

Design of the Detector Support Structure for ProtoDUNE SP

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1.0 Introduction

This document will describe the design of the structure that will support the ProtoDUNE single phase (SP) time projection chamber (TPC) planned for installation at EHN1 at CERN.

The ProtoDUNE-SP TPC, illustrated below comprises two drift volumes, defined by a central cathode plane (CPA) that is flanked by two anode planes (APA), both at a distance of ~ 3.6 m, and a field cage (FC) that surrounds the entire active volume. The active volume is approximately 6 m high, 7 m wide and 7.2 m deep (along the drift direction).

Each anode plane is constructed of three Anode Plane Assemblies (APAs) that, in the installed position, are 6 m high by 2.3 m wide. Each APA consists of a frame that holds three parallel planes of wrapped wires; the wires of each plane are oriented at different angles with respect to those on the other planes to enable 3D reconstruction. The wire pitch for all wire planes is 4.5 mm, and each APA holds a total of 2,560 wires.

The cathode plane, also called the Cathode Plane Assembly (CPA) is an array of 18 (six wide by three high) CPA modules, which consist of flame-retardant G10 frames, each 1.18 m wide and 2 m high, that hold thin sheets with a resistive coating on both sides. The CPA is held at 180 kV providing the 500-V/cm drift field in the 3.6-m-deep drift regions. The use of a FC helps to maintain a more uniform electronic field.

The cold electronics (CE), mounted onto the APA frame, and thus immersed in LAr, amplifies and continuously digitizes the induced waveforms on the sense wires at several MHz, and transmits these data to the Data Acquisition system (DAQ). From the DAQ the data are transmitted through the buffer to disk, then to the central CERN Tier-0 Computing Center, and finally to other partner sites for processing and analysis.

The modular photon Detectors (PDs) are integrated into the APAs. Each PD module in the system consists of a thin, wavelength-shifting radiator plate mounted on a wavelength-shifting, bar-shaped light guide. The plates are coated with a layer of tetraphenyl-butadiene (TPB) that converts incoming VUV (128 nm) scintillation photons to longer-wavelength photons in the visible blue range. Half of the converted photons are emitted into the bar, a fraction of which are then internally reflected to the bar's end where they are detected by silicon photomultipliers (SiPMs).

Each APA frame is designed with ten bays into which PDs are inserted after the TPC wires have been strung. This allows final assembly at the integration area (in a clean room) at the CERN neutrino platform prior to installation inside the cryostat.

2.0 DSS description

Prior to the installation of the TPC, the Detector Support Structure (DSS) will be installed inside the cryostat. The DSS along with the TPC is shown in Figure 1. A more detailed view of the DSS is shown in Figure 2. This structure is being designed following EN 1993 1 (Eurocode 3: Design of steel structures) and EN 1993 6 (Eurocode 3: Design of steel structures – Part 6: Crane supporting structures).

The DSS will be positioned near the ceiling supported by 9 penetrations through the cold side of the membrane extending up to the warm structure of the cryostat. A drawing of the cryostat penetrations can be found at <https://edms.cern.ch/document/1543241/3>. The warm structure of the cryostat will support all of the loads from the detector. The DSS consists of two layers of I-beams. The top layer is oriented in the y direction and designated as the runway beams and the bottom layer is oriented in the x direction and designated as the bridge beams.

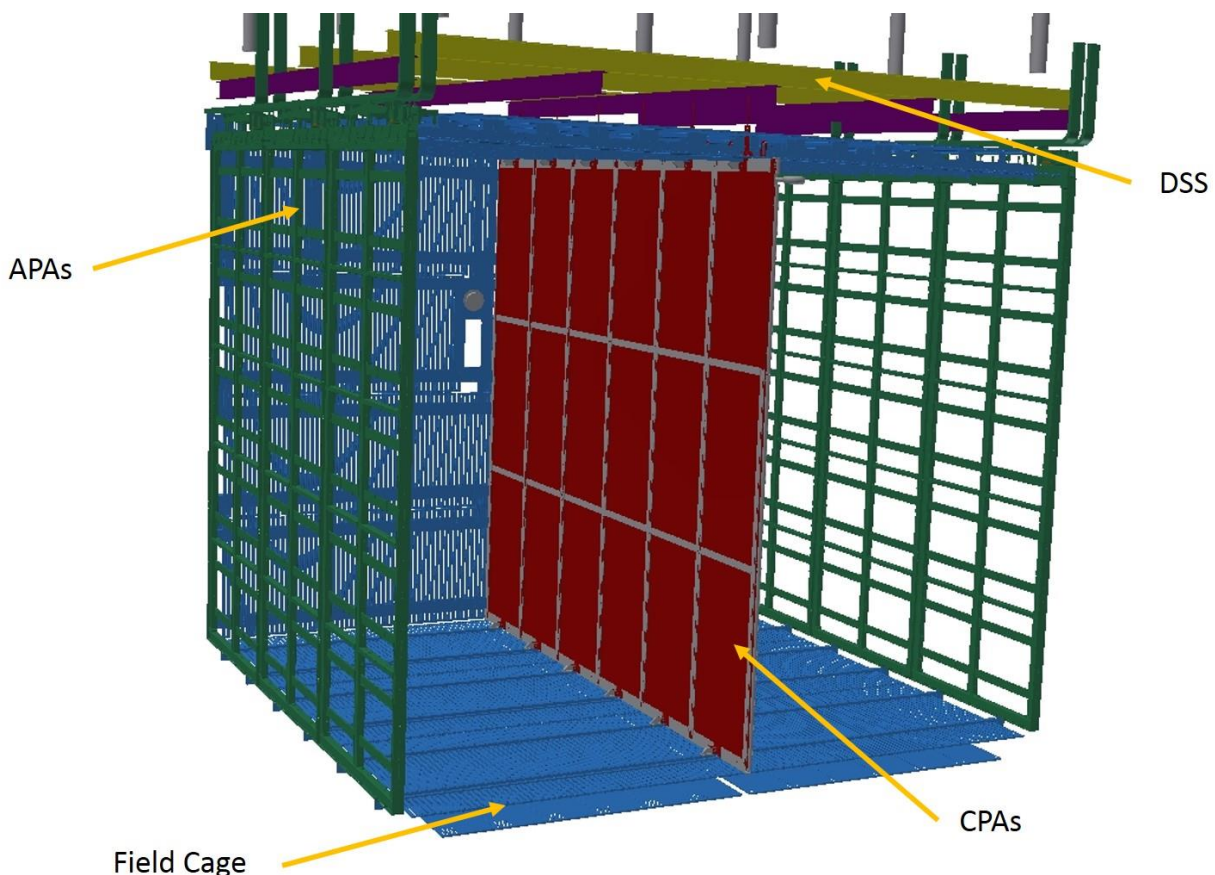


Figure 1 Overview of DSS and TPC

The bridge beams are used for the direct support and positioning of the TPC components. These are shown, along with the naming convention for the bridge beams in Figure 3. Bridge beam A will support the row of APAs near the Saleve side of the cryostat. Bridge beam B will be used for the movement and support of the end wall FCs during installation in the Saleve drift of the cryostat. Bridge beam C will support the row of CPAs. Bridge beam D will be used for the movement and support of the end wall FCs

during installation in the Jura drift. Bridge beam E will support the row of APAs near the Jura side of the cryostat.

The bridge beams will have the ability to translate on rolling trolleys in the Y direction in order to move the TPC components from the temporary construction opening (TCO) entrance to their correct position in Y inside the cryostat. At the TCO, a section of the same beam used for the bridge beams will be temporarily supported for items to move from the clean room inside the cryostat. Once all of the TPC has been moved into the cryostat, this section of beam will be removed and the TCO will be closed.

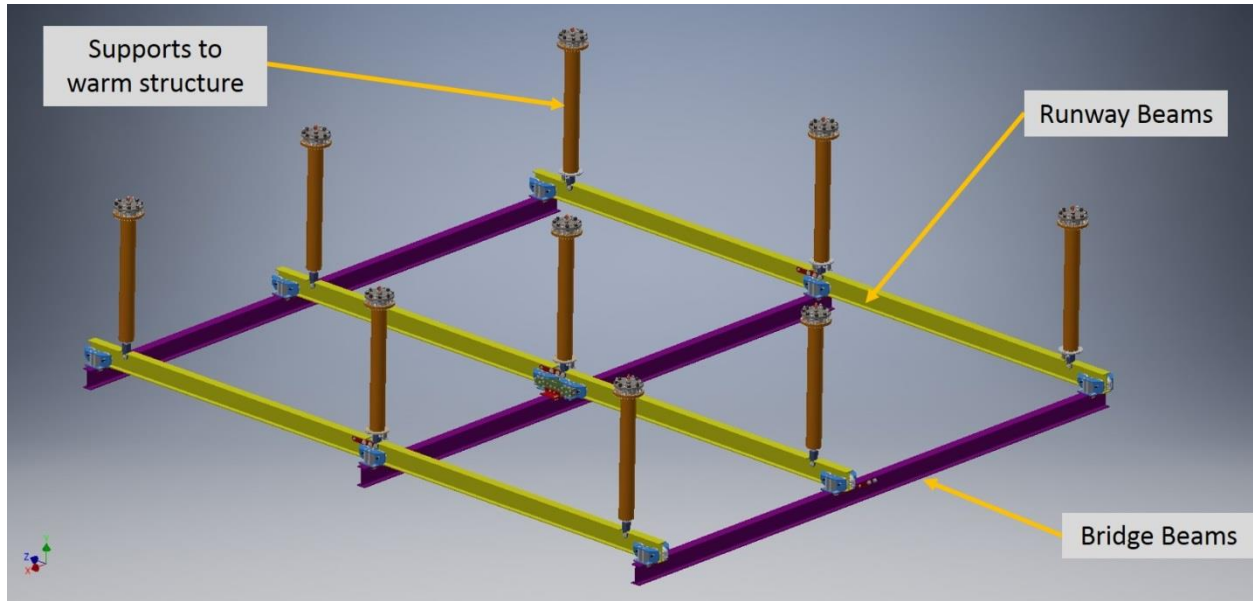


Figure 2 Major DSS components (only 3 bridge beams are shown)

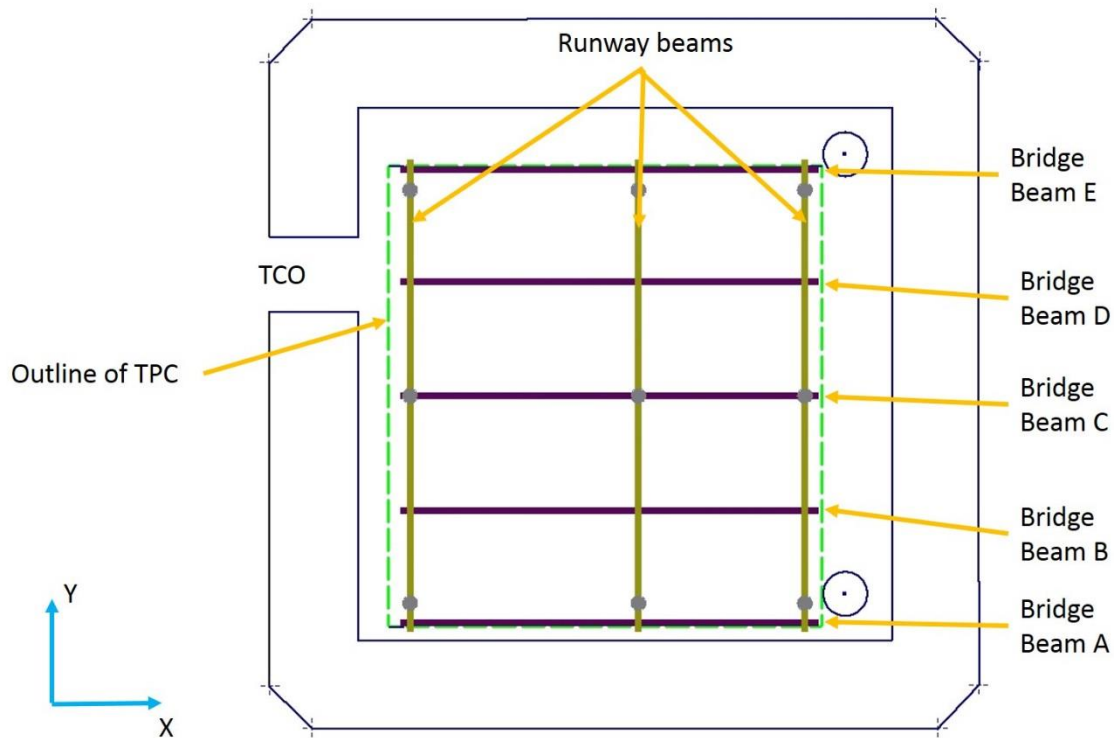


Figure 3 Naming of the various beams in the DSS

The runway beams will be fixed in the Y direction at the center support point, but free to move during the cooldown at the two outer points. The ends of the runway beams are expected to shrink ~ 10 mm towards the center during cooldown to LAr temperature.

The bridge beams will be fixed in the X direction at the beam side of the cryostat to the runway beams. This is done to limit the movement of the beam side of the TPC with respect to the membrane wall due to the fact that the beam plug will be mounted at this side of the TPC.

The movement of the bridge beams also accommodates the shrinkage of the TPC components during the cooldown to LAr temperature. This shrinkage is expected to be ~ 10 mm. The beams in each layer will have a vertically articulating joint near the middle of each. This joint will allow the three connection points to move independently. This is necessary as the roof of the cryostat deforms under the various load conditions. These conditions cause the roof to flex in both directions. FEA analysis of the structure produces a range from +3.1 mm to -2.6 mm. A detailed report of this analysis can be found at <https://edms.cern.ch/document/1531441/1>.

3.0 Requirements

Positional TPC

Mechanical

Mechanically, the DSS needs to support the TPC, possibly provide vibration isolation from the warm structure, allow for vertical adjustment, and provide stability for the detector.

A series of 8 springs are being added to provide vibration isolation. The spring constant is damping vibrations less than 6Hz. However, the design is flexible and the springs can be changed, if necessary, after the TPC is installed and commissioned.

Also included in the spring mount is vertical adjustment at each of the nine support points of the DSS. There is a minimum of +/- 10 mm of adjustment available for each point. This may be needed to accommodate motion and deflection in the cryostat warm structure and accommodate the shrinkage of the TPC when cold. It is planned to install the detector in such a manner that the height of all three planes are the same after the cryostat is filled and the TPC has cooled down. This adjustment will be used if needed.

Electrical

The DSS will be mechanically and electrically connected to the cryostat warm structure using metallic elements, therefore it will be on the detector ground. There cannot be any floating conductive components in the cryostat. There needs to be an electrical connection between all of the elements of the DSS. This will be evaluated after construction and proper grounding straps will be added as needed.

The TPC elements will provide the connection linkages that connect to each of the moving trolleys. There will be an electrical break between the DSS and the TPC in each of these linkages.

TPC Reconfiguration

The TPC will be installed initially at the nominal drift distance planned for the DUNE far detectors. This distance is 3637 mm from the center of the APA to the center of the CPA. The cryostat will be filled and the detector commissioned and take data at this drift distance. There are some concerns about space charge build up in this configuration. The TPC is being designed with a reconfigurable drift distance. This is one reason for the runway beams in the DSS. Specifically the alternate drift distance has been set at 2500 mm.

4.0 Connections and Interfaces

Figure 4 shows a cross section through the various layers of the DSS. This will help explain the various connections and interfaces.

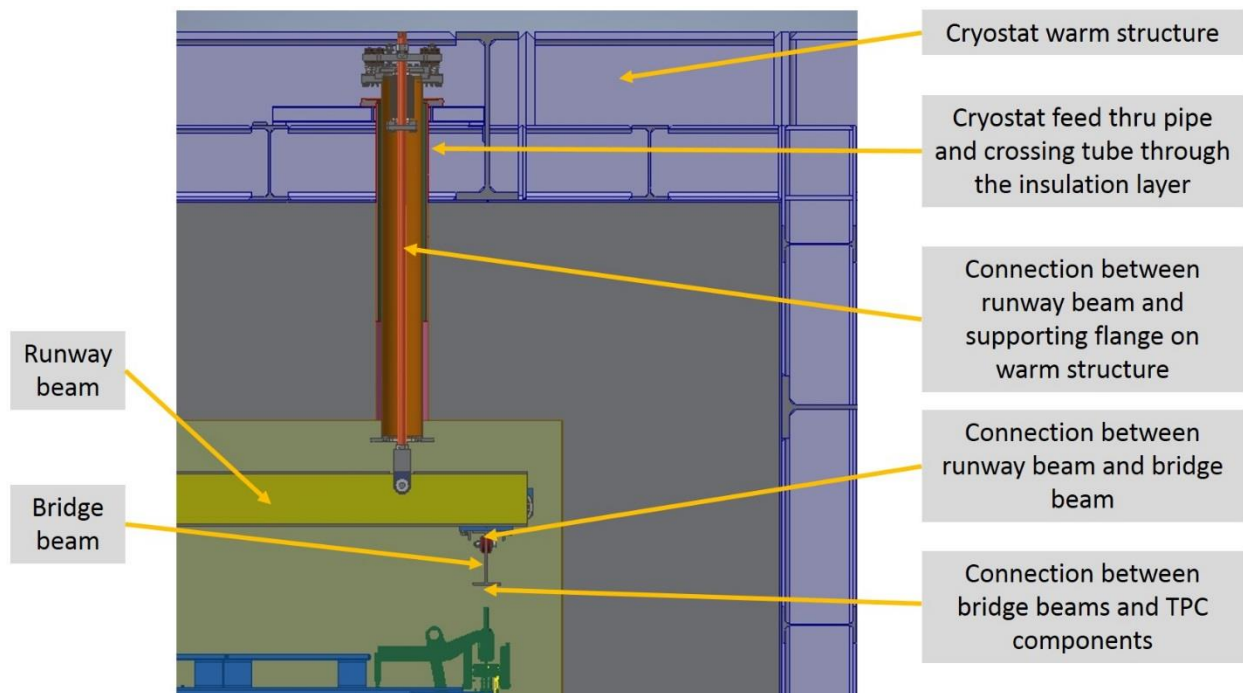


Figure 4

Interface and connection to the cryostat warm structure

The DSS runway beams will connect and be supported at nine places to the cryostat warm structure. On the warm structure, a feed thru pipe will be welded to the 10 mm plate of the warm structure. A conceptual design of this support is shown in Figure 5.

For the support structure, the feed thru pipes will be 200 mm OD / 180 mm ID and will extend ~300 mm above the 10 mm plate. The exact distance above the 10 mm plate will be determined by the thickness of the additional support needed for the feed thru flange. These pipes will be supplied and analyzed with the cryostat. The feed thru pipe will extend ~ 100 mm into the cryostat insulation layer below the 10 mm plate and will be welded to a crossing tube of the same OD that is supplied by the cryostat membrane manufacturer. The crossing tube will then extend down through the inner 2 mm membrane where it will be welded to the membrane to create the seal at the primary membrane layer. **(we need figures here to show this. I will inquire from CERN)**

The feed thru pipe will be supported and braced above the 10 mm plate to the shorter I-beam members of the cryostat warm structure. The beam height of these members is 274 mm. This additional structure will be designed to carry and react loads from the TPC on the feed thru pipe such that no loads are transmitted to the crossing tube or the inner membrane. This additional structure is not part of this design paper.

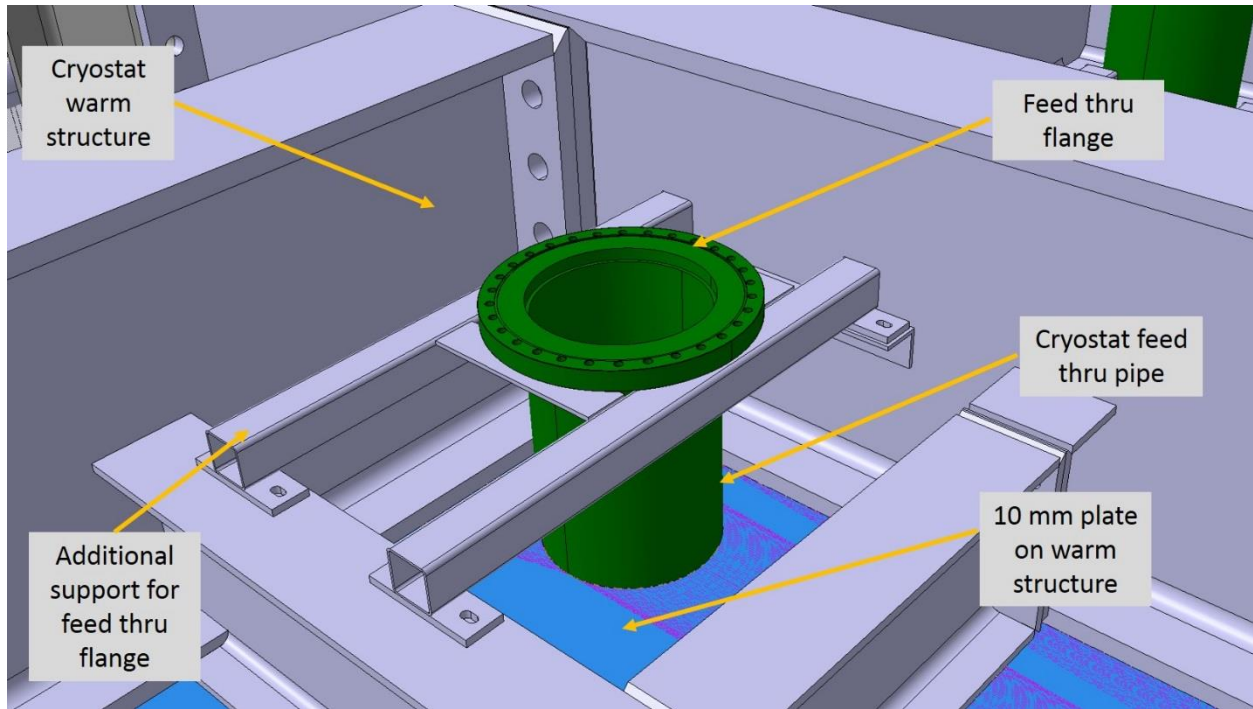


Figure 5 Detail view of the feed thru support and the cryostat warm structure.

At the top of the 200 mm feed thru pipe, a DN 250 conflat (CF) flange ring will be welded. This is a size larger than the standard flange for this pipe OD. These flanges have some custom attributes and will be machined from standard CF blanks. This is done to accommodate the 10 mm wall thickness of the pipe. Having the oversized flange gives us a larger surface area to be supported by the warm structure. It also gives us a larger surface area on the mating upper flange to connect the inner support rod that will extend down to the runway beams. The mating upper flange connection to the lower welded flange ring is the interface point between the DSS and the cryostat warm structure. CERN will provide the lower flange along with the additional supporting structure and ProtoDUNE will supply the upper flange along with the support rod. This is the flange support assembly shown in Figure 6.

Calculations of DSS motion will be used to set the position of the DSS so the TPC is in the proper position once the cryostat is filled and the TPC is cold. These calculations will include the roof deflection of the cryostat, the deflection of the support beams, and the shrinkage of all of the components in the DSS and the TPC. These calculations are in progress.

The baseline design of these connection points at the flange interface will have some vertical adjustment to vary the height of the three rows of the TPC. This feature may be used if it is found during commissioning that the TPC is out of position vertically. The movement of the top of the support rods can be monitored and adjusted during operation, if it is found that the roof motion is not as anticipated. The design also can be configured with or without vibration isolation. This feature can be used if it is found that mechanical vibrations are being transmitted to the APA and producing

microphonic induced electrical noise.

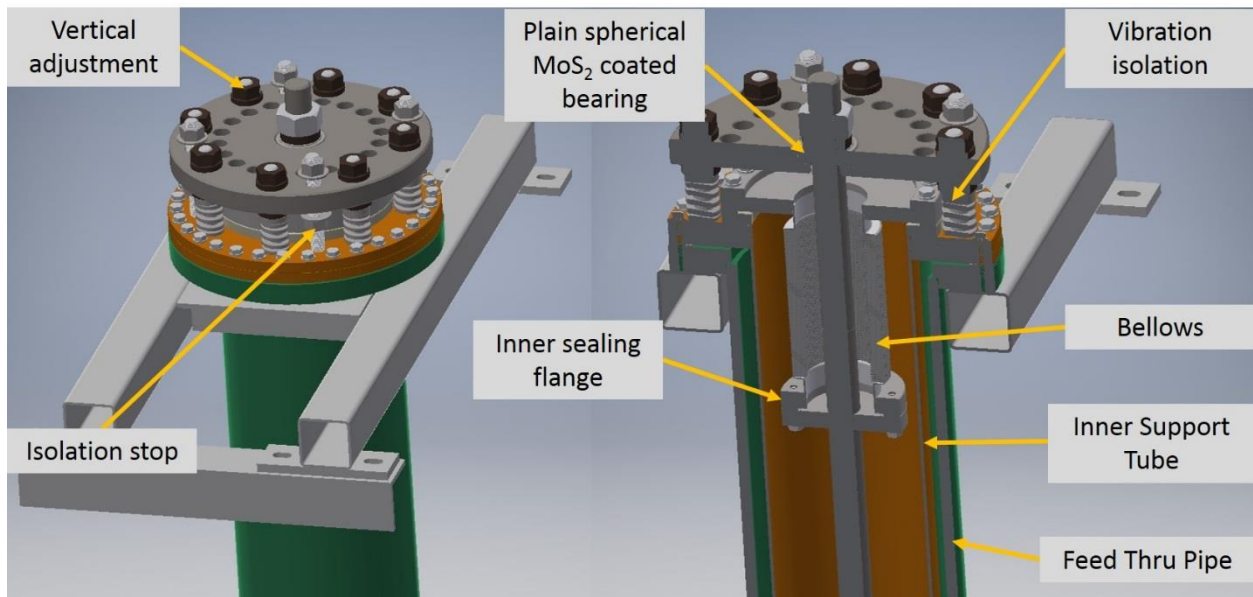


Figure 6

The support rod is fixed to the upper most flange using a plain spherical bearing. This bearing is coated with Molybdenum disulfide (MoS_2). The inner sealing flange is welded to the support rod to create a gas seal. This flange attaches to its mating flange that has been welded to a bellows. The bellows is used to allow the support rod to move as needed as the runway beam length changes during cooldown.

Flange support rod to runway beams

A support rod will be connected to the flange at the warm structure. This connection point will have a ball joint that allows the rod to move in all directions to accommodate the movement of the TPC during cooldown. The support rod will pass through the inner support tube that is also connected and supported by the flange at the warm structure. At the end of the inner support tube will be a restrictor plate. The restrictor plate will have slots machined through it to allow movement of the support rod passing through. These slots will be oriented to allow or limit the movement of the support rod in a controlled and predetermined manner. This is done to allow the TPC to move in pre-specified directions, as illustrated in Figure 7.

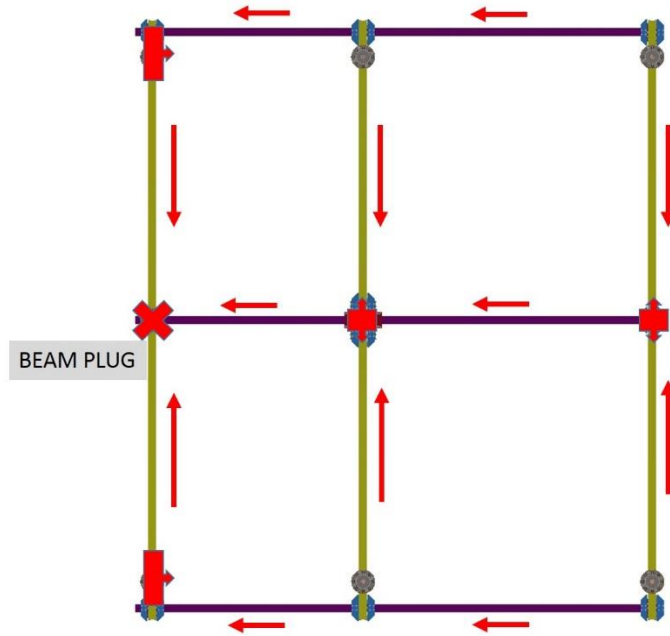


Figure 7

The degrees of freedom at each of the connection points were determined to minimize the distance change between the TPC and the membrane wall on the beam window side of the cryostat in the X direction. In the Y direction, the plan is to keep the CPA row position fixed and force the two APA rows to shrink towards the center. The slot orientations are done to allow for these movements.

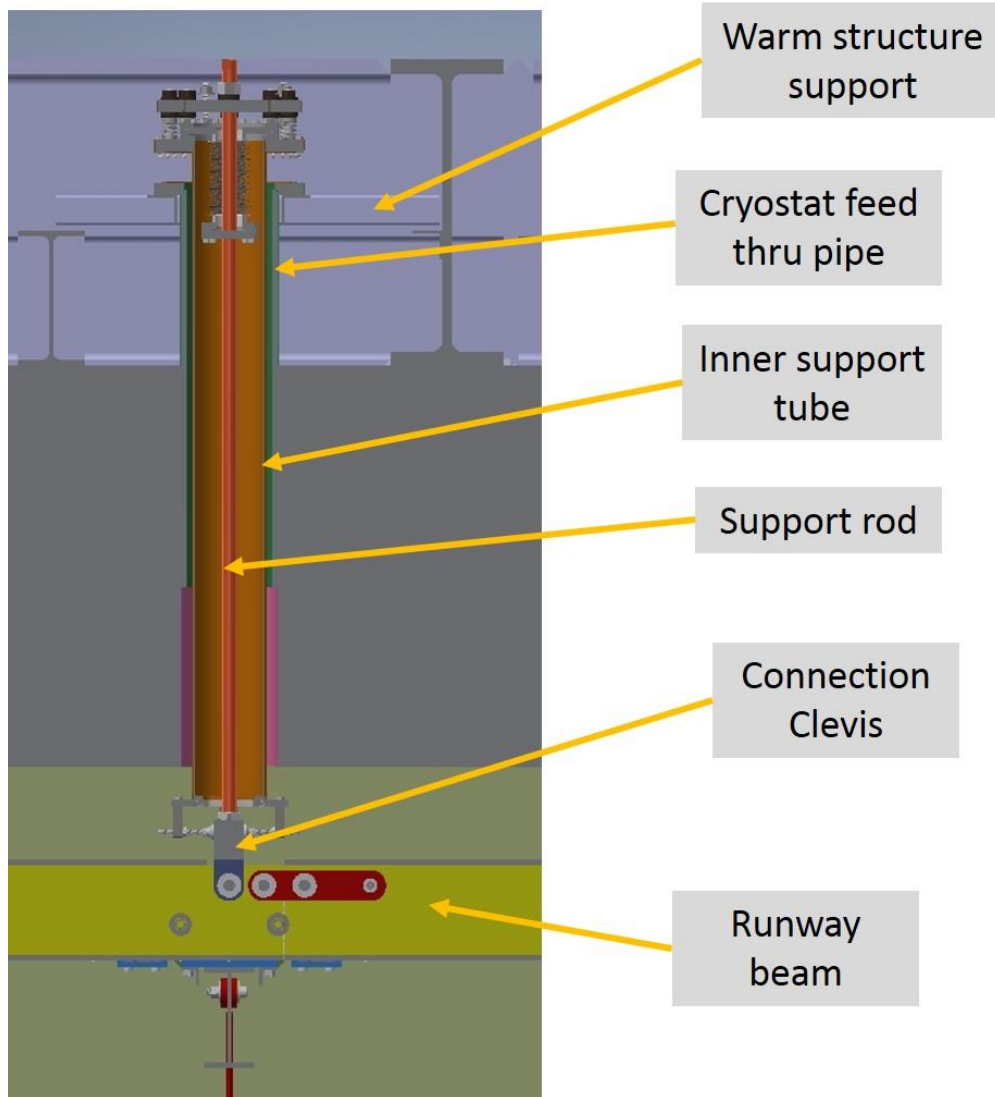


Figure 8

The movement of the TPC places minor horizontal forces on the inner support tube. The location and connections of the inner support tube is shown in Figure 8. This motion will result from installation tolerances in the TPC and pivoting with the cooldown of the TPC element. The inner tube has been designed to react these loads and transfer them to the flange connection at the warm structure. The analysis of this will be shown in the analysis section.

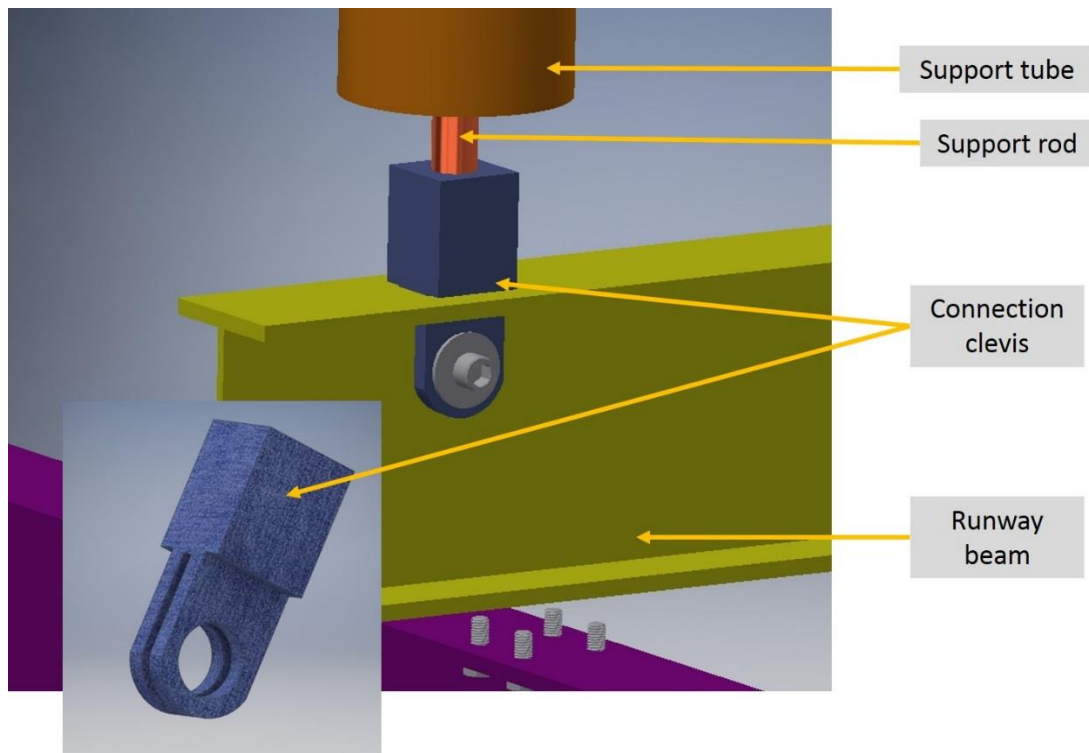


Figure 9

At the end of the support rod, a clevis will be attached. This is shown in Figure 9. Slots will be machined into the upper flange of the runway beam on each side of the web to allow the clevis to be inserted. A matching hole will be added to the web of the runway beam for the attachment of the clevis. This design allows for motion along the axis of the runway beam to accommodate the shrinkage of the beam during cooldown. The ball joint connection of the support rod at the flange will accommodate the change in angle of the support rod.

Runway beam to bridge beam connections

Other than the movement from the shrinkage of the components during cooldown, the runway beams will remain basically stationary. There may be some slight movements during the installation, but these can be accommodated by the pivoting joint at the flange. However, the bridge beams will be used to translate the rows of TPC components from the TCO entrance to their positions in Y for the TPC. This will be accomplished by fixing a trolley to the upper flange of the bridge beam and allow it to travel on the lower flange of the runway beam. This is shown in Figure 10.

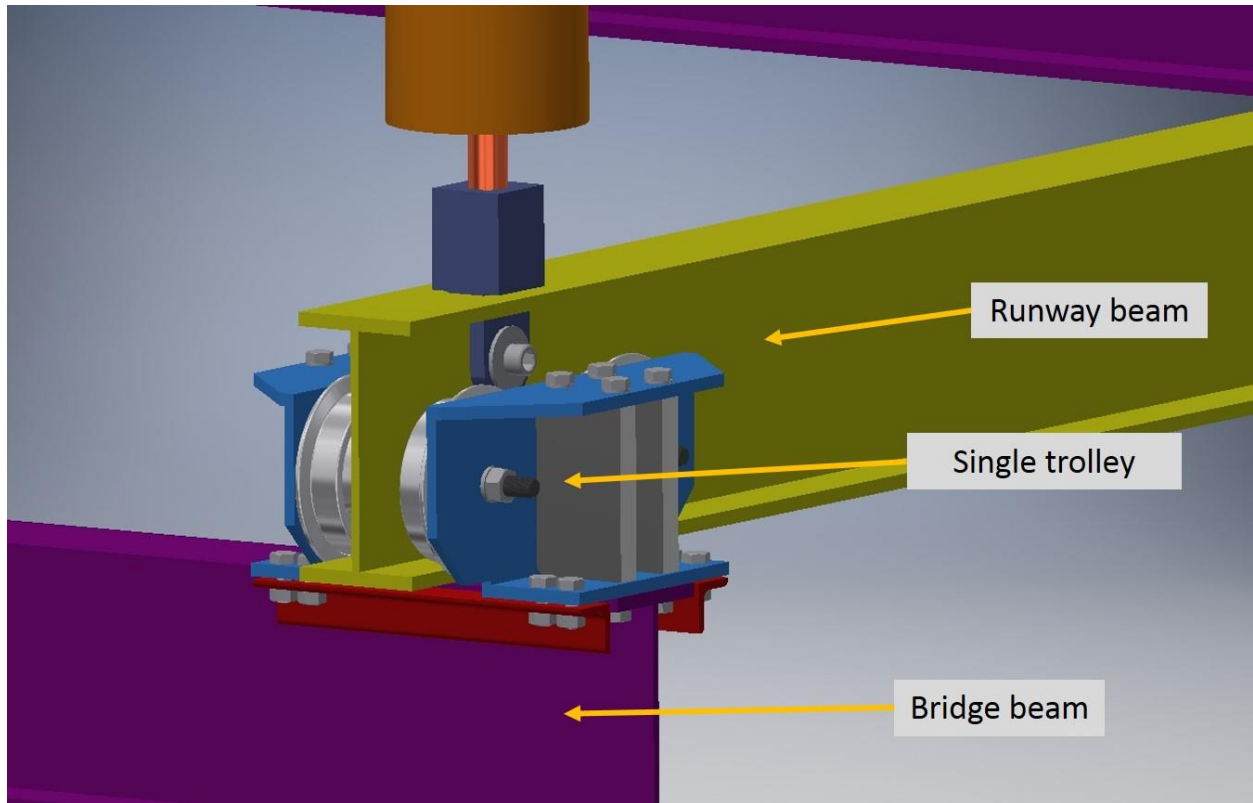


Figure 10

The trolleys are customized for use at cryogenic temperatures. They were designed without lubricants and manufactured from alloys and composite materials that maintain their ductility. Detailed views of a single trolley are shown in Figure 11.

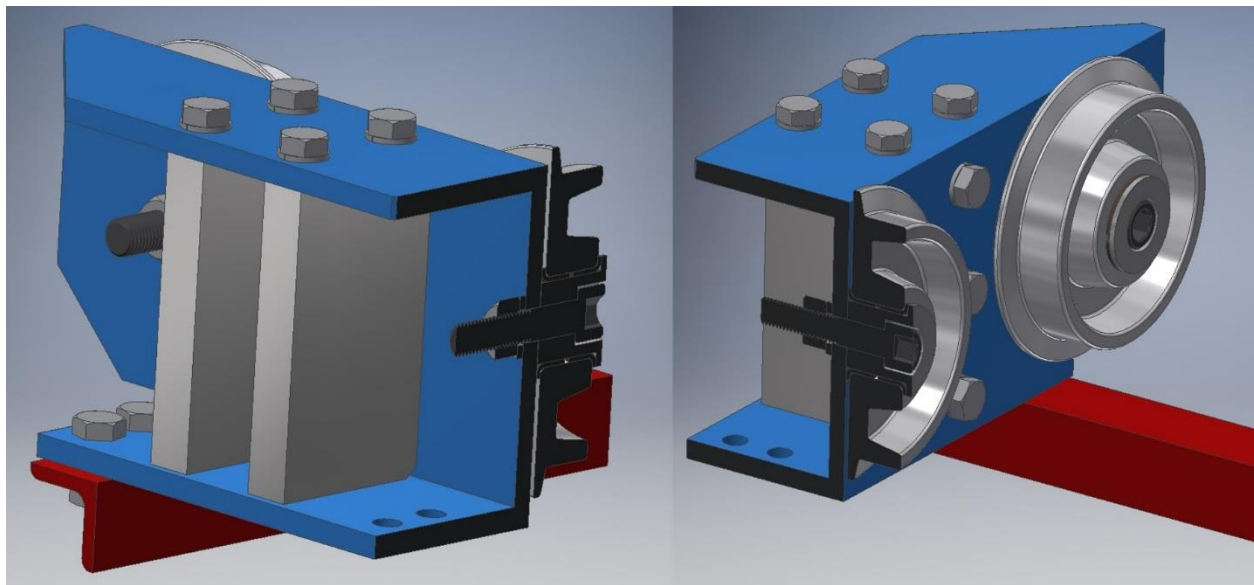


Figure 11

One major issue for use at cryogenic temperatures is the rolling surfaces. Many bearing materials become brittle at cold temperatures and their load capabilities are drastically reduced and very hard to predict. For these trolleys, which will remain loaded in the cold, the bearings are replaced with an SKF bushing that is rated for -200 °C. The cross section of this assembly is shown in Figure 12. The bushing consists of coated steel backing with a layer of sintered tin/bronze. The pores are completely filled and covered with a running-in layer of PTFE with MoS₂ additives. A four to one wheel to bushing diameter ratio will help reduce the rolling friction of the trolley.

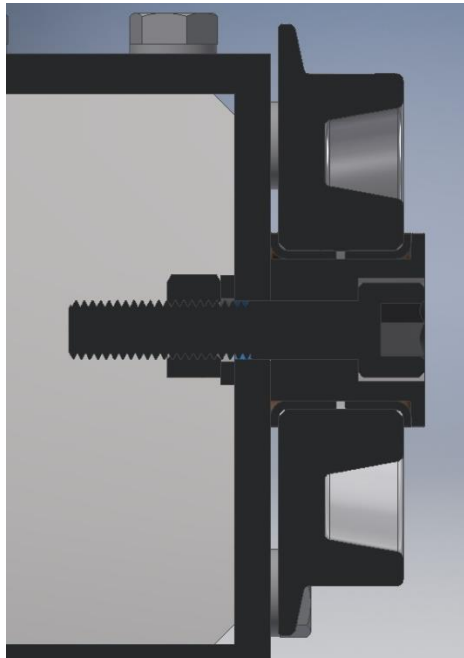


Figure 12

The loading of the bridge beam is the greatest at the center most support point in the cryostat. A double trolley has been designed to accommodate these loads. The double trolley uses many of the same features as the single trolley, however there are 8 roller assemblies to accommodate the higher loads. To ensure that the trolley wheels share the load, the trolleys are mounted on pivot points to an interconnecting beam. A view of the double trolley is shown in Figure 13.

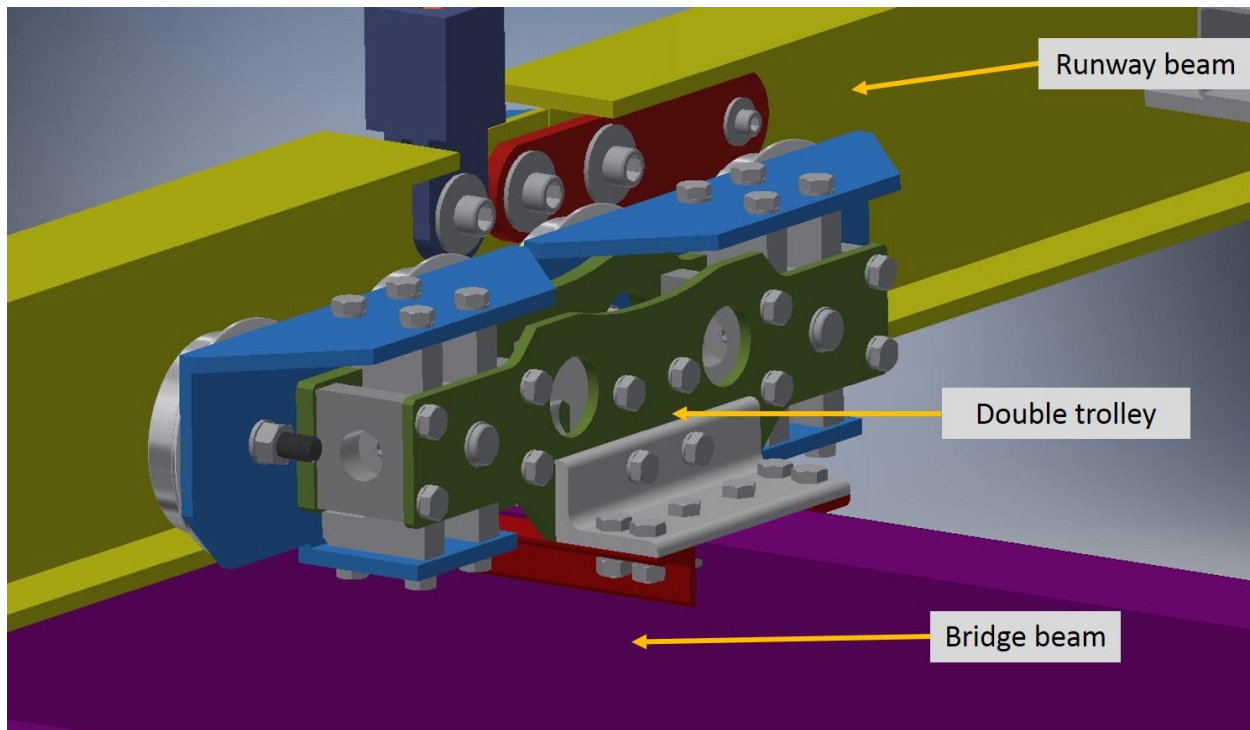


Figure 13

Bridge beam to APAs and CPAs

The APAs and CPAs will be moved into the cryostat onto the bridge beams positioned at the TCO. Trolleys will be used to move these items on the bridge beams. For this, commercially available trolleys will be used. The APAs will be moved supported by two trolleys that are equidistance from the center of the APA. Once the TPC elements reach their appropriate position on the beam, the APAs will be translated to a stationary permanent support rod for each element located at the center of the APA. Features will be machined on the lower flange of the bridge beam to make this connection. For the APA, this is shown in Figure 14.

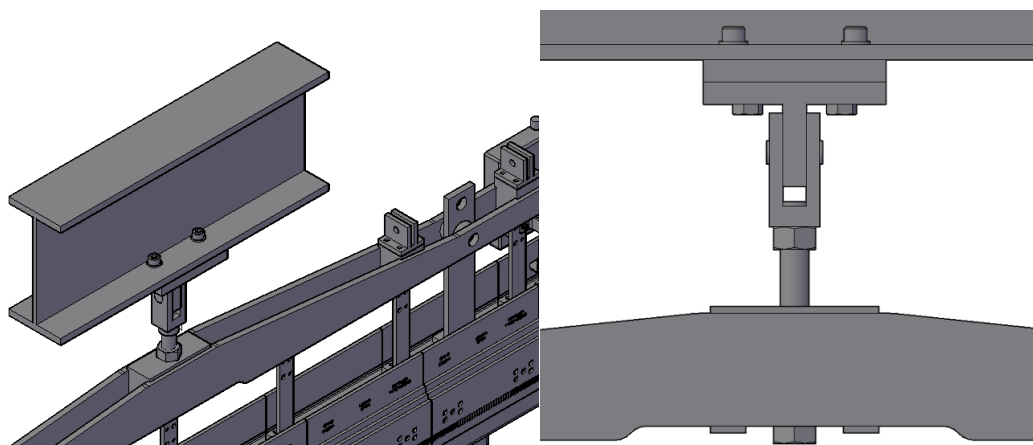


Figure 14

The left panel shows the connection from above. A plate is bolted from the lower flange of the bridge beam from above. The fasteners are located to allow the wheels of the trolleys to pass. The right panel shows an elevation view of the connection. An articulating hanger will be attached at the top of the APA. At the top of the hanger will be a fixation plate. When in position, the plate on the hanger and the plate fastened to the bridge beam will be bolted together from below. This connection method is used as access to this area will be limited during installation. After the permanent connection is made, the temporary connections to the trolleys will be unloaded using vertical adjustment of the central hanger. The trailing trolley will be removed by pushing it back up the bridge beam that it just traveled. And for the first APA, the leading trolley can be removed by pushing it off the opposite end of the bridge beam. However for APA 2 and 3 in the row, the leading trolleys will be trapped between the two APAs. It is possible to partially disassemble the trolley to remove or simply leave it inside. If it is left inside, care must be taken to insure that there are no materials or lubricants that may contaminate the LAr.

Unlike the APAs that are moved on two trolleys into the cryostat and then transferred to a central hanger, each CPA will only be attached to one trolley while being moved. This trolley will be positioned in the same point where the permanent connection will be made. The CPAs will be moved in pairs as they will also have the top and bottom field cages attached. The pair will act similarly to the APA while being moved. The transfer to the permanent hanger is similar to that of the APA but the hardware must be modified to accommodate the position of the trolley. Details of this are shown in Figure 15.

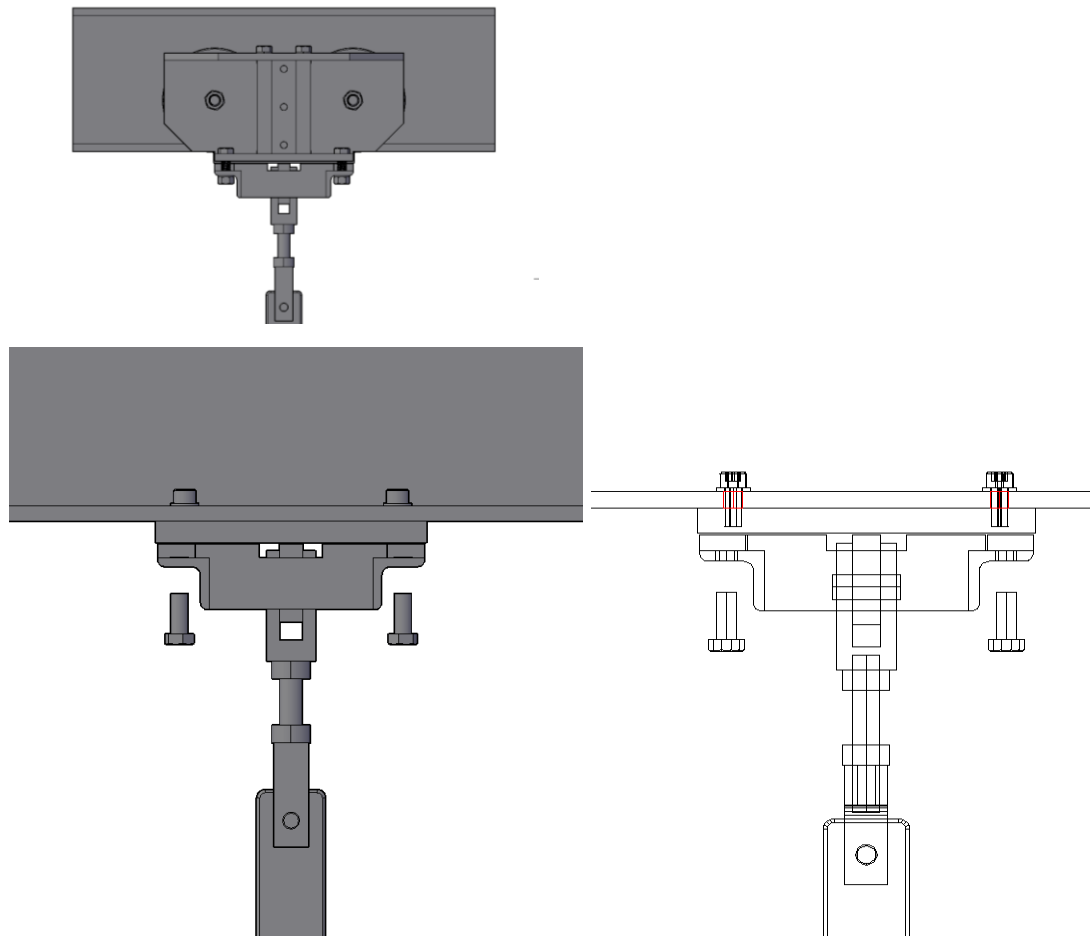


Figure 15

In the top panel, the CPA is shown attached to the trolley on the bridge beam. A similar plate to that of the APA will be bolted to the lower flange of the bridge beam. The trolley connection to the CPA will be modified to straddle and pass by the plate bolted to the lower flange. Once in position, the plate at the top of the CPA hanger will be bolted to the plate on the lower flange. The bolts that held the CPA to the trolley can be removed. Then the trolley is free to be removed, and the CPA is supported by the bridge beam.

Bridge beam to end wall FC during installation

Bridge beam to end wall FC final position

Articulating joint in each beam

Each of the bridge and runway beams will have one articulating joint at its approximate mid-point. Exact locations are shown in Figure 16. These joints will allow the beam to articulate in the vertical direction. This motion is needed to accommodate the various deflections in the roof of the cryostat. Without these joints, the support system would try to transfer these deflections to the beams through the support rods and the support rods would become overloaded. Details of this joint are shown in Figure 16.

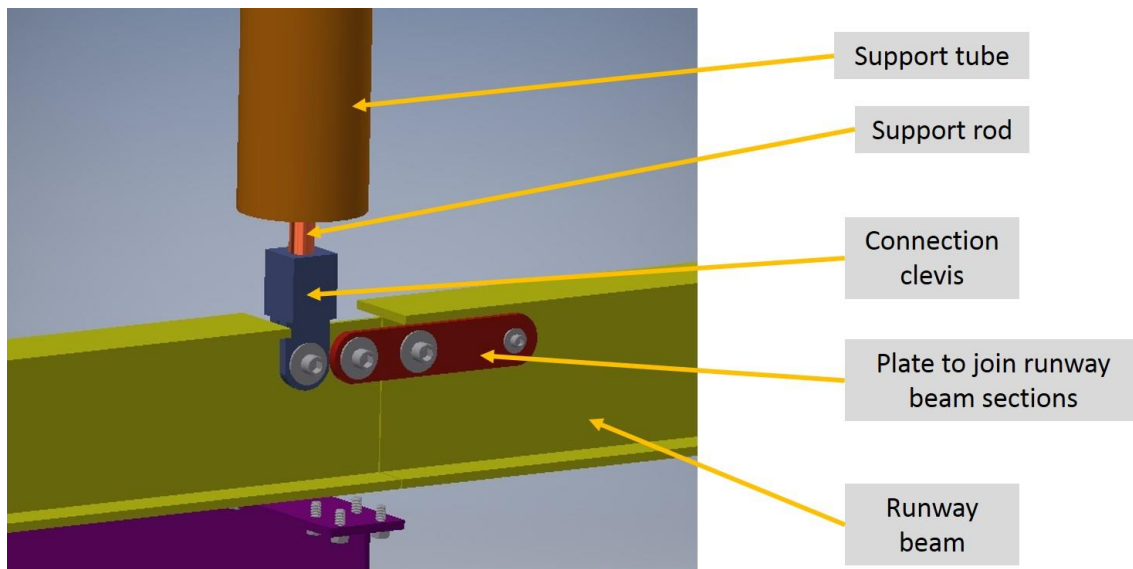


Figure 16

Interface to internal cryogenic piping

The internal cryogenic manifolds occupy the space near the inside ceiling of the cryostat on the Jura side. The proximity is shown on Figure 17.

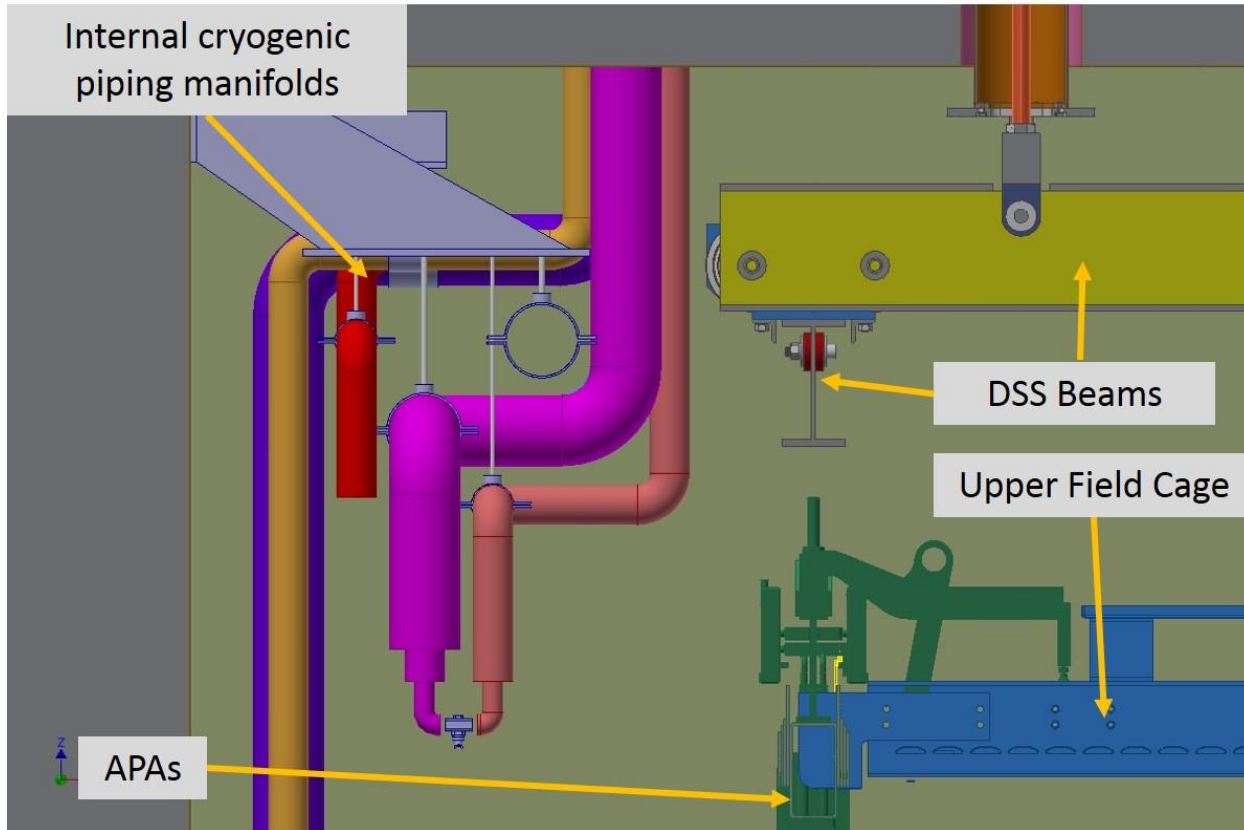


Figure 17

5.0 Materials

Materials used and properties


I-beams

The I-beams specified for the structure are S sections. Specifically, these are S8 x 18.4. This corresponds to a beam that is 8 inches (203.2 mm) and has a weight 18.4 lbs/ft (27.38 kg/m). For stainless sections of this size, they are manufactured using a laser fusion technique. These sections are produced by welding individual flat laser cut strips of the base material together. Some examples of the laser fusion beams are shown in Figure 18. Laser fusion is a type of laser welding that does not add filler material in the process. The use of lasers creates a very small heat affected zone, which reduces distortion. Using flat laser cut strips produces a final product with a higher quality surface finish.



Figure 18

The base material will be 304L grade stainless steel that conforms to ASTM A1069 (Standard Specification for Laser-Fused Stainless Steel Bars, Plates, and Shapes), ASTM A6 for dimensions and EN 1090, which is requirement for structural steels sold and used in Europe. The beams will be supplied with material compliance and test reports as per EN 10204 3.1. An example of this is shown below.



9004177

Stainless Structural Works, LLC
575 Conroe Park West Drive
Conroe, Texas 77303

Product		MTR#	
S8X18.4		400206	
Bundles	PCS #	Weight (lbs)	Length (in)
400318	5	1832	240
400319	2	736	240

SHIP TO:
STAINLESS STRUCTURALS LLC
575 Conroe Park West Drive
Conroe, Texas 77303

Grade	PO Nr.	Certificate
304/304L	3721	EN 10204 3.1
Melting	Net Weight	Standard
EA/AOD	2568	ASTM A1069

Heats	C	Si	Mn	P	S	Ni	Cr	Mo	Ti	Al	N	Cu
03035D	0.012	0.272	1.768	0.029	0.001	8.047	18.089	0.354	0.000	0.000	0.079	0.488
06047A	0.014	0.236	1.794	0.032	0.001	8.041	18.312	0.315	0.000	0.000	0.079	0.410
	Rm (KSI)	Rp (KSI)	Rp1% (KSI)	A2%	Z%	HB						
03035D	91.76	54.23	0.00	50.52	65.33	160.00						
06047A	92.04	52.60	0.00	53.09	65.01	158.00						

- We hereby confirm that the material certified in this document is conform to enclosed data sheet
- Anti mixing checked
- No weld repair on base material
- Material free from Mercury and radioactive contamination
- Parent material solution annealed
- Material is produced in compliance with ROHS (2002/95/EC)
- Country of Melt WEB: USA FLANGE: USA
- Country of Manufacturing Origin: USA

MTR date of emission:	08/11/16
The Work's Inspector (signature)	<i>Mike Scott</i>
Mike Scott	

Many producers offer post-production machining. We plan to purchase these beams with all of the machining completed and features added. After welding and any post-machining or straightening, the beams are shot blasted and passivated to prevent any corrosion in the processed surfaces. The need for additional testing and certification for the load bearing sections is currently being evaluated.

Trolleys, Bushings and Bearings

Feed thru flange connections

All of the connections at the feed thru flanges will be designed using standard ultra-high vacuum CF materials. These parts are made from 304 stainless steel. The flanges will be sealed with either standard copper or Viton gaskets.

Fasteners

6.0 Loads, load cases and analysis

Load

An important requirement of the DSS is to deliver the TPC subassemblies to their final position in the TPC. The subassemblies are loaded onto their supporting bridge beam, and the bridge beam is then translated to the proper position on the rail beams.

The DSS must safely support the TPC subassemblies throughout the installation process and once in the final position.

The mass of the TPC elements are as follows:

Insert chart here.

Load cases

It is important to identify and analyze all the worst case loads and stresses for the many different installation load cases. Many cases do not represent the worst case loads. For instance, there is less bending stress in a beam when supporting one APA on a beam span than 2 APAs. Some installation configurations may load certain structural components more in one case and other components more in another case. This is generally true during the later phases of assembly when all the mass is hanging from the DSS and load is being transferred from one component to another.

Identification of load cases to be analyzed is determined by the following components through the load path from the bridge beam to the DSS support flange.

Bridge beam loads

There are five identical bridge beams that support the TPC subassemblies. During installation the AP plane and CPA planes are connected to the bridge beam on trolleys that are 1160mm apart. During installation the APAs are also supported on trolleys separated by this same distance. Since the CPA w/ FC weighs more than the APA, the CPA w/FC loading on the bridge beam needs to be analyzed. Furthermore, the bridge beam supports are not equal distance apart. As a result, it is only necessary to check the longer span section of beam. The worst case for this section of beam is when the load is maximum and the closest to the center of the beam. Please see the analysis section for results of this analysis.

Bridge to rail connection points (Trolleys)

In order to determine the maximum load on the bridge beam to rail beam connections, three load cases that exist near the end of the installation process are considered. The first case assumes that the CPA beam is fully loaded with FCs, the APP beam is fully loaded with APAs and the EW beam is fully loaded with EWs near the center of the EW beam. This loading determines the maximum loading on the bridge beam to rail connections at the center of the CPA and EW beams. **This is probably not the maximum loading on the APA beam to rail connections and needs to be compared with the results from the third case.**

The second case assumes that the CPA beam is fully loaded with FCs, the APA beam is fully loaded with APAs and the EW load has been transferred to the CPA and APA beams. This loading determines the maximum loading on the CPA beam to rail connections on the ends of the beams.

The third case assumes that the FCs have been deployed and the CPA beam is carrying one end of the FCs, the APP beam is fully loaded with APAs and carrying the other end of the field cage, and the EW load has been transferred to the CPA and APA beams. This is actually the final dry loading of the DSS. **This should be the maximum loading on the APA beam to rail connections but should be compared with the loading from the first case.**

Rail beam loads

As with the bridge beam, it is important to check the heaviest load in the center of the longest span that will be seen during installation. The heaviest load on the rail beam will be the connection from the center of the CPA beam to the rail when it is in the center of the north drift span. Please see the analysis section for results of this analysis.

Rail beam to support rod connections

The three load cases that exist near the end of installation process that were considered for the bridge to rail connections are the same load cases that need to be evaluated for the support rod connections. The first case will determine the loading on the support rod at the center of the CPA beam. The second case determines the maximum loading on the support rod on the ends of the CPA beam. The third case should provide the maximum loading on the support rods above the APA beam, but should be compared to the first case.

7.0 DSS QA and Testing

The DSS functions much like an overhead crane and will be tested as such. Once the installation is complete, a proof load test will be conducted. For a crane, this test would have loads of 125% of the hoist capacity lifted and cycled through all range of motions. For the DSS, we will apply loads similar to those foreseen for the TPC components. The actual loads applied will be 125% of the TPC loads. The loads will be applied to the trolleys planned for the TPC in the clean room. Each of the loads will then be transferred to the position corresponding to the specific TPC component. Once the bridge beam is fully loaded, it will be translated in Y over the entire range of motion of the runway beams.

In order to compare the physical model to the mathematical model, we plan to measure the deflection of the bridge beam in specific locations to verify the calculations.

Some of these comparisons can be made in the trial assembly set up at Ash River, MN. Depending on the similarity of the prototype parts used in the test, similar measurements may be taken if suitable.

The only welds in the DSS design are connecting the bellows in the flange support assembly. These are at each end of the bellows and between the inner sealing flange and the support rod. None of these welds are structural, but they are gas seals. These will be He leak tested under vacuum to insure that they are leak tight before installation. We will test them to xxx leak rate. .

8.0 Installation

The DSS will be the first major system installed inside the cryostat after the completion of the membrane system.

9.0 Risks and Hazard Analysis

10.0 DUNE compatibility

11.0 Appendix

11.1 Calculations

11.2 Drawings

11.3 Materials

Table 1 Equivalencies for all grades of 304 and 316 Stainless Steel.

12.0 USA	France	Germany	UK	European Union
AISI	AFNOR	DIN 17006	BSI	EURONORM
304 ¹⁾	Z 6 CN 18-09	X 5 CrNi 18 10 X 5 CrNi 18 12	304S15 304S16	X 6 CrNi 18 10
304 N ¹⁾				
304 H ¹⁾				
304 L ¹⁾	Z 2 CN 18-10	X 2 CrNi 18 11	304S11	X 3 CrNi 18 10
	Z 2 CN 18-10- Az	X 2 CrNiN 18 10		
316 ¹⁾	Z 6 CND 17-11	X 5 CrNiMo 17 12 2	316S31	X 6 CrNiMo 17 12 2
316 ¹⁾	Z 6 CND 17-12	X 5 CrNiMo 17 13 3	316S33	X 6 CrNiMo 17 13 3
316 F ¹⁾		X 12 CrNiMoS 18 11		
316 N ¹⁾				

12.0 USA	France	Germany	UK	European Union
AISI	AFNOR	DIN 17006	BSI	EURONORM
316 H ¹⁾				
316 H ¹⁾				
316 L ¹⁾	Z 2 CND 17-12	X 2 CrNiMo 17 13 2	316S11	X 3 CrNiMo 17 12 2
	Z 2 CND 17-12- Az	X 2 CrNiMoN 17 12 2		
316 L ¹⁾	Z 2 CND 17-13	X 2 CrNiMo 18 14 3	316S13	X 3 CrNiMo 17 13 3
	Z 2 CND 17-13- Az	X 2 CrNiMoN 17 13 3		
	Z6 CNDT 17-12	X 6 CrNiMoTi 17 12 2	320S31	X 6 CrNiMoTi 17 12 2
		X 10 CrNiMoTi 18 12	320S33	X 6 CrNiMoTi 17 13 3
	Z 6 CNDNb 17- 12	X 6 CrNiMoNb 17 12 2		X 6 CrNiMoNb 17 12 2
		X 10 CrNiMoNb 18 12		X 6 CrNiMoNb 17 13 3

1) Austenitic grades

Table 2 Mechanical properties of various grades of Stainless Steel

Room temp properties of 304 SS

	UTS ksi. (MPa)	0.2% YS ksi. (MPa)	Elongation % in 2" (50.8 mm)	Rockwell Hardness
Type 304	95 (655)	42 (290)	55	B84
Type 304L	95 (655)	40 (276)	55	B82

Low temp properties of 304 SS

Condition	Temperature °F (°C)	UTS ksi. (MPa)	0.2% YS ksi. (MPa)	Elongation % in 2" (50.8 mm)
Annealed	-320 (-196)	235 (1620)	56 (386)	40
	-80 (-62)	161 (1110)	50 (345)	57
	-40 (-40)	145 (1000)	48 (331)	60
	32 (0)	122 (841)	40 (296)	65
	70 (21)	85 (586)	35 (241)	55

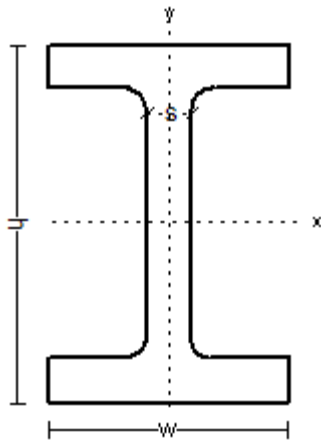
Physical properties of 304 SS

Density, lbs./in. ³ (g/cm ³)	0.29 (8.03)
Electrical Resistivity, $\mu\Omega\cdot\text{in.}$ ($\mu\Omega\cdot\text{cm}$)	
68 °F (20 °C)	28.4 (72)
1200 °F (659 °C)	45.8 (116)
Thermal Conductivity, BTU/hr./ft. ² /°F (W/m/K)	
212 °F (100 °C)	9.4 (16.2)
932 °F (500 °C)	12.4 (21.4)
Mean Coefficient of Thermal Expansion, in./in./°F ($\mu\text{m}/\text{m}/\text{K}$)	
32 – 212 °F (0 – 100 °C)	9.4×10^{-6} (16.9)
32 – 600 °F (0 – 315 °C)	9.9×10^{-6} (17.3)
32 – 1000 °F (0 – 538 °C)	10.2×10^{-6} (18.4)
32 – 1200 °F (0 – 649 °C)	10.4×10^{-6} (18.7)
Modulus of Elasticity, ksi. (MPa)	
in tension	28.0×10^3 (193×10^3)
in torsion	11.2×10^3 (78×10^3)
Magnetic Permeability Annealed, (H/m at 200 Oersteds)	1.02 max.
Specific Heat, BTU/lbs./°F (kJ/kg/K)	
32 – 212 °F (0 – 100 °C)	0.12 (0.50)
Melting Range, °F (°C)	2550 – 2650 (1399 – 1454)

Table 3 Dimensions of I Shaped cross sectioned beams

Designation	Dimensions					Static Parameters			
						Moment of Inertia		Elastic Section Modulus	
Imperial (in x lb/ft)	Depth h (in)	Width w (in)	Web Thickness s (in)	Sectional Area (in ²)	Weight (lb/ft)	I _x (in ⁴)	I _y (in ⁴)	W _x (in ³)	W _y (in ³)
S 8 x 23	8	4.171	0.441	6.77	23	64.9	4.31	16.2	2.07
S 8 x 18.4	8	4.001	0.271	5.41	18.4	57.6	3.73	14.4	1.86
S 7 x 20	7	3.860	0.450	5.88	20	42.4	3.17	12.1	1.64
S 7 x 15.3	7	3.662	0.252	4.5	15.3	36.7	2.64	10.5	1.44

- $1 \text{ cm}^4 = 10^{-8} \text{ m}^4 = 10^4 \text{ mm}^4$
- $1 \text{ in}^4 = 4.16 \times 10^5 \text{ mm}^4 = 41.6 \text{ cm}^4$
- $1 \text{ cm}^3 = 10^{-6} \text{ m}^3 = 10^3 \text{ mm}^3$



I = moment of inertia

W = section modulus

The standard method for specifying the dimension of a American Standard Beam is for example W 20 x 86, which is *20 inches* deep with a weight of *86 lb/ft*.

- Britain : Universal Beams (UB) and Universal Columns (UC)
- Europe : IPE. HE. HL. HD and other sections
- US : Wide Flange (WF) and H sections