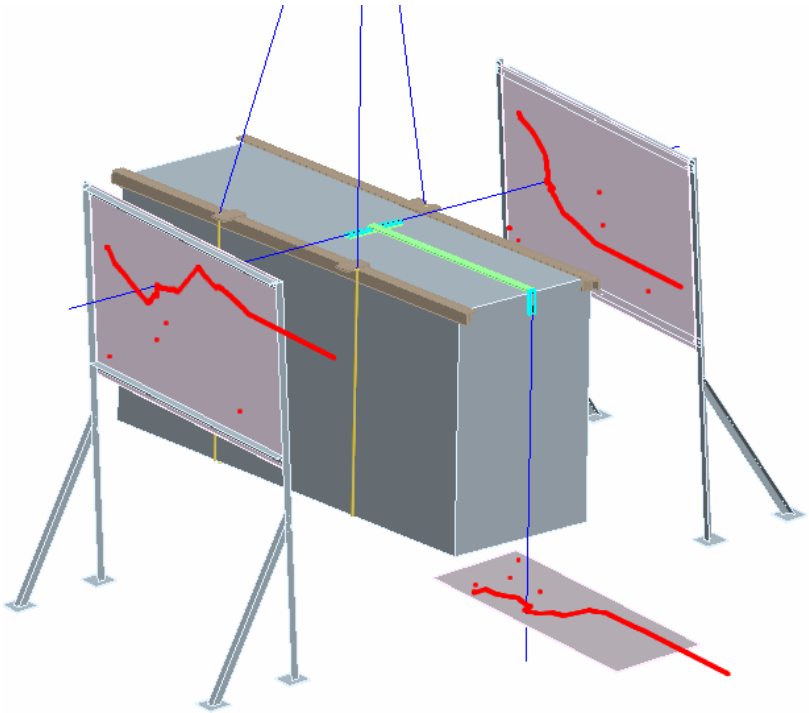
Type B distance to shell off-normal points is 1.53” at the 60% step





R&D activities were used to help developed the Stage 3 assembly approach.

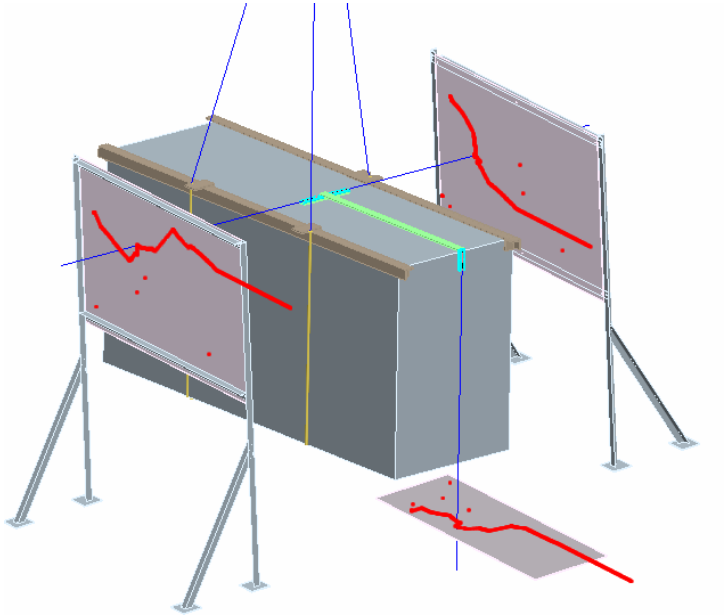




Crane Supported – hand assisted assembly

MC Installation Development Activity

MC crane assisted assembly simulation was set up using a concrete block with three lasers mounted to it.



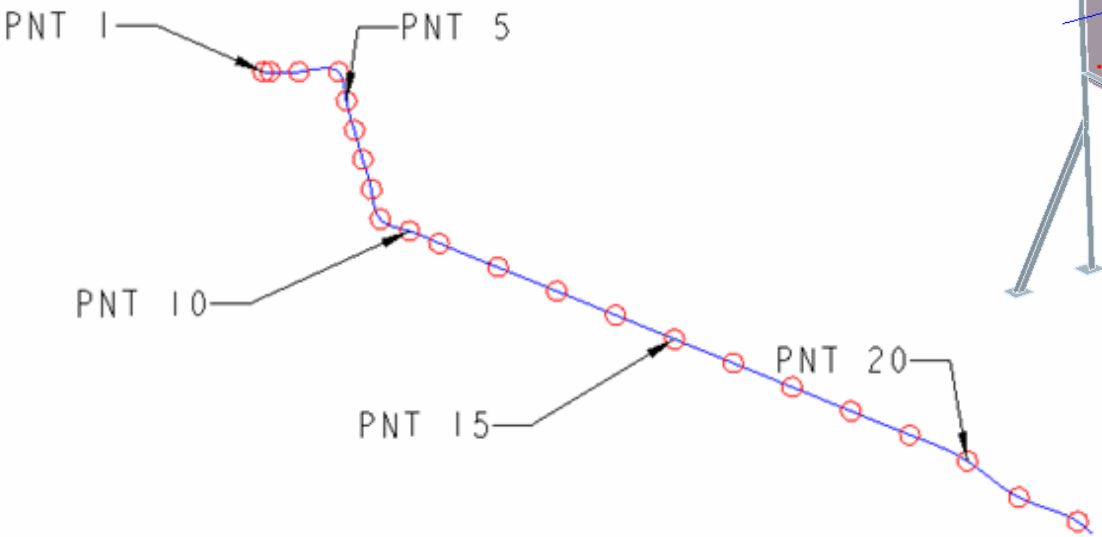
25,000 lb concrete block

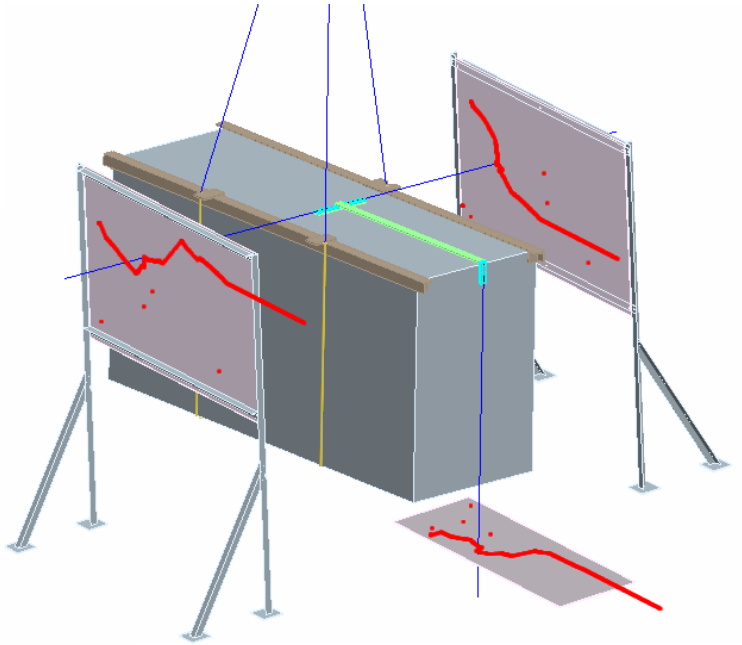
120” long, 40” wide and 60” high

The concrete block motion was controlled by using a combination of the D-site test cell crane and three chain-fall supports mounted to the crane hook.

The path traveled by each laser was plotted on sheets of velum and mounted to the screens, aligning pre-marked crosshairs located on the screen with marks on the printed paper

One-quarter inch circles were used to define the required laser positions along the curve path.

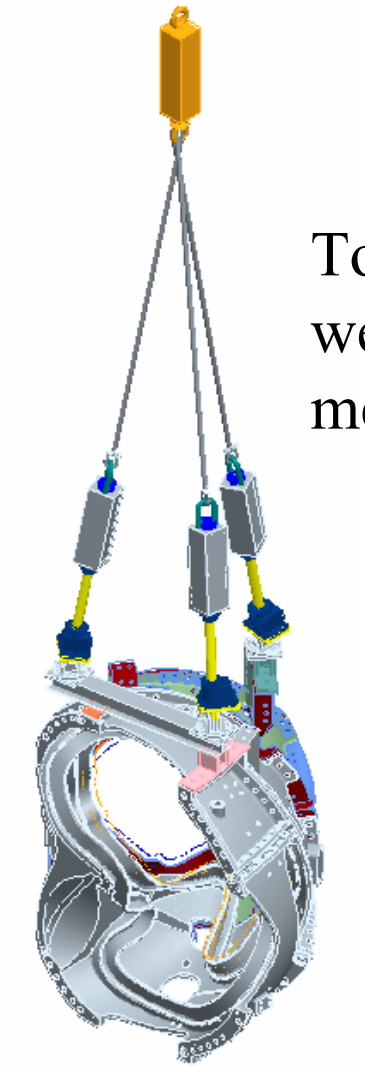




Improvements will be made using motor driven mechanical screws with in-line encoder.

The block was manipulated to follow the sequential points with an occasional maximum deviation of about ¾” to 1”, all within our allowed assembly tolerances.

Crane system updated with mechanized screws

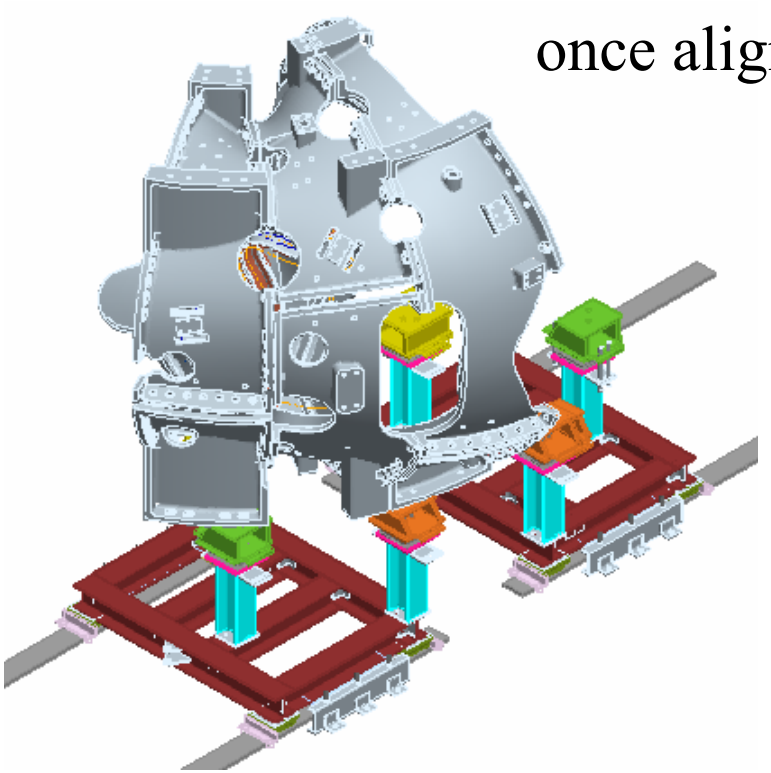


To improve the accuracy of moving the MCHP we will be replacing the chain falls with mechanized screw systems with inline encoders.

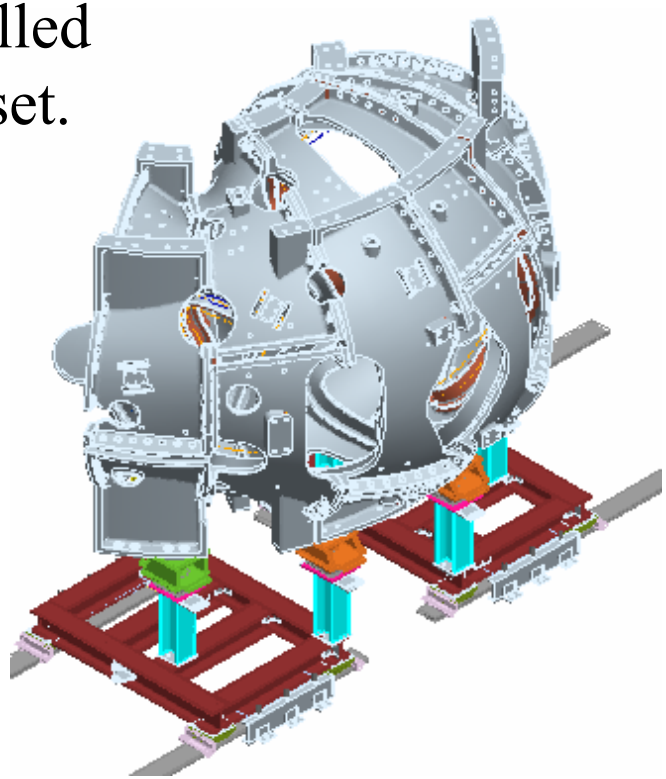
Pre-fit flange shim installation at Type-A interface

NCSX
National Compact Stellarator Experiment

All shims are installed once alignment is set.



Metrology measurements taken to establish left MCHP position



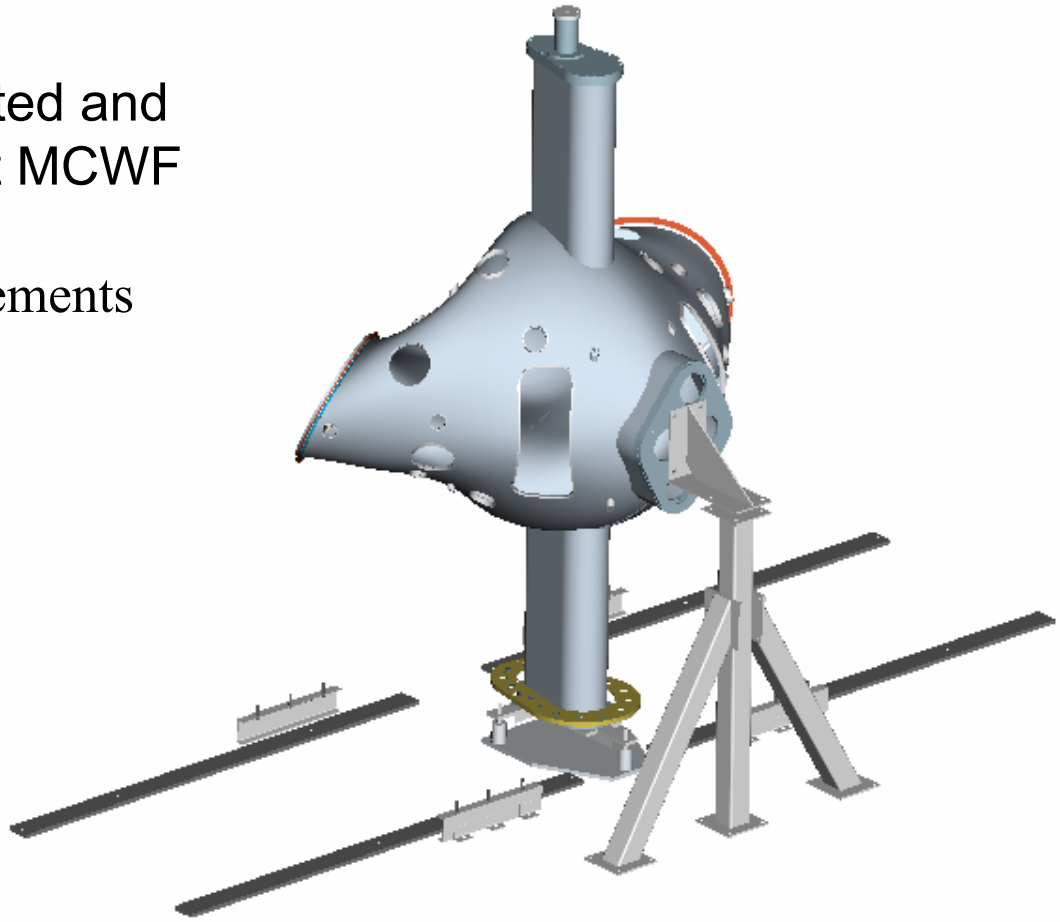
The right MCHP position set to spherical seats using the crane/mechanized screw system

Final Stage 3 fixture details and assembly sequence.

NCSX National Compact Stellarator Experiment

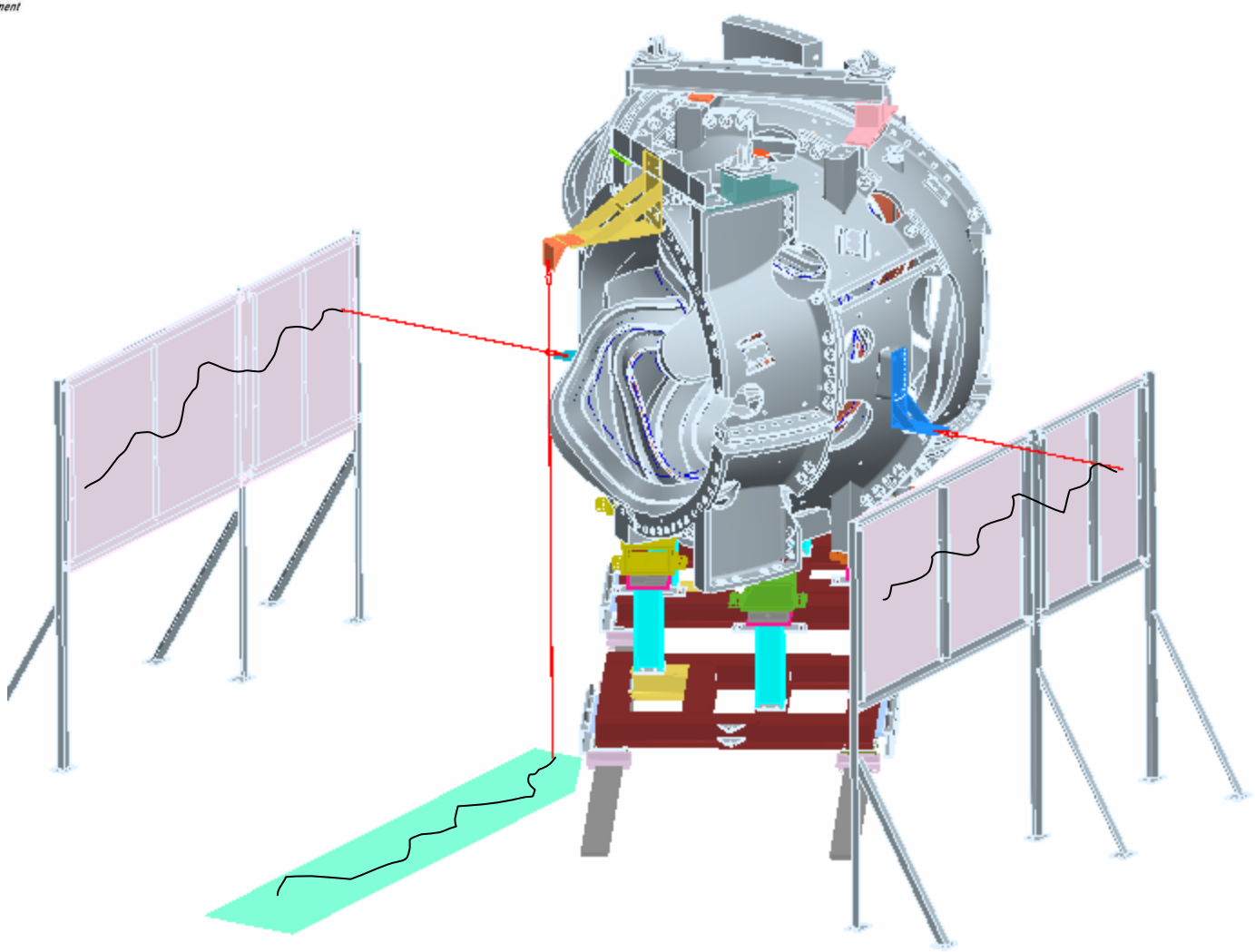
Vacuum Vessel supported and in position to receive left MCWF

- Take metrology measurements
- Define VV position



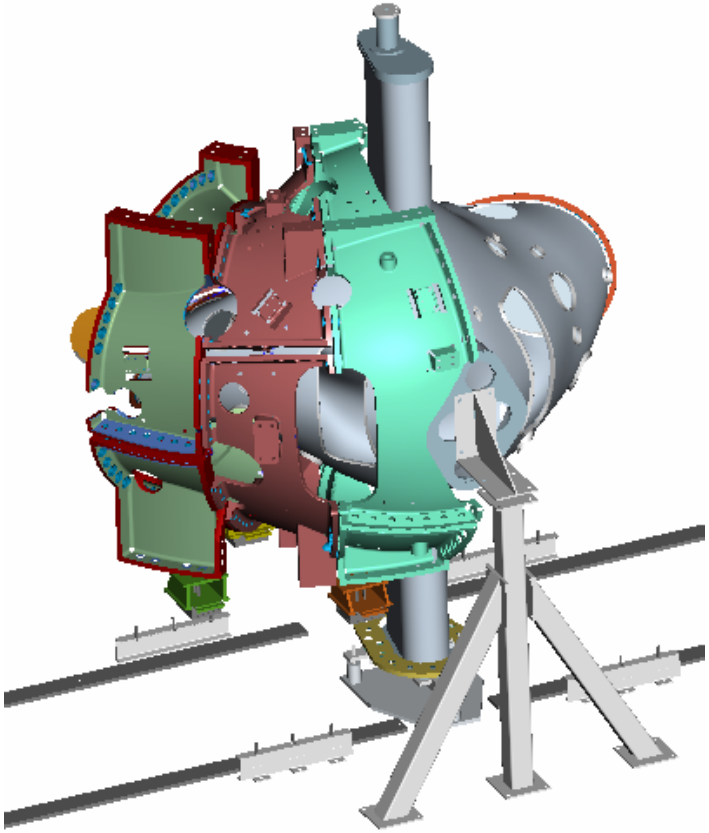
Laser system is used to follow the assembly path

NCSX
National Compact Stellarator Experiment

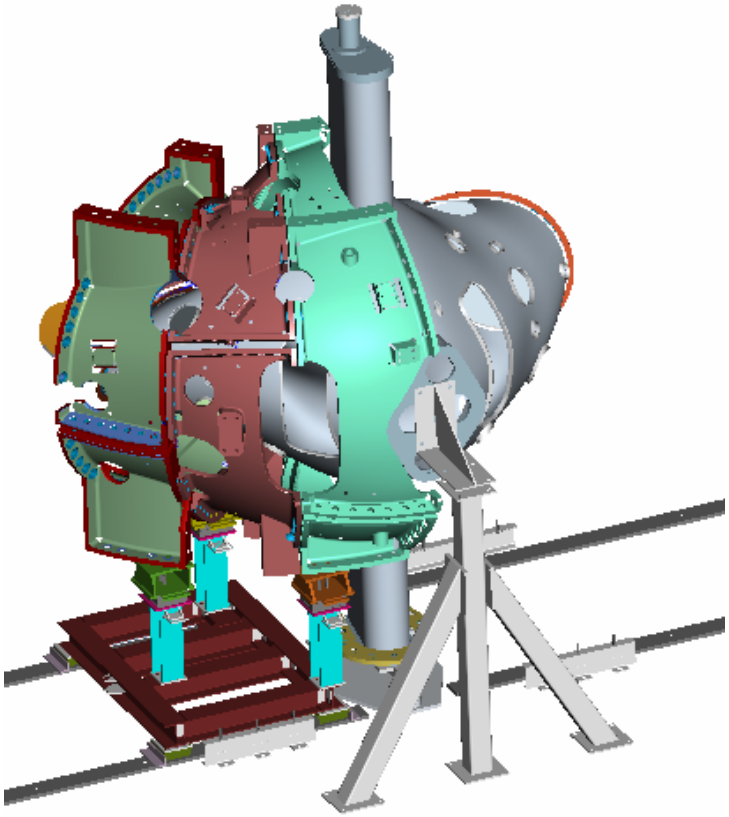


Stage 3 fixture details and assembly sequence (cont).

The left side is rotated over the VV and placed ¾" from its final position and supported from the roller system below.



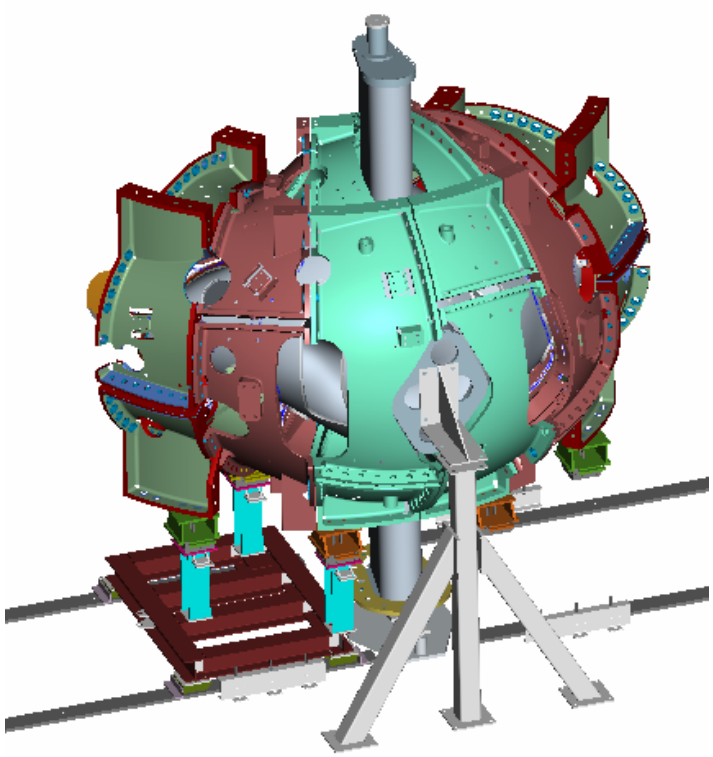
Left MCWF moved into position by overhead crane



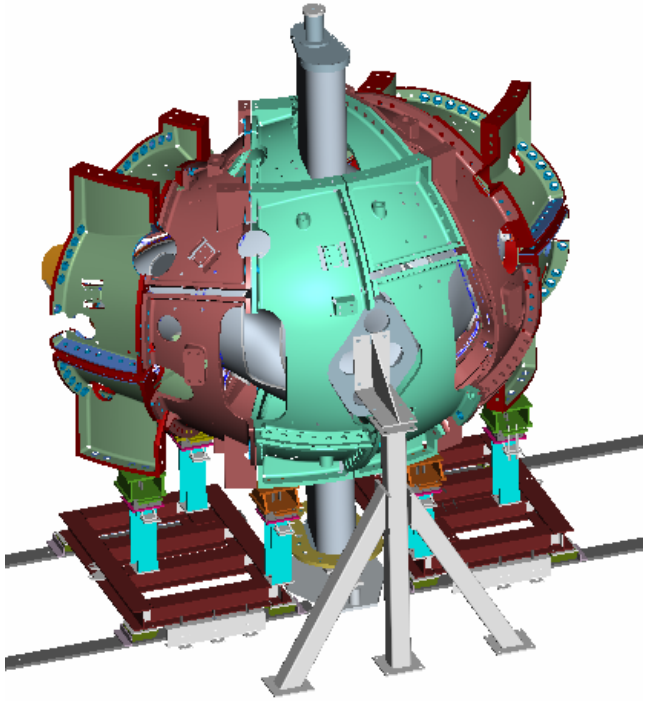
Left support cart moved into position. Load supported and crane removed

Stage 3 fixture details and assembly sequence (cont).

The right side is rotated to within ¾" of its final position and held by the crane. The left side is then moved to its final position via rollers and the right side mates with the spring loaded spherical seats via the crane system.

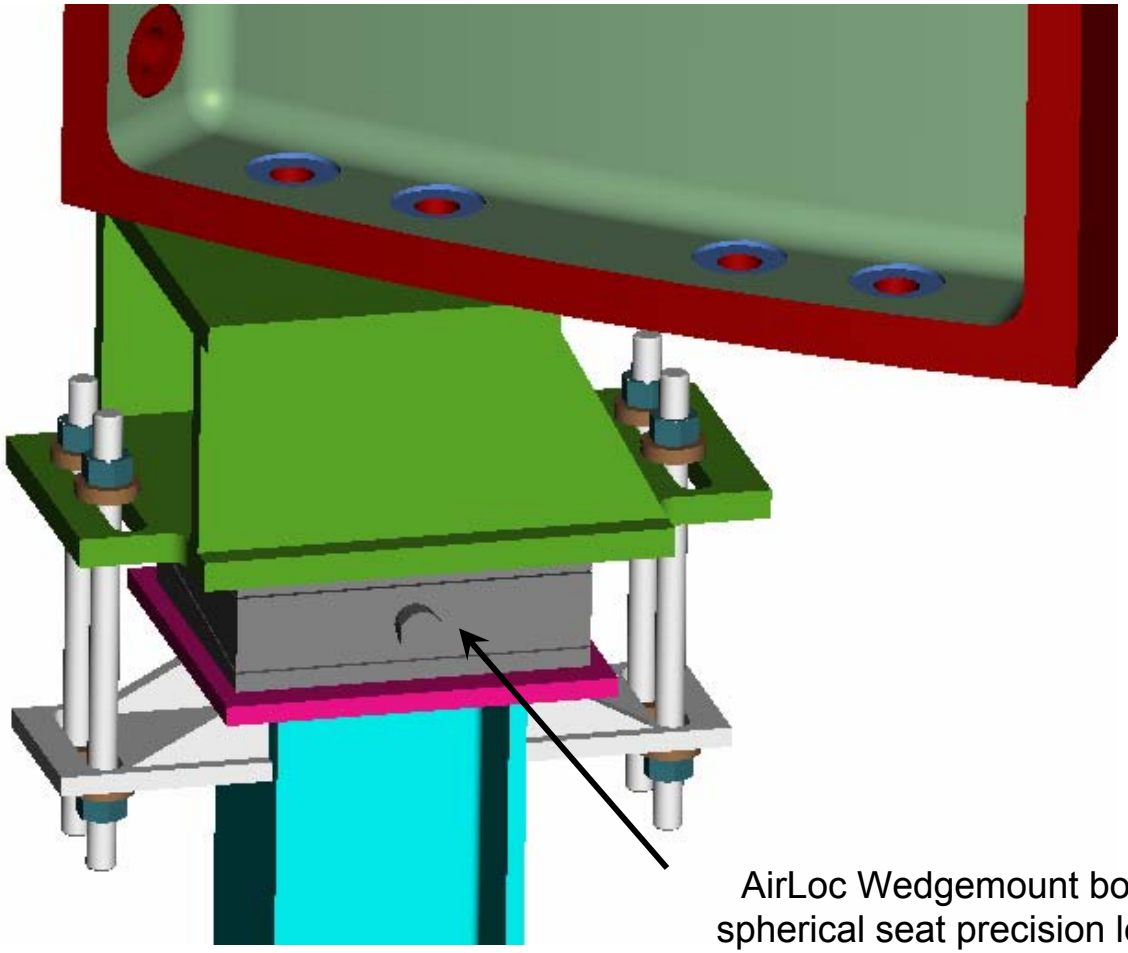


Right MCWF moved into position by overhead crane



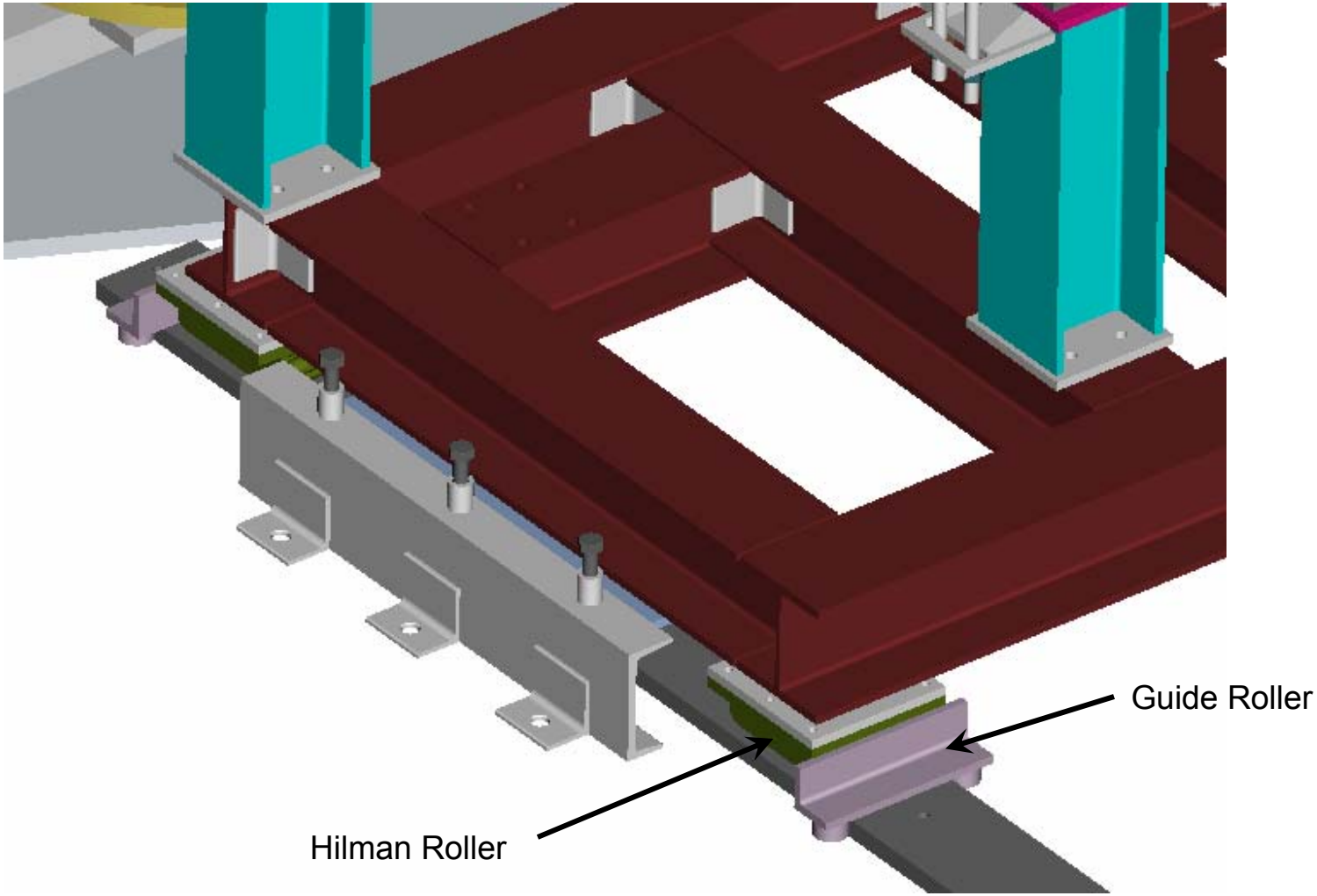
Right support cart moved into position. Load supported and crane removed. Metrology measurements taken.

A high load leveler system supports the MCHP



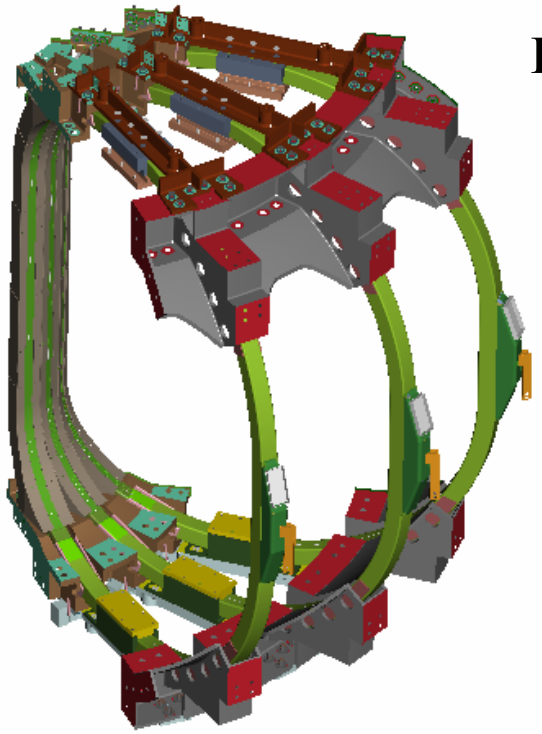
AirLoc Wedgemount bolt on
spherical seat precision leveler

A roller system is used to guide support cart



TF Half Period Assembly– Stage 4

Stage 4 involves assembling three TF coils and structure into a three coil half period.



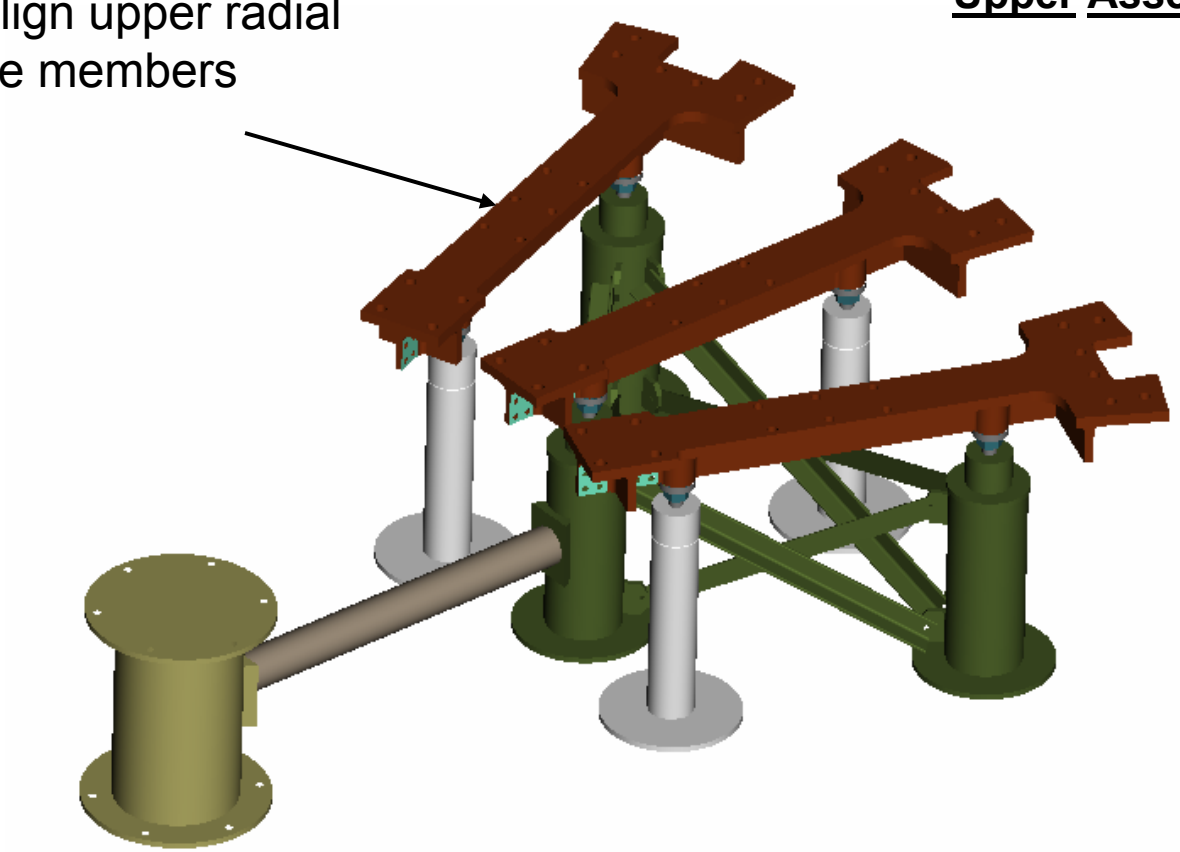
BASIC REQUIREMENTS:

- Assemble three TF windings to form a TF Half Period.
- The assembly fixture must support the TF windings and allow access to complete the fit-up and all hardware installation.
- The assemble tolerance for each TF winding at the final machine assembly is ± 0.12”.

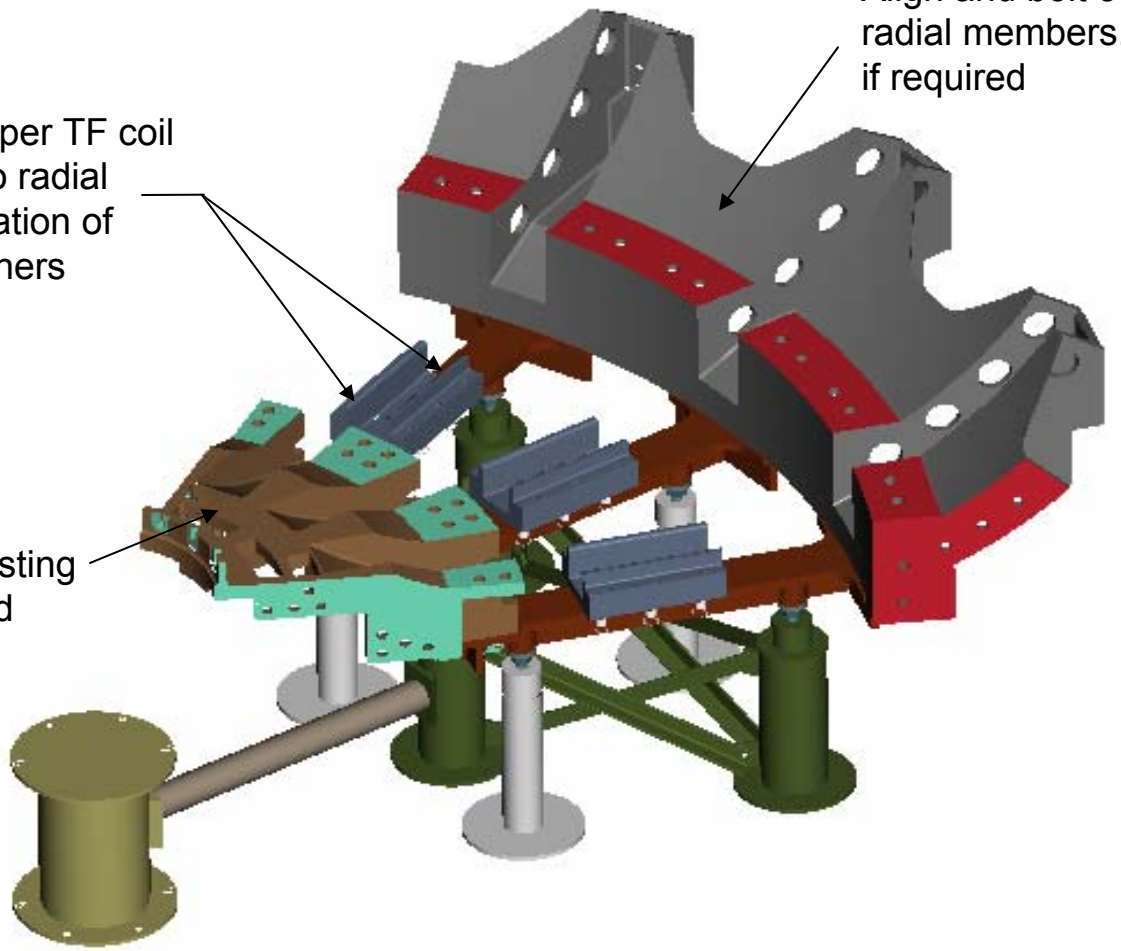
Stage 4 fixture details – Assembly Base Support.

Level and align upper radial coil structure members

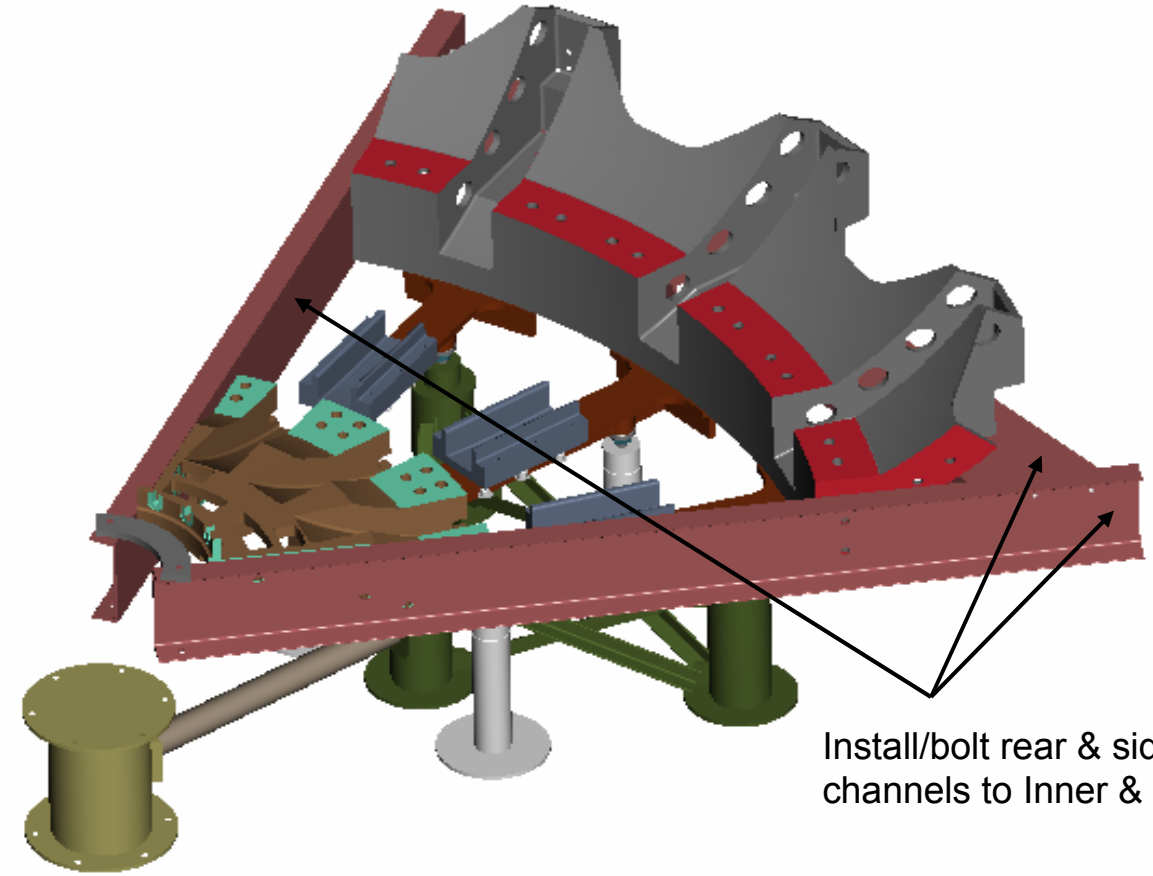
Upper Assembly



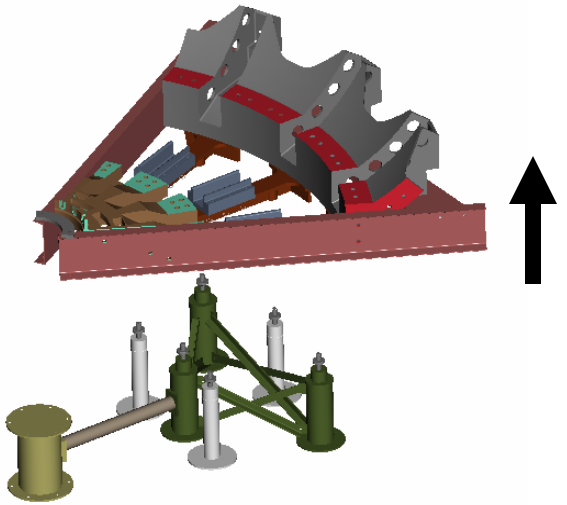
Stage 4 fixture - Upper Assembly.



Stage 4 fixture - upper assembly temporary supports.

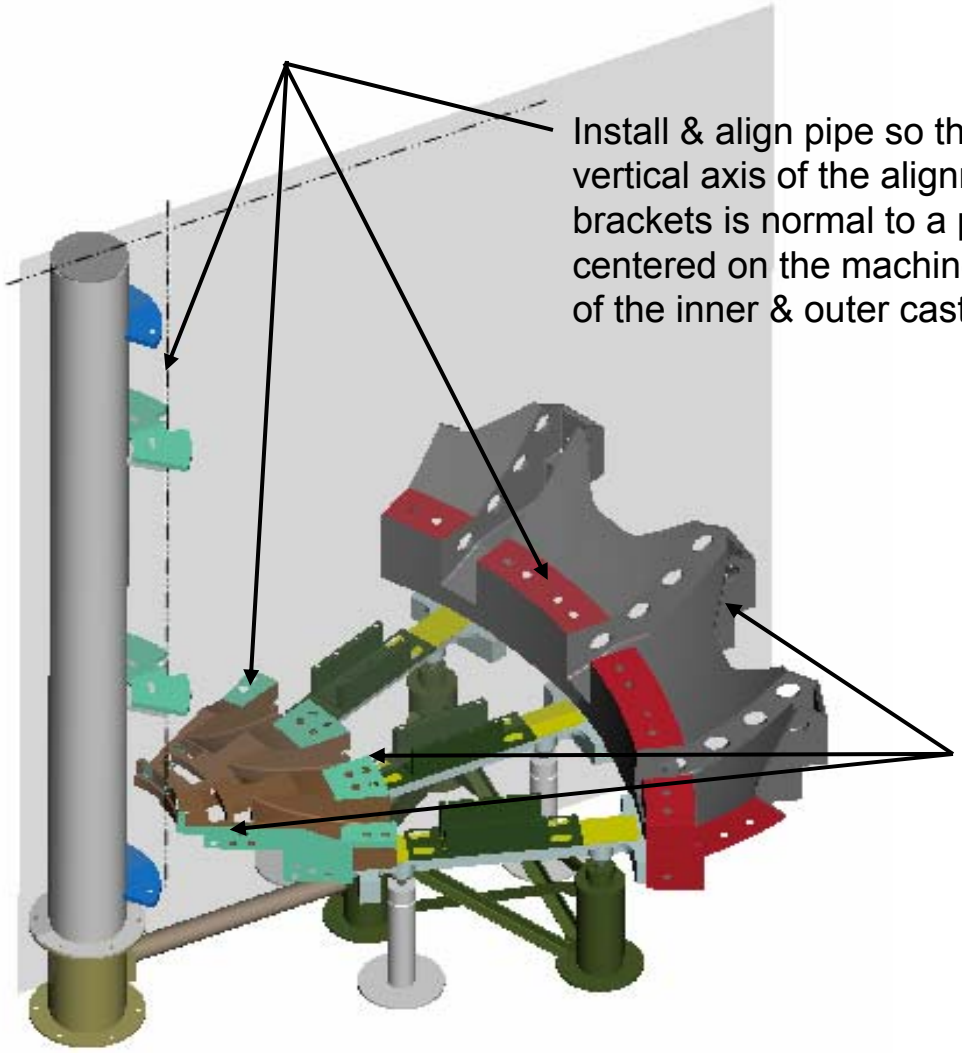


Install/bolt rear & side support channels to Inner & Outer castings



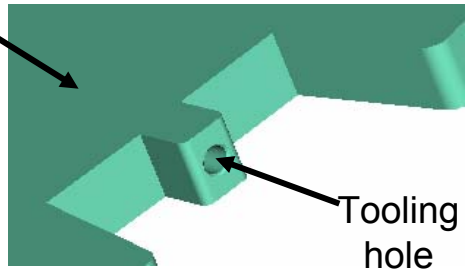
Lift upper assembly off support stand and move to temporary storage.

Stage 4 fixture details – set-up for coil alignment.

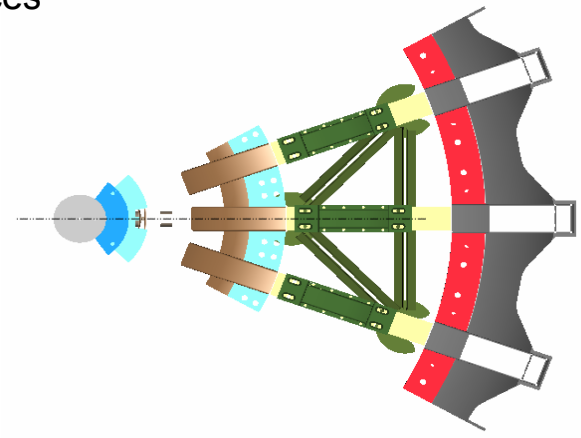


Install & align pipe so that the vertical axis of the alignment brackets is normal to a plane centered on the machined surfaces of the inner & outer casting.

Alignment bracket

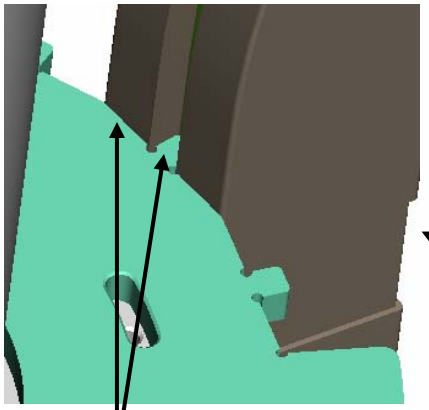


Tooling hole

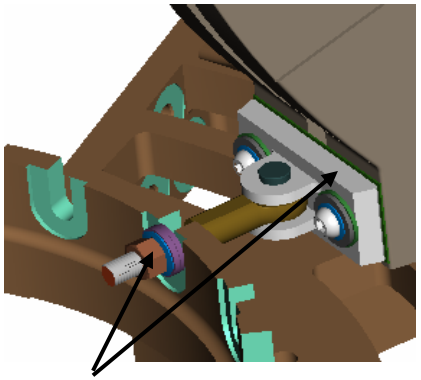


Align vertical axis of the alignment brackets angularly to a plane defined as equidistant (centered) in the TF Coil opening of the Inner & Outer castings and through the centerline of the pipe

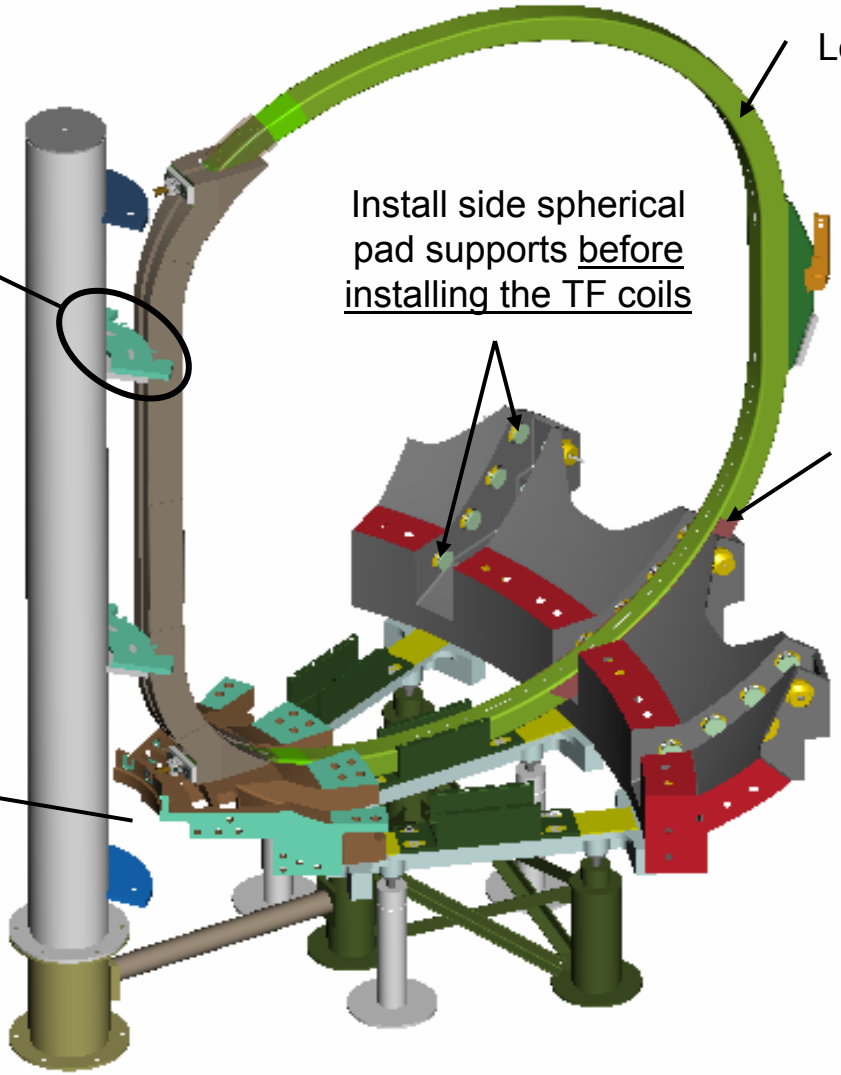
Stage 4 fixture details – center TF coil.



Seat coil against stop and center on tab (typical top & bottom).



Install hardware to TF castings and secure to lower Inner hub & upper tempoary support

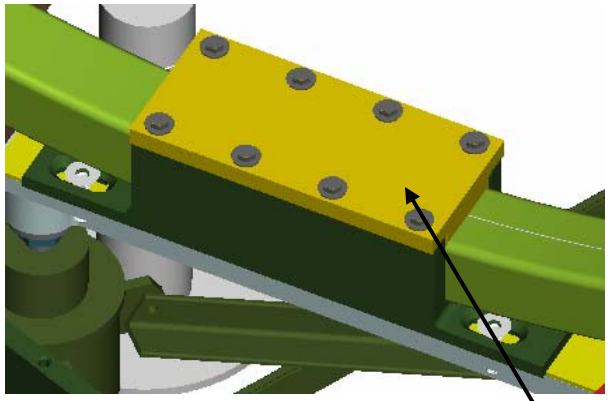


Lower the center TF coil into position

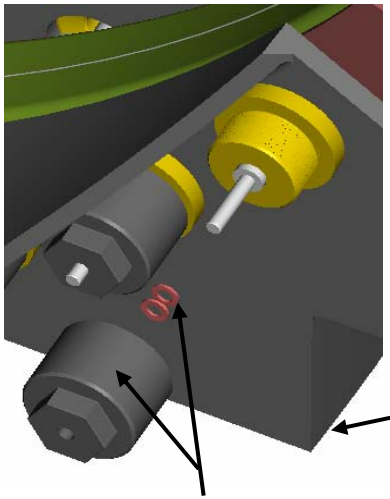
Install side spherical pad supports <u>before installing the TF coils</u>

Install side shim plates (typical each side).

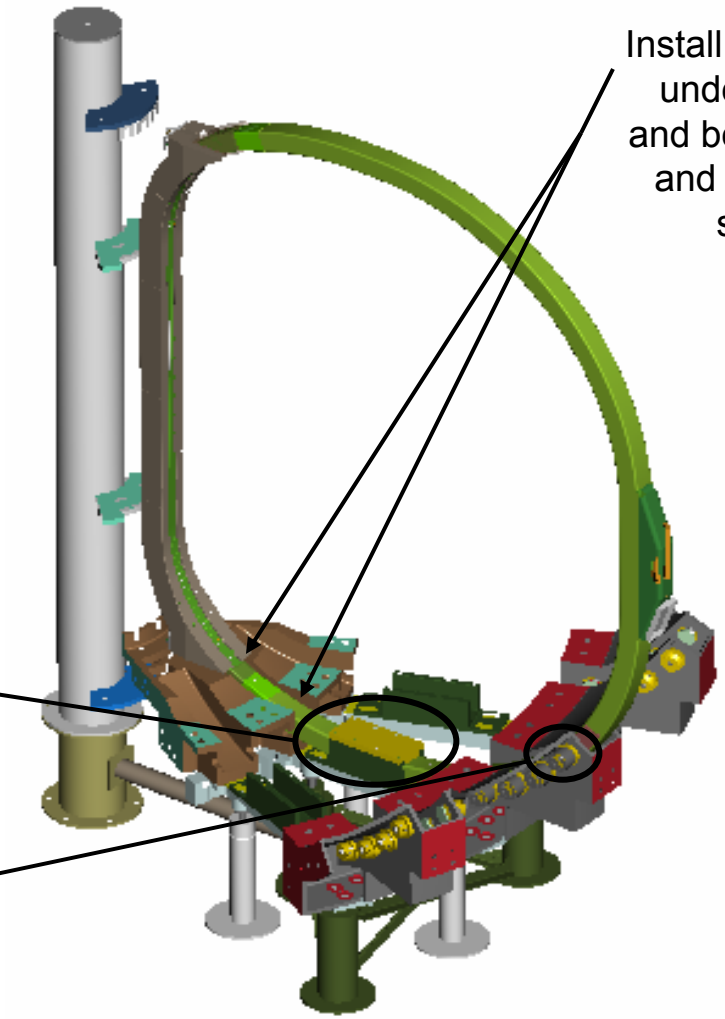
Stage 4 fixture details – secure center TF coil.



Install lower support cover plate

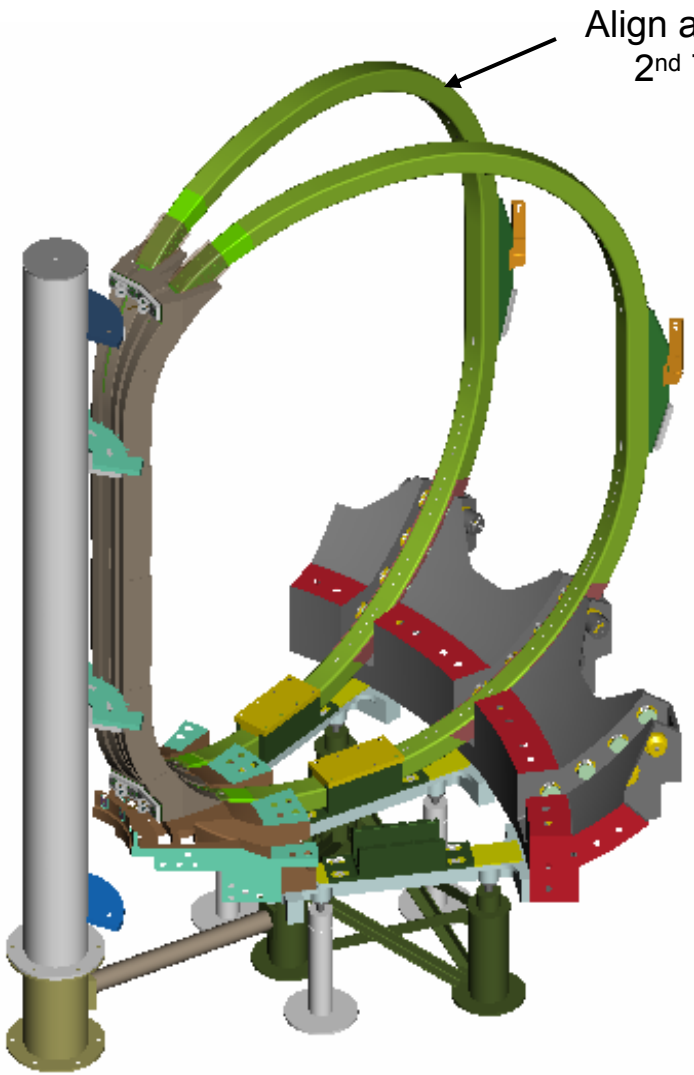


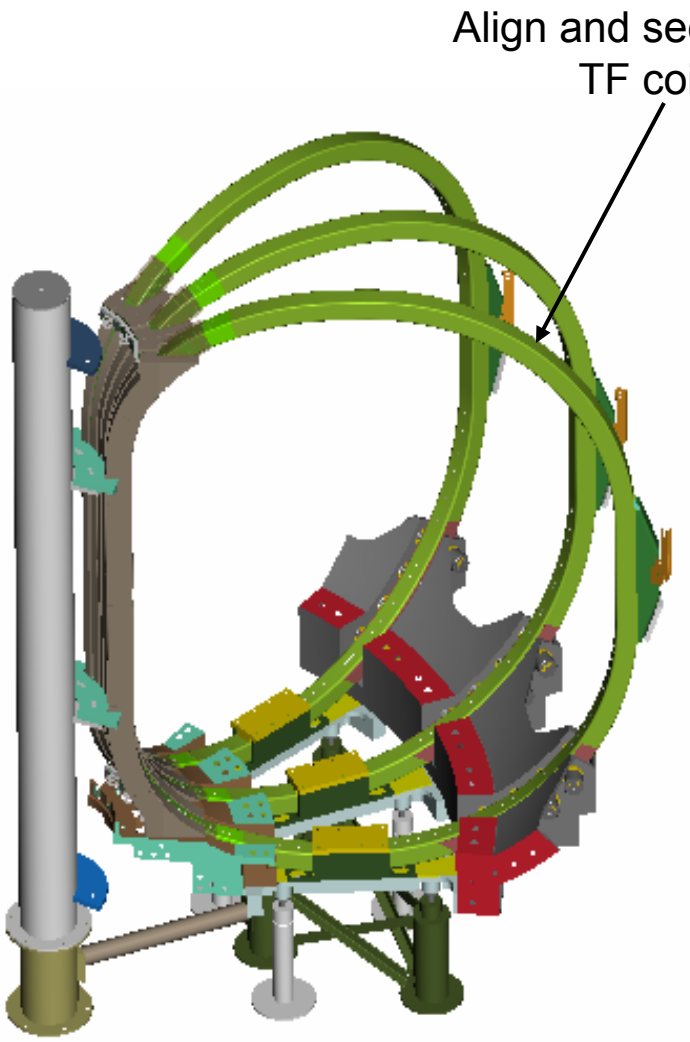
Install belleville washers & adjusting nut. (typical both sides)



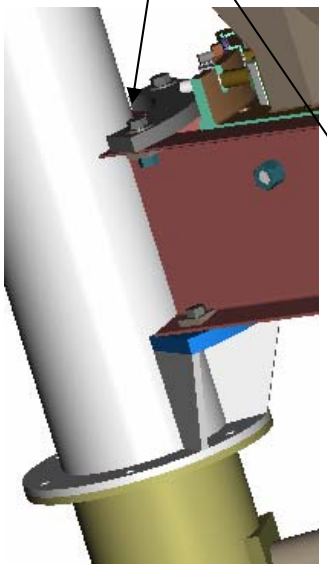
Install temporary shims under nose casting and between coil sides and inner casting to stabilize coil

Stage 4 fixture details – add remaining TF coils.

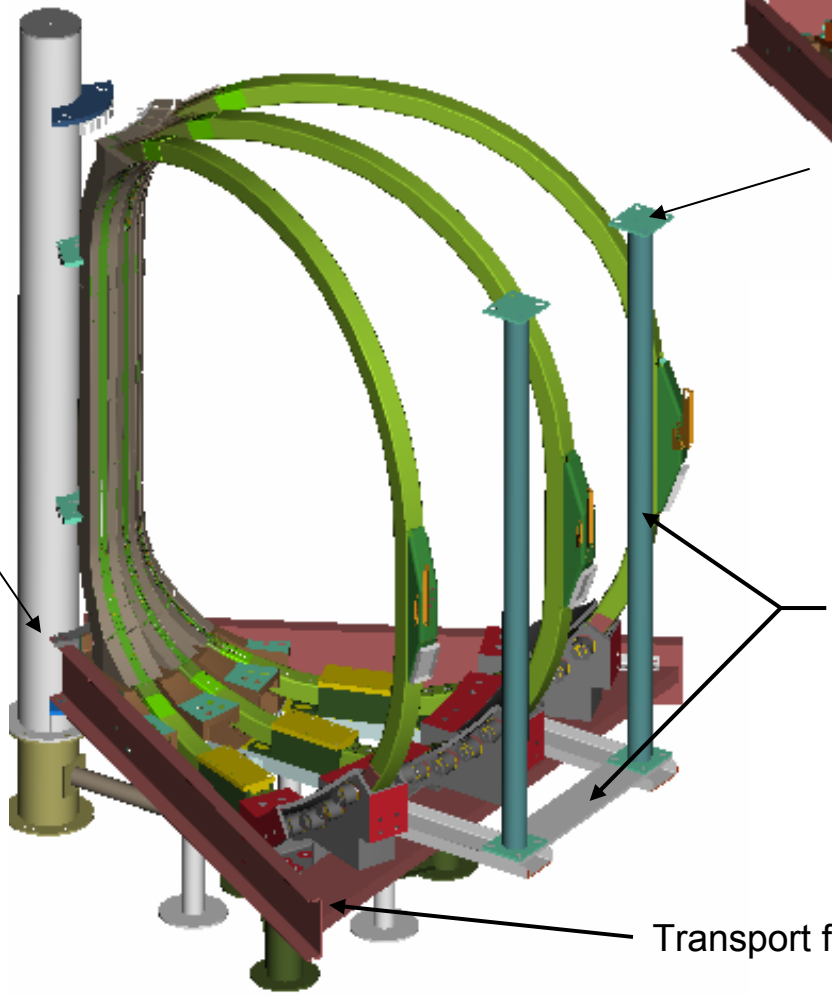


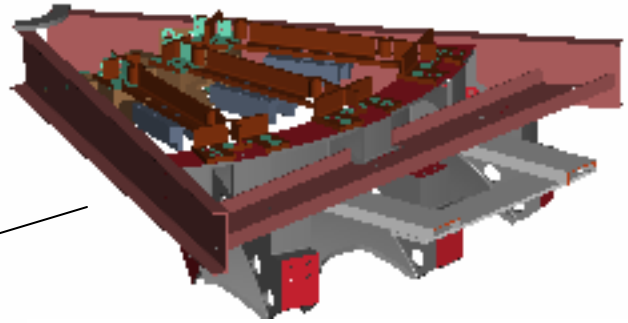


Stage 4 fixture details – install upper structure.



Bolt transport frame to Inner & Outer castings and center pole



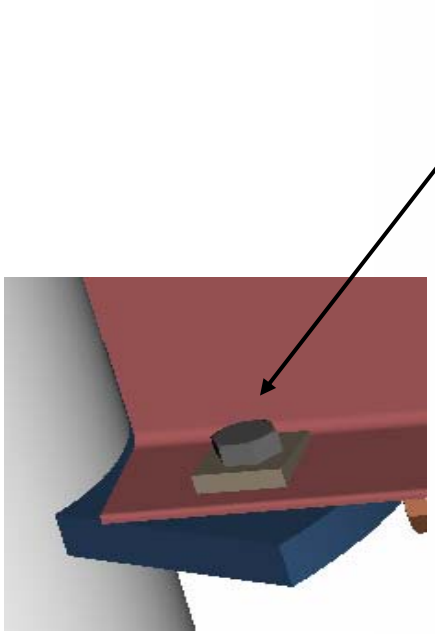


Lift upper structure and position above fixture

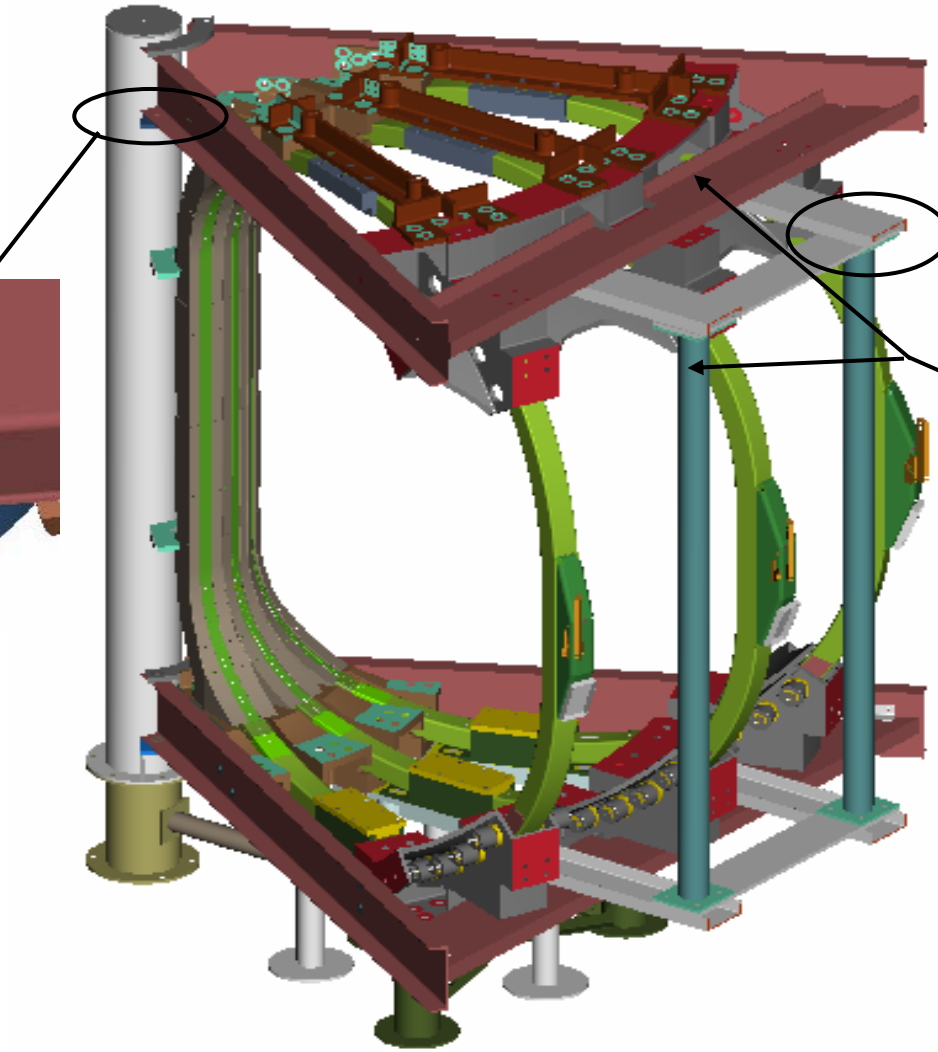
Install vertical support base and posts to lower structure

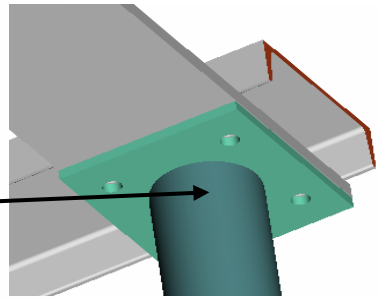
Transport frame

Stage 4 fixture details – secure upper structure.



Bolt upper support structure to pipe



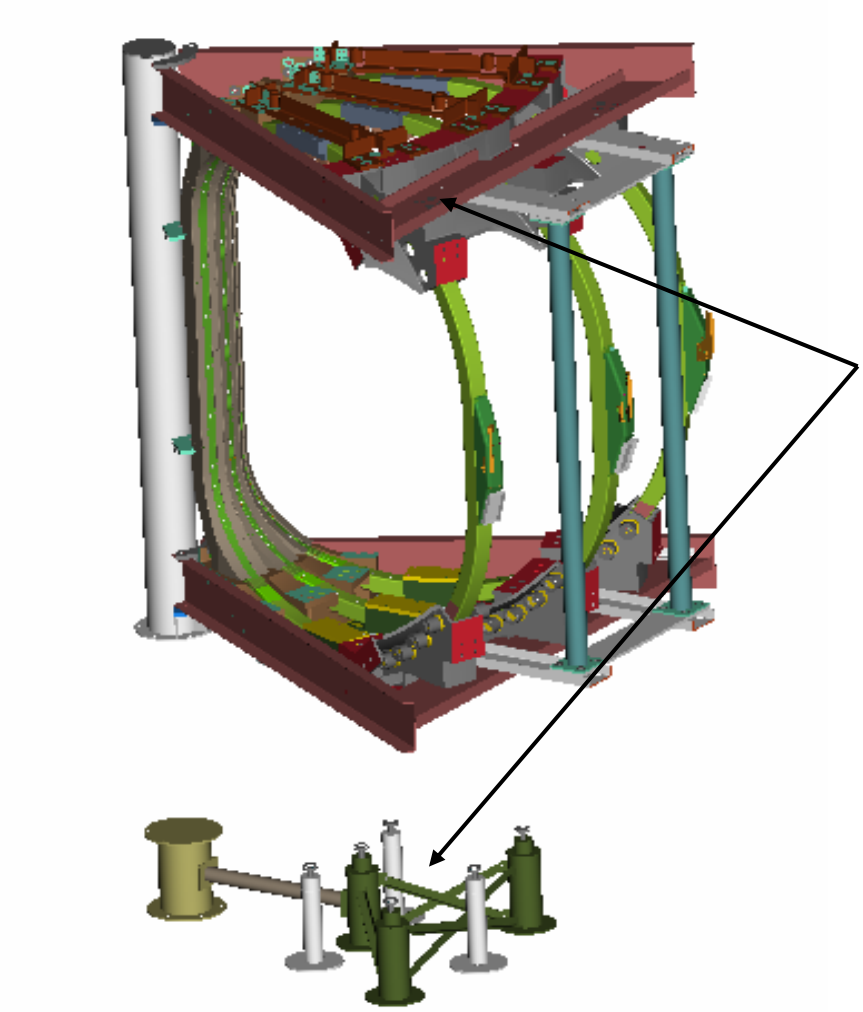


Bolt upper support structure to outer vertical supports

Stage 4 fixture details – secure upper structure.

Install the upper clamp plates and associated hardware

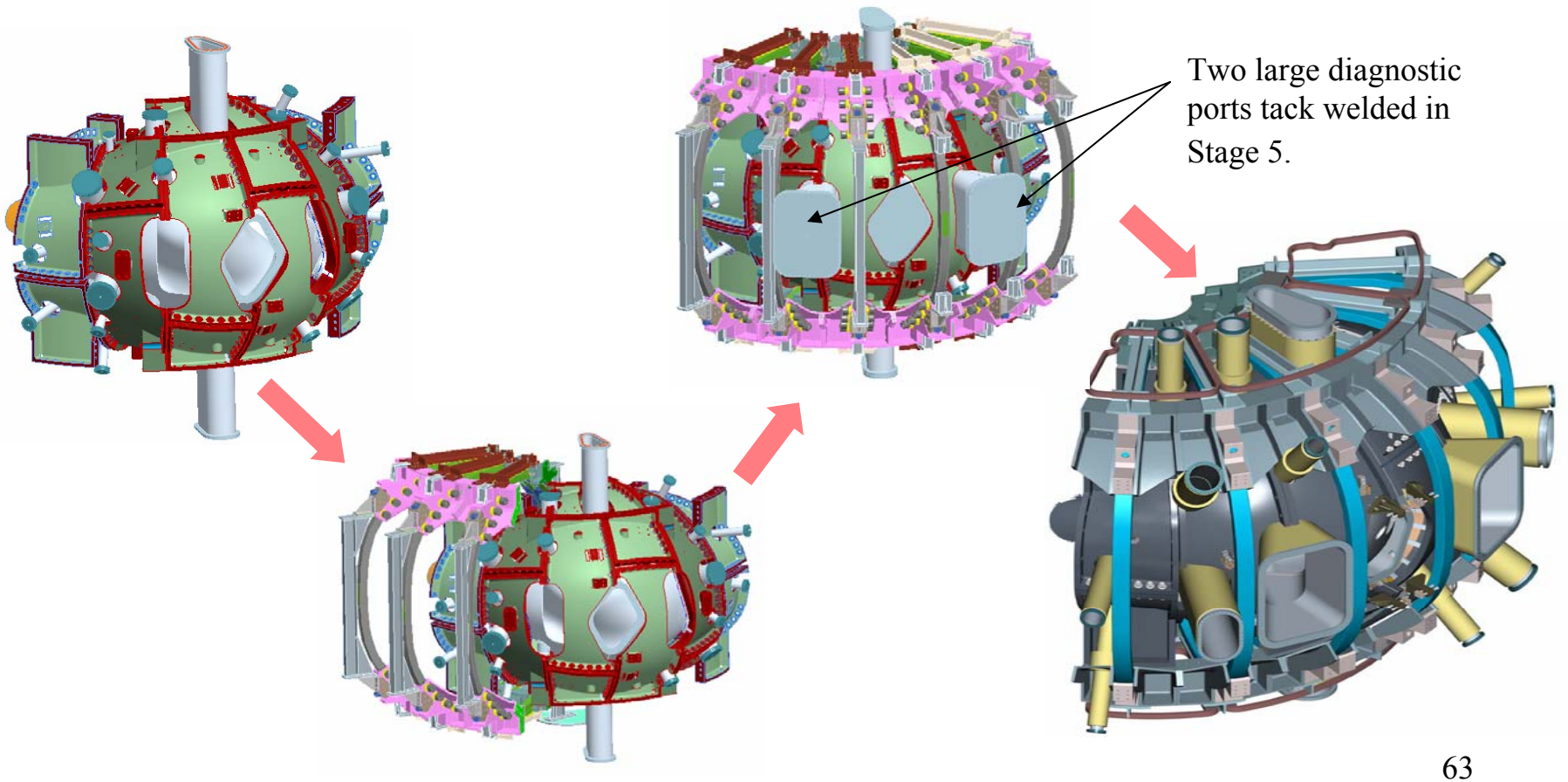
Stage 4 fixture details – move to Stage 5.



Lift assembly off support stand
and move to Station #5

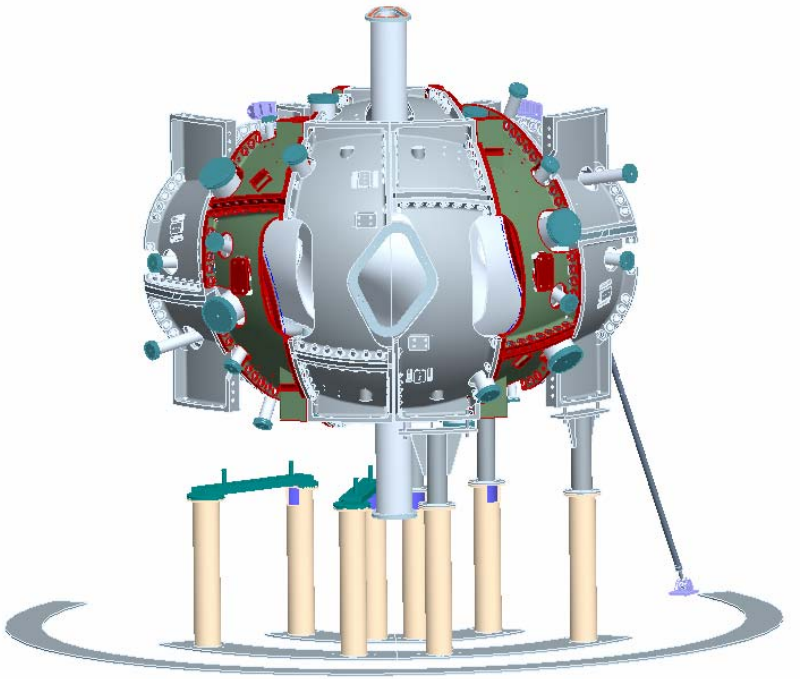
Final FP Assembly– Stage 5

Stage 4 completes the FPA assembly process bringing together the VV/MCHP assembly, TFHP and attaching VV ports, correction coils and services.

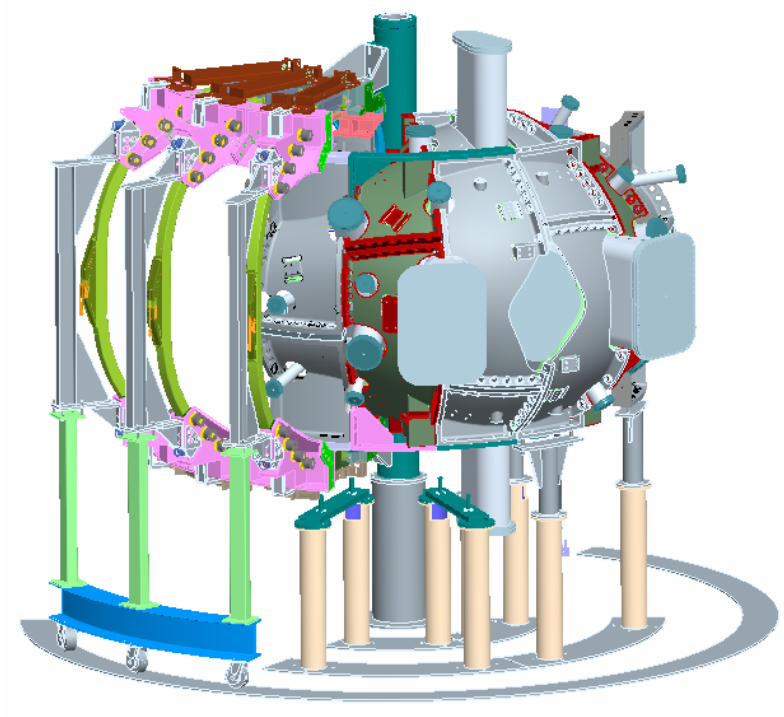


Stage 5 assembly design details are preliminary

Stage 5 assembly details have been developed in sufficient detail to develop preliminary cost and schedule estimates.



Cantilever support used to gain TF access.



TF rotated around MCHP

Summary

NCSX
National Compact Stellarator Experiment

- The FPA tooling design is in progress
  - Stage 1 is complete and assembly activities are in progress
  - The Stage 2 fixture is out for bids
  - The Stage 3 fixture design is nearing completion and a final design review has been scheduled
  - Stages 4 and 5 fixture design are in progress
- Additional small scale tooling and handling fixtures will developed as they are identified.
- The assembly design and fixture details will continue to be updated through our prototyping process