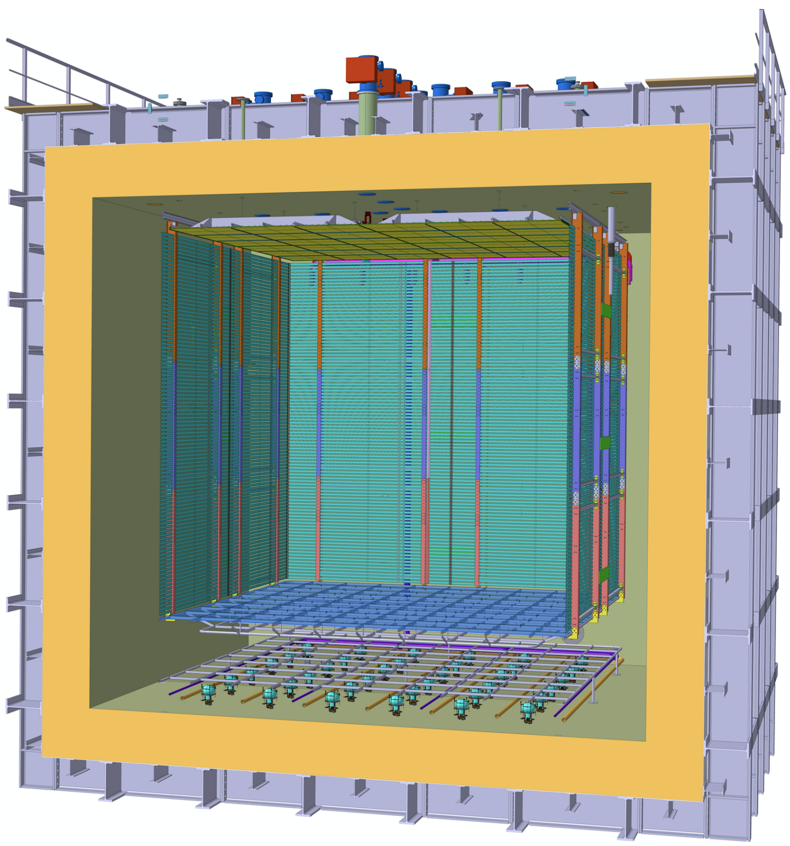
ProtoDUNE-DP installation sequence and load calculations

WA105 collaboration - June 2017

Draft



Abstract

This document describes the installation and provides the load calculations for each required detector components. It is organised as followed: part I briefly describes the detector concept and provides an overview of the construction and installation activities in various locations at CERN. The last chapter of part I summarises the installation sequence and identifies all the load cases of the various components during installation and operation of the detector. Part II provides the corresponding FEA calculations.

Contents

Part I

Detector and installation sequence overview

Chapter 1

Detector overview

1.1 Introduction

The ProtoDUNE-DP/NP02 detector is large liquid argon TPC working in dual phase mode with a fiducial volume of $6 \times 6 \times 6$ m^3. It will be constructed inside a large membrane cryostat in the hall EHN1. The dual phase liquid argon TPC prototype at CERN will give information about the construction and operation of one of the first 10 kt DUNE far detector modules and will measure and study the response of the detector to charged particles of different types and energies. The construction and operation of ProtoDUNE-DP will serve to validate the membrane cryostat technology and associated cryogenics, and the networking and computing infrastructure that will handle the data and simulated data sets. A charged-particle beam test will enable critical calibration measurements necessary for precise calorimetry. It will also enable the collection of important data sets for optimizing the event reconstruction algorithms – i.e., for finding interaction vertices and for particle identification – and ultimately for quantifying and reducing systematic uncertainties for the DUNE far detector. These measurements are expected to significantly improve the physics reach of the DUNE experiment. As shown in Figure 1.1 The experiment is located in the NP Hall (extension of building 887 – Prevessin site) on the beam line H2 from the SPS, zone 887/S2-T05. This experimental area is inside a trench of xxx depth and xxx m2. On the ground and first floor level are placed all the necessary installations for the experiment (electrical racks, cryogenics, etc.). Just next to the NP02 experimental area, there is a similar experiment called NP04, which differs from the first one for a different detector technology. This document is a follow up from the Initial Safety Information on Experiments at Cern (ISIEC) that can be found in EDMS 1806145

1.2 Main detector components

The detector is composed of multiple parts most of which are pre-assembled outside of the cryostat. The pre-assembled components are then brought inside the cryostat one by one in a well specified order through a Temporary Construction Opening (TCO). As shown in Figure 1.1 a clean room buffer (CRB) is attached to the cryostat. Filtered air is injected through one top opening of the cryostat and exits via the TCO through the CRB. The setup guaranties that the cryostat interior can be considered as a class 100'000 clean room and that both cryostat+CRB are at a few mbar over-pressure with respect to the EHN1 hall. The detector is composed of six main elements: the CRPs, the drift cage, the cathode, the ground grid, the photo-multipliers and the feedthroughs. A 3D CAD view is shown in Figure 1.2. Some Information on the main detector components and infrastructure is summarized in Table 1.1 and briefly described below.

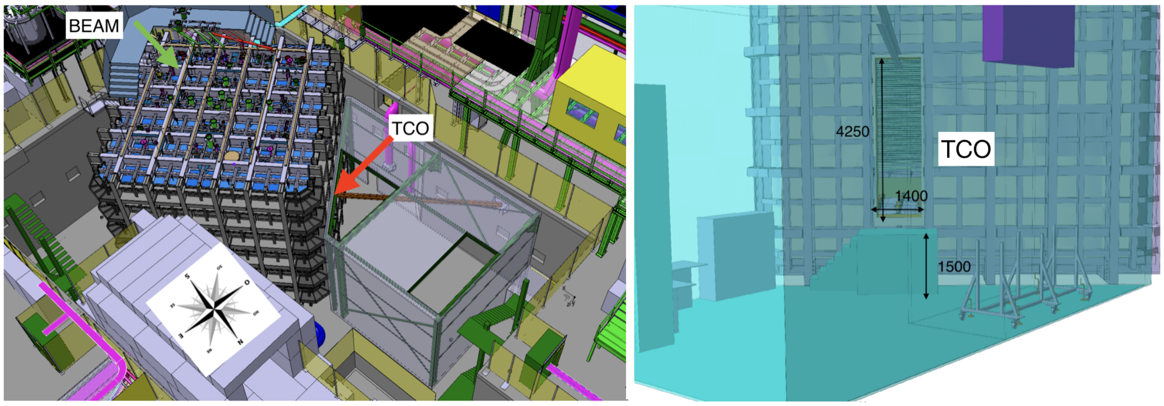


Figure 1.1: Left: overview of the experiment in the EHN1 extension. Right: view of the Temporary Construction Opening as seen from the CRB.

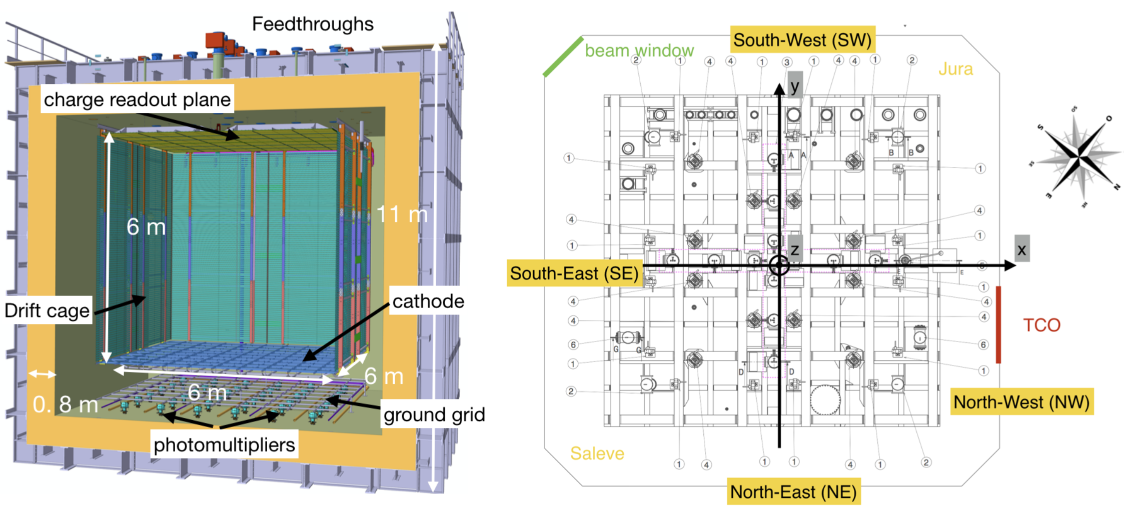


Figure 1.2: Left: cut view of the detector inside the cryostat. Right: 2D top view with coordinates.

The main chapters of this document then go in the detail of the installation procedure. Part II is dedicated to the load calculations. In Brief the detector is composed as follow:

- Four **Charge Readout Plane modules** (CRP), each of $3 \times 3 \times 0.5$ m^3. They will be assembled in the clean room of building 185 and brought to EHN1 in individual boxes at a delivery rate of about 1 module per month. Each CRP is suspended from the cryostat roof on 3 points through dedicated chimneys and attached to lifting devices on top of the roof. This allows to accurately aligne the CRPs with respect to the LAr surface. The final installation consists of a motorized system controlling the vertical position of the CRP modules during detector operation. Each CRP will be cabled to signal and slow control flanges.

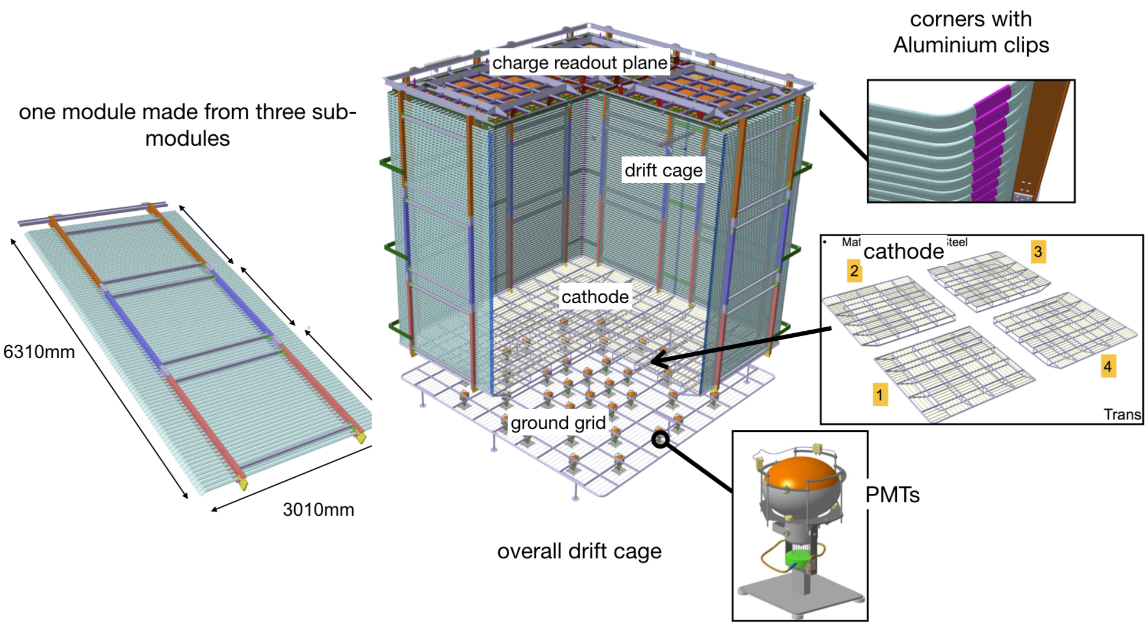


Figure 1.3: Exploded view of the detector

- The **Drift Cage** (DC, Figure 1.3) is made of extruded aluminum profiles inserted in Fiber-Reinforced Plastic (FRP) I-beams. The aluminum profiles are completely open in order not to trap air inside and to facilitate the evacuation of the impurities during the gas purge phase of the cryostat filling. The drift cage comes in fully assembled sub-modules of 2079 × 3017 mm^2 for ease of installation in the cryostat. Three sub-modules panels including 33 profiles with 60 mm pitch are integrated in a vertical module of 6238 × 3017 mm2 hanging from the roof of the cryostat. The bottom sub-module, which is supporting the cathode, includes, differently than the other two sub-modules, 32 profiles plus the cathode. In total there are 98 profiles per vertical module and two vertical modules per detector face. In total 8 vertical modules compose the field cage. The sub-modules will be built in the CRB and then installed inside the cryostat. The field cage construction proceeds by assembling the sub-modules in vertical modules chains which are progressively built and lifted towards the roof of the detector by using ropes suspended from the field cage hanging feedthroughs, one row at the time. At each corner the modules are connected via custom designed aluminum clips providing the electrical and mechanical continuity of the field shaping ring. Once assembled all the modules are fixed together with lateral FRP beams so that the final drift cage consists of one single rigid element.
- **the cathode** The cathode consists of a stainless steel (316L) mechanical structure made from tubes of various diameters: an external frame made from 40 mm tube, internal rectangular tubes of 20 × 40 × 2 mm^3 and smaller tubes of 12 mm diameter forming a grid. All diameters are optimized to guarantee a uniform drift field and minimize the local electric fields to ground. The cathode comes in 4 modules all of which are then bolted together and fixed to the bottom of the drift cage supporting FRP I-beams.
- **the ground grid** Similarly to the cathode the ground grid consist of 316 L stainless tubes. It also comes in 4 modules and is placed on the membrane floor by supporting feet. The central feet is glued to the membrane (glue: STYCAST 2850FT, Material Safety Data-sheet)

- **the photo-multipliers** An array of 36 Cryogenic Hamamatsu R5912mod02 photomultipliers are fixed on the membrane floor in the areas between the membrane corrugations. The fixation is done via a stainless steel supporting base that will be point glued to the membrane (glue: STYCAST 2850FT, Material Safety Data-sheet). The arrangement of the photomultipliers has been optimized in order to be compatible with the presence of the cryogenic piping on the membrane floor. The weight of the support overwhelms the photomultiplier buoyancy. Given the large standing surface of the stainless steel plate support basis, these supports will ensure as well stability against lateral forces possibly acting on the photomultipliers due to the liquid flow. The photomultipliers will be coated with TPB. A light calibration system has been designed in order to monitor the calibration of the PMTs installed inside the detector. An optical fiber will be installed at each PMT in order to provide a homogeneous and configurable amount of light.

Critical components to the functioning of the detector are the feedthroughs. More detailed drawings of each are provided in Appendix B.

- **Very high voltage feedthrough** provides the 300 kV to the cathode of the field cage. It follows a coaxial configuration and is made from stainless steel inner and outer conductors separated by a 100 mm diameter rigid high density polyethylene tube. A prototype manufactured by the company CINEL Strumenti Scientifici s.r.l. was successfully tested up to -300 kV in pure argon in a dedicated setup and is currently installed on the 3×3 m^2. Since the high voltage has to be guided from the top of the cryosat to the cathode, an extension been designed. The extension contains an inner conductor (at -300 kV) surrounded by an insulator. Since the extension runs over the entire height of the drift cage and approximately 20 cm away from the drift cage field shaping profile, metallic rings are installed on the periphery of the extension. Each ring is electrically connected to the drift cage profile immediately opposite, thus guarantying keeping the field in liquid at between the extension and drift cage to a minimal value.

- **signal feedthroughs** The signal feedthroughs (SGFT) guide the signals from the anodes to the front end amplifiers and to the digital electronics. A cut view and picture of a prototype SGFT is shown in Figure 1.4. Their design allows to place the amplification stage close to the anodes, thereby also profiting from the cold environment, while still being able to access the boards for maintenance. Each feedthrough reads out 640 channels and consists of a ~ 2 meter long stainless steel "chimney" sealed on both ends by circular multilayer printed circuit boards (PCBs) with connectors welded on both sides. The PCBs are carefully designed to provide ultra-high vacuum leak-tightness. The bottom PCB serves as interface between the connection to the anode and the 10 amplifier boards located inside the chimney. Each board is guided from the top thanks to specially designed FR4 blades. A complete insertion of the blade guaranties that the amplifier board is electrically connected to the bottom PCB. The top PCB then serves as interface between the amplified signals and the digital electronics located on top of the cryostat. The SGFT is therefore its own volume independent from the from the main cryostat volume. Prior to its operation the entire volume of the SGFT is pumped to residual pressure of about 1e-3 mbar in order to remove air and humidity and subsequently filled with gas nitrogen near atmospheric temperature. During cooling down of the cryostat and during detector operation the internal pressure of the SGFT remains near atmospheric pressure. In stable operating conditions the temperature of the gas nitrogen is measured to be around 140 K at the bottom of the tube and room temperature at the top. As indicated in Figure 1.4 the top flange of the SGFT has a pressure release valve fixed on a 10 mm internal diameter pipe and set at about 100 mbarG to protect the SGFT in case of unforeseen over pressures inside the nitrogen volume.

- **CRP suspension feedthroughs** The CRP is suspended by three cables, each of which is independently driven by a motor positioned on top of the cryostat. Details of those feedthroughs are provided in Chapter 4.

- **drif cage suspension feedthroughs** Each drift cage module is suspended by two ropes which are mounted from the cryosat roof by manual winches. The detail of those feedthroughs are provided in part II and in Appendix B.

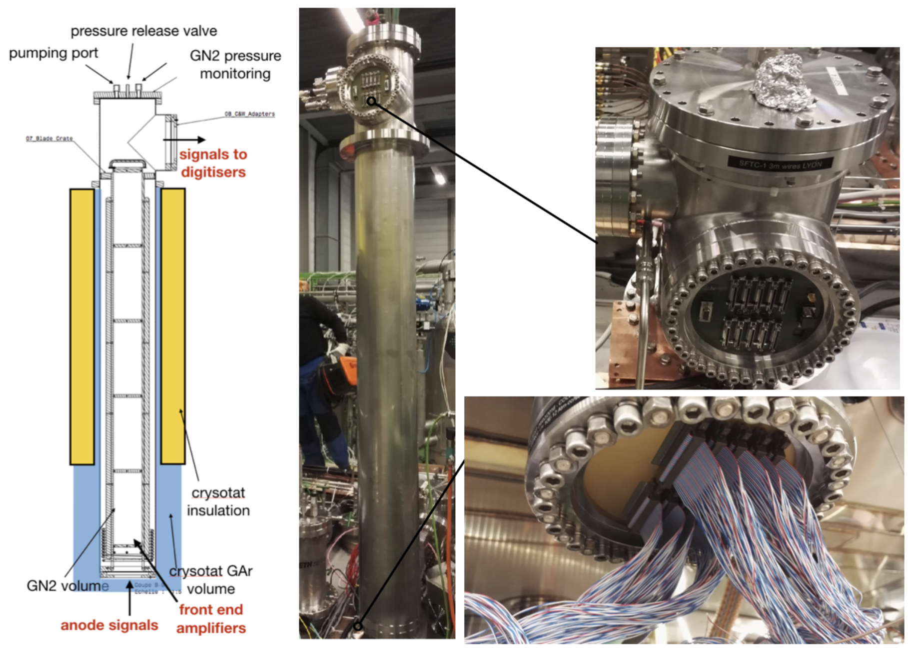


Figure 1.4: Details of one signal feedthrough. The picture are from one installed on the WA105-3×3 m^{2}detector.

1.3 Infrastructure locations and main activities

Below the three main locations where the integration and detector installation activities are listed. Table 1.2 summarises the different locations along with identified safety risks.

- **Clean room b. 185**. The assembly of the 4 CRPs will take place in the clean room initially constructed for the refurbishment of the ICARUS detectors. The facility is classified as ISO 8 (CLASS 100000) with a ventilation system that inputs filtered air and provide a constant 15 Pa over-pressure. The clean room has internal dimensions of 20560 (l)$\times$ 5980 (w)$\times$ 5295 (h) mm^3 and a sliding door with opening of 5900 x 4500 mm^2 for loading/unloading. More information can be found on EDMS1376017 or on the WA105-CERNbox. The main activities foreseen in the clean room of b. 185 are the assemblies of the four CRPs described in Chapter 2. .

- **Cryostat interior** The cryostat will be used as a class 100000 clean room. It has dimensions of 8000$\times$8000$\times$8000 mm^3 with a temporary construction opening (TCO) of 1400 (w)$\times$ 4250 (h) mm^2 located on the NW side that will have to be sealed once the installation of the detector

component	dimensions (one module)	weight (one module in air)	# modules	more information
CRP	$3 \times 3 \times 0.5 m^3$	400 kg	4	2D drawings (CERNbox)
Drift cage	$6.3 \times 3 \times 0.5\ m^3$	150 kg	8	2D drawings (CERNbox)
Cathode	$3.15 \times 3.15 \times 0.25\ m^3$	175 kg	4	presentation (CERNbox)
Ground grid	$3.15 \times 3.15 \times 0.25\ m^3$	40 kg	4	presentation CERNbox
PMTs + bases	$0.2 \times 0.2 \times 0.3\ m^3$	2 kg	36	3D drawings and presentations CERNbox
very high voltage FT	$2 \times 0.4 \times 0.4\ m^3$	50 kg	1	3D drawings and presentations CERNbox
signal feedthrough	$\oslash 0.2 \times\ 2.1\ m^3$	100 kg	12	2D drawings CERNbox
CRP suspension feedthrough	$0.4 \times 0.4 \times 1.25\ m^3$	50 kg	12	??
drift cage suspension feedthrough	$0.25 \times 0.25 \times 0.55\ m^3$	10	12	2D drawings

Table 1.1: some properties of the main detector components. Links to drawings or further information is also provided.

is complete. The TCO is located at 1500 mm height from the bottom of the pit making it level with the crysotat's temporary construction floor. Filtered air is injected from one of the top chimneys and exits through the TCO. The installation sequence of the detector inside the cryostat is described in Chapter 5

- **Cryostat Clean Room buffer (CRB).** The primary purpose of the CRB is to provide a semi-clean environment to avoid polution from entering the main cryostat. It will be used to assemble the drift cage sub-modules and for buffer storage of material. The CRB is fixed to the cryostat on one side and has a trapezoidal shape with external dimensions of 12600×8272×7228×8000. It is located at the bottom of the pit and completely covers the TCO. Details of the CRB are provided in EDMS-178297 or CERNbox. The main activities foreseen in the CRB are the assemblies of the drift cage sub-modules described in Chapter 3.

- **Cryostat roof.** Work will also take place on the cryostat roof in order to insert and cable the various feedthroughs. Particular cases are those of the suspension feedthroughs that allow to attach various detector elements and lift them into position. During detector installation each CRP frame is lifted by its three anchoring points by three manual winches which have to be independently operated from the cryostat roof. This activity will require simultaneously 3 worked on the roof to operate the winches and 2 workers inside the cryostat to visually check the lifting of the frames. Similarly for the drift cage each sub-module is suspended by two points and has to be lifted manually by two people situated on the roof.

location	main activities	chemicals	use of HV (<10 kV)	work under suspended objects	work at height on mobile elevating platform	soldering
clean room b. 185	CRP assembly	orthophosphoric acid, ethanol, alcohol, Stycast glue	yes	yes	no	yes
clean room buffer	DC sub-module assembly	ethanol, alcohol	no	no	no	no
cryostat roof	insertion of feedthroughs, cabling	ethanol, alcohol	no	no	no	no
cryostat interior	detector installation	ethanol, alcohol	no	yes	yes (up to 6 m)	no

Table 1.2: brief overview of the activities and safety aspects for each location.

1.4 Brief description of the installation sequence

An overview of the installation sequence in EHN1 is illustrated in Figure 1.5 and each step is described in more detail in the following chapter. All detector parts are modular for easy insertion through the TCO. The largest component is the CRP box with dimensions $3.1 \times 3.1 \times 0.7$ m^2. All detector material to be installed in the cryostat (including cables) are halogen free components with the exception of the FRP I-beams for the drift cage (total weight of FRP 1'326 kg). We understand that according to a derogation described EDMSxxx this amount is authorized. We foresee use of small amounts of cryogenic glue (STYCAST 2850FT, Material Safety Data-sheet) and alcohol. No welding activities by the detector installation team are foreseen inside the cryostat (with the exception of the TCO closure which is under the responsibility of CERN). A rather large amount of work on an elevating platform at about 6 meter height will take place, the workers will have undergone the relevant safety training.

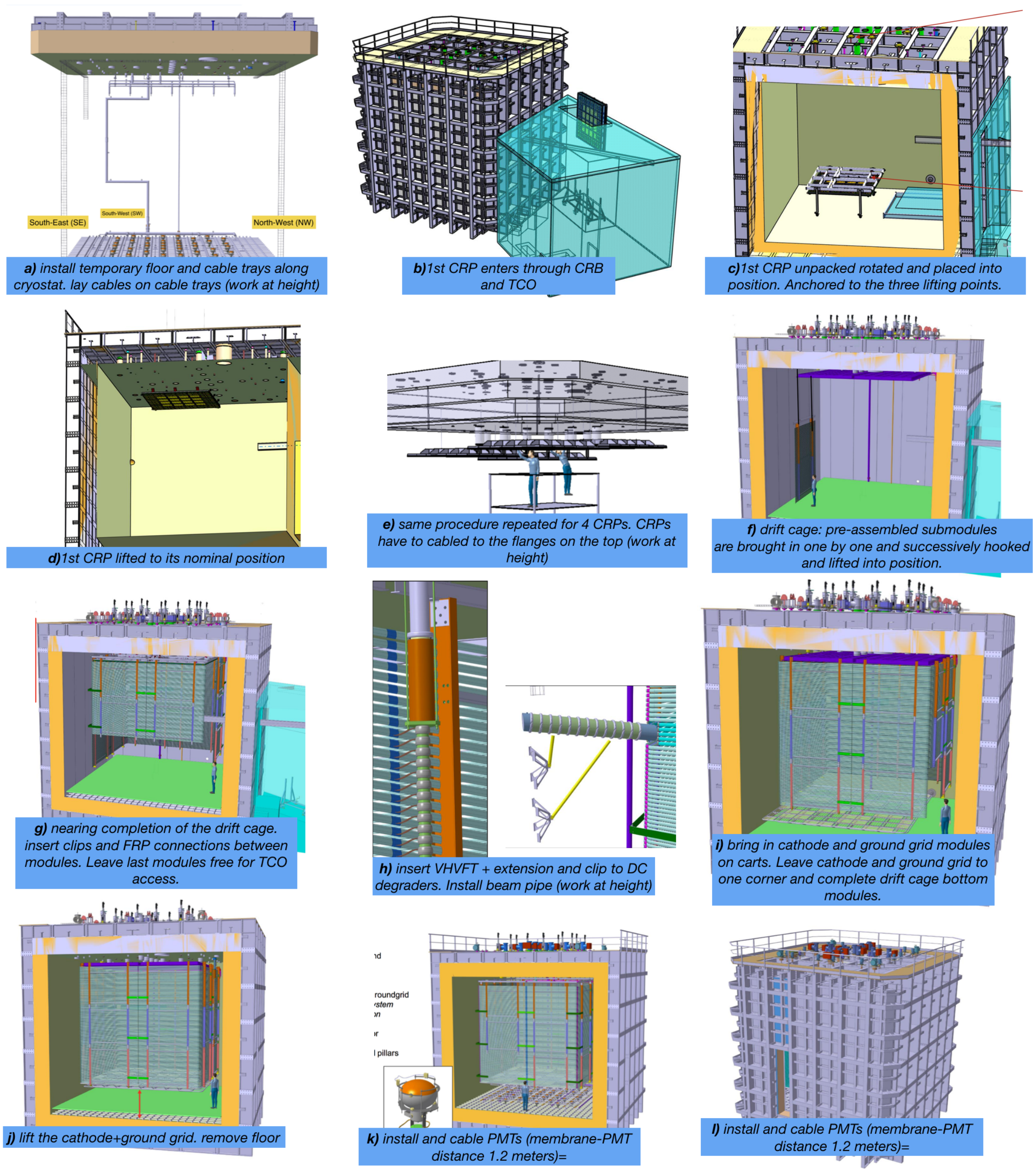


Figure 1.5: illustration of the mounting sequence in EHN1

Chapter 2

Construction of Charge Readout Plane in building 185 clean room

2.1 Overview of the design

The Charge Readout Planes (CRP) are the basic readout components of the protoDUNE-DP detector. This common design is based on CRP modules of 3×3 m^2 suspended from 3 points in order to be accurately aligned with respect to the LAr surface. The CRP includes a submersed extraction grid at 1 cm from the bottom face of the LEMs. The extraction grid and the LEMs bottom face define the electric field which is exploited in order to extract the electrons from the liquid to the gas phase. The liquid argon level should be across the 1 cm gap in between the grid and the LEMs. The suspension system allows adjusting the position of the gap with respect to the liquid level as well as the parallelism of the CRP plane with respect to the liquid surface. protoDUNE-DP consists of 4 CRPs pre-assembled and transported to EHN1 in ad-hoc transportation boxes. Each CRP integrates 36 LEMs and anodes of 50×50 cm^2. Figure 2.1 shows the integration of these 4 CRP planes in order to cover the 36 m^2 readout surface of protoDUNE-DP. The installation procedure at EHN1 will be mimicking as much as possible the DUNE underground installation procedure. Also the assembly and QA/QC procedures should as well represent a complete implementation test of the production chain foreseen for DUNE.

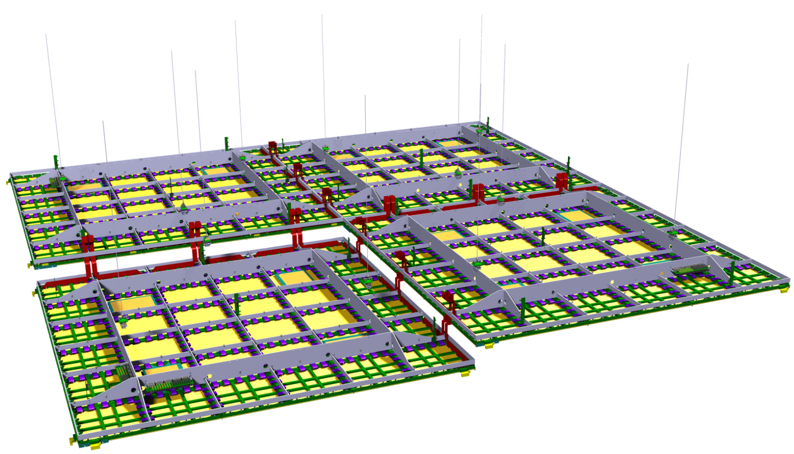


Figure 2.1: Four 3×3 m^2 CRP planes covering the 6×6 m^2 readout surface.

An important aspect of the CRP design concerns the planarity requirement of $\pm 0.5mm$ over the 3×3 m^2 CRP surface. The planarity requirement must be respected even in presence of a potential temperature gradient in the gas phase above the LAr level and of gravity effects on the CRP structure associated to its flexibility by the manner by which it is suspended. The CRP is subject to thermal contractions when put at cold. Differential contractions effects may occur because the structure includes composites materials and also because of the thermal gradient present in the argon gas, implying a different shrinking at various heights with respect to the liquid argon level. These differential effects may induce deformations and non-planarity conditions. The design of the CRP satisfies the planarity requirements mentioned above by exploiting a main structure built in Invar which then supports a G10 frame integrating the LEM-anode sandwiches. The G10 structure has a thermal expansion behavior very similar to the one of the LEM/anode sandwiches Figure 2.2.

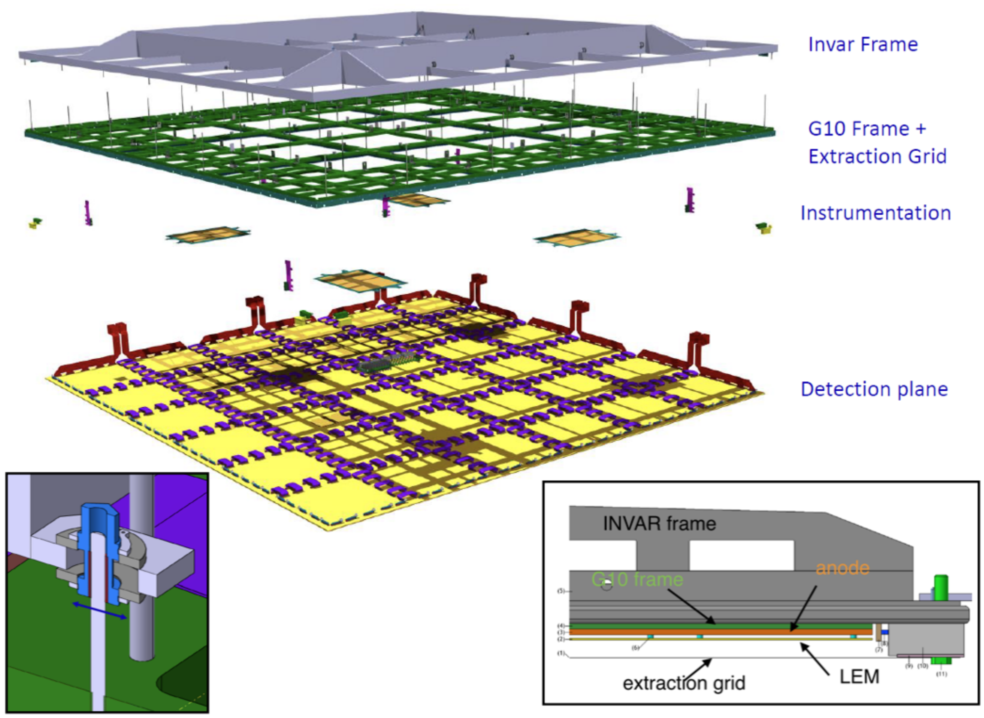


Figure 2.2: Exploded view of a CRP plane structure. The left snippet shows the decoupling mechanism for linking the CRP G10 frame (green) to the Invar main frame (gray). This mechanical support defines the vertical separation and link among the two frames but it is free to move horizontally in order to allow for the different thermal shrinkage. The right snippet shows a side view of the CRP clearly indicating the different components.

The Invar frame has little sensitivity to differential shrinkage effects related to the thermal gradient in the gas. The connection between the Invar and G10 frames integrates sliding decoupling mechanisms (Figure **??**) in the fixation points. 48 devices distributed on the $3{\times}3$ square metres surface are used to hang the G10 frame and anodes+LEMs assemblies. The decoupling mechanisms ensure the mechanical support from the Invar structure and a fixed vertical positioning of the two structures, while allowing for horizontal movements of the G10 frame related to the differential in thermal shrinkage. The G10 frames supports as well the submersed extraction grid. The extraction grid is made from 100 micron diameter wires matching the readout pitch of 3 mm and tensed across the 3x3 m2 area of the CRP. The 3m wires are soldered inside the clean room on Printed Circuit Board (PCB) wire holders by group of 32 with a specific toolin that keeps the wires under tension. Once on the frame, a specific system also allows for further adjustment of the wire tension. Illustrations and details of how the extraction grid is fixed to the frame are shown in Figure 2.3.

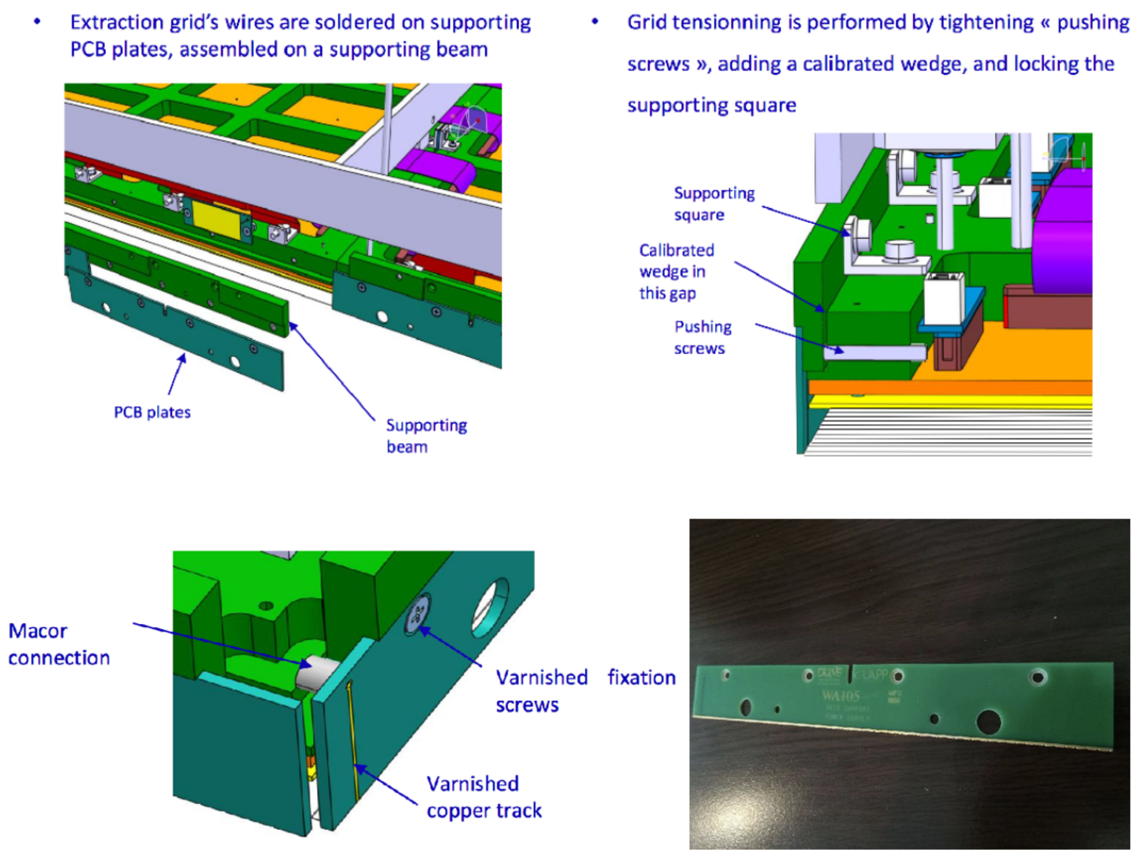


Figure 2.3: top:: illustration of the PCB plates that hold the wires and of the tensioning system on the frame. Bottom: details of the grid HV contact and picture of one PCB wire holder.

The CRP structure executive design has been thoroughly optimized by taking into account simulation results and a campaign of dedicated cold bath tests performed on a similar 3×1 prototype CRP. Open cold bath tests in liquid nitrogen accompanied by digital photogrammetry measurements and a full slow control instrumentation (temperature probes, strain gauges) have been systematically performed.

Each of the four CRP of ProtoDUNE-DP has 36 LEMs and anodes that need to be electrically connected to the different feedthroughs. Concerning the anodes, their role is to collect the amplified charge signals and guide them to the signal feedthroughs (see Section 4.5 for explanations on the signal feedthrough). As shown in Figure 2.4 the anode boards are electrically connected together providing continuous 3 meter long readout strips in both x and y directions. The strip are connected to the signal feedthrough at both their ends. One end is brought to the analogue and digital electronics for processing. The other end is connected to a system that distributes a pulse with a known amount of charge. This pulsing system permits a precise calibration of each strip and allows to check their electrical continuity at any time during data taking. Concerning the LEM, each board requires to be biased with two separate high voltage (HV) channels in order to provide sufficiently high electric field inside the holes for charge amplification. The voltages are typically of -1000 V on one side of the board and -4000 V on the other. 72 HV channels are hence required to operated the 36 LEMs of one CRP. In order to simplify the installation procedure of the cables two called "patch panel" are fixed on the periphery of each CRP. The presence of such interface boards provide the possibility of pre-cabling the large area CRP up to its peripheral edge during assembly, before the installation inside the main vessel. Particular care needs to be taken in designing the high voltage contacts (either on the LEMs or on the patch-panel) to avoid discharges in pure Argon gas. We have developed solutions for contacts in gas based on ceramic (Macor) insulators which have proven to be very reliable over the many years of operations on smaller prototypes.

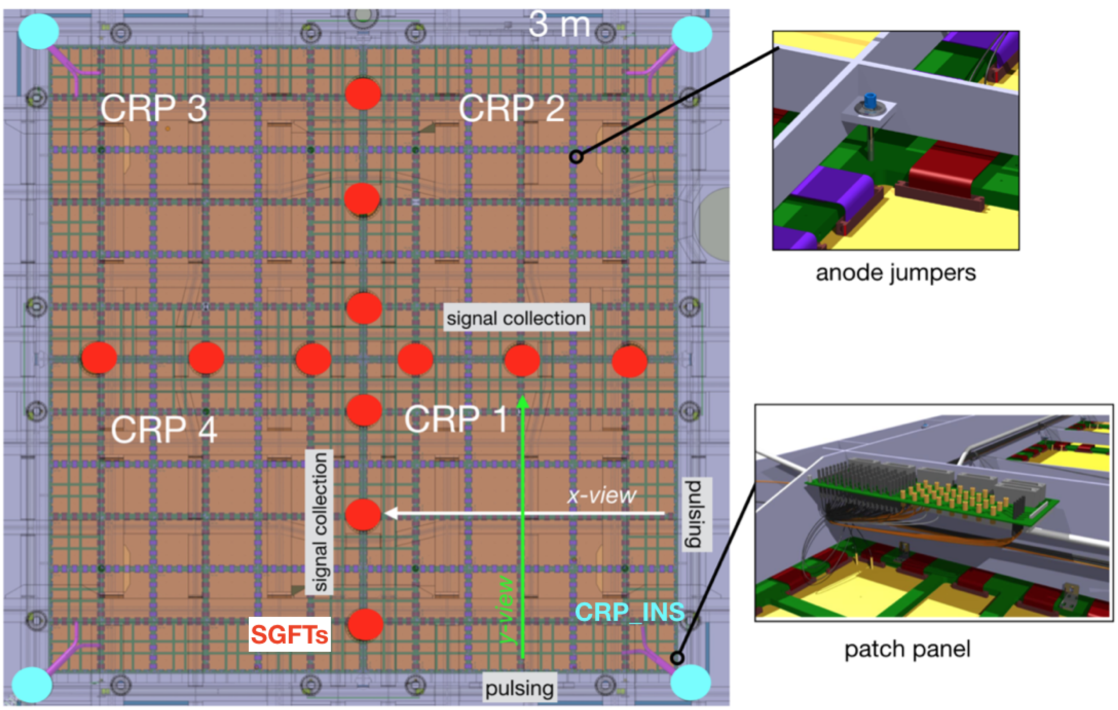


Figure 2.4: Top view of the detector showing the layout of the signal feedthrough (in red) and the CRP- instrumentation chimneys (in cyan) with respect to the 4 CRPs. The top zoom shows the details of the connection between two anode boards to provide the 3 meter long readout strips. The bottom zoom shows the details of the patch-panel

2.2 General CRP assembly procedure

The clean room of building 185 will be organized as shown in Figure 2.5 and the main steps of the construction are illustrated in Figure 2.6. A detailed animation on the assembly procedure is available by clicking here.

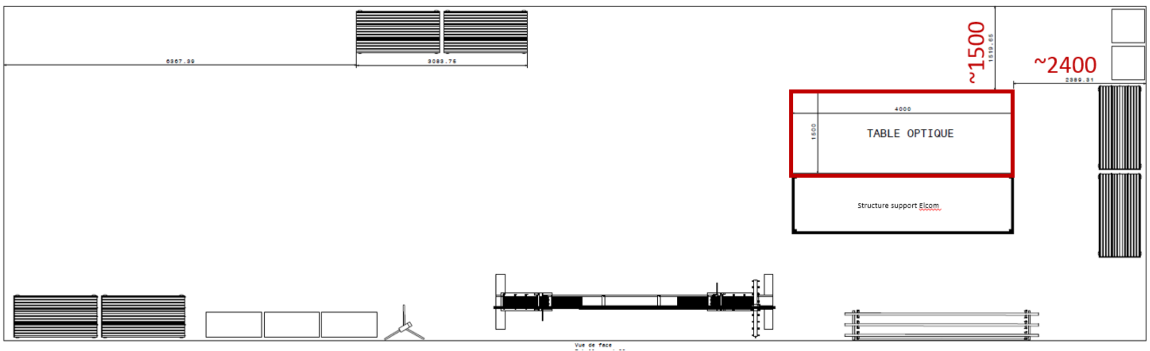


Figure 2.5: Layout ot the building 185 clean room during CRP installation

The $3 \times 3\text{m}^2$ Invar frame is brought inside the clean room and suspended under a movable assembly structure at approximately 1.5 meters height from the floor of the clean room (a). Meanwhile, the $3 \times 3\text{m}^2$ G-10 frame is assembled on an optical table as shown in step b (the frames is delivered as various parts of about 1 m^2). The Invar frame is then placed on top of the G10 structure and both parts are connected together with the decoupling screws described in the previous section (c). After that the 36 50×50 cm^2 LEM and anode modules are screwed one by one under the G10 frame (d,e). Each LEM+anode module is fixed to the G10 frame by 29 M2 peek screws as shown in Figure **??**. Once all LEM+anodes are fixed the extraction grid wires can be installed (f): to do so a tooling was developed that allows to braze the wires by group of 32 on a custom designed PCB and safely fix them on the frame. Pictures of the tooling are shown in Figure 2.7. During this operation each wire is constantly kept at a tension of 0.4 N. The brazing of the stainless steel wires to the PCB wire holdes is performed with Stannol soldering tin (Sn/Ag 96/4)[17] and small amount of orthophosphoric acid as soldering flux (a very small amount of acid is required, a cotton bud soaked is sufficient.). The properties of the orthophosphoric acid and the safety data-sheet are provided in [8]. This activity will be performed under appropriate smoke extraction hood (with dedicated filters)[1] and the soldering tin with phosphoric acid will be cleaned carefully with distilled water and appropriated lint-free cloth and smooth brush, then air dried.

Once the extraction grid is installed, some survey is foreseen and the frame is ready to be packed and shipped g,h). The CRP assembly structure serves as frame for the tranport box, the details of the box and anchoring points are provided in Section **??**.

2.3 Waste treatment

Following waste treatment are foreseen inside of the clean room

[1]WELLER T0053651689 KIT EXTRACTEUR DE FUMEES WFE 2ES 230V

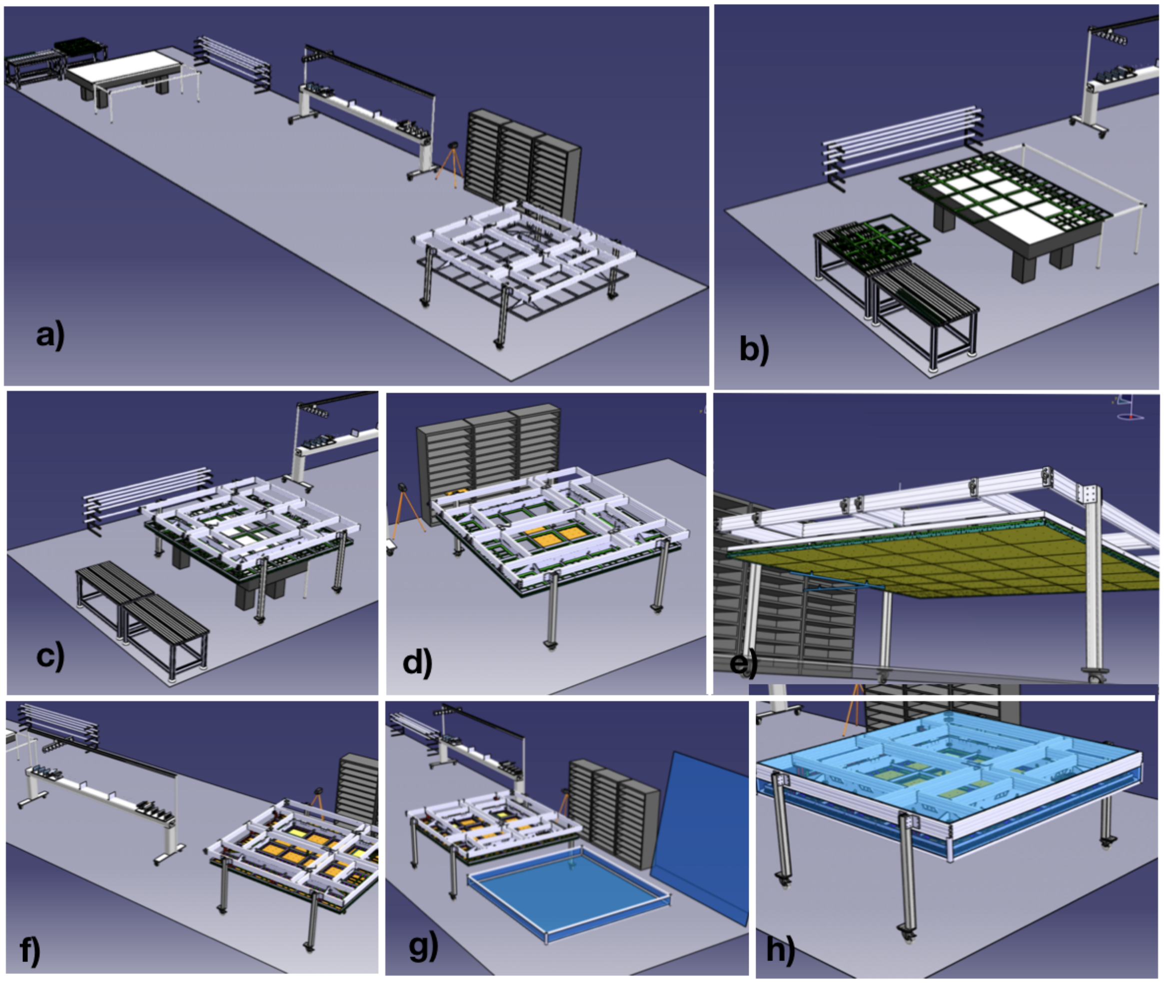


Figure 2.6: Main steps of the CRP construction in the clean room of building 185

Waste	**Treatment**
General packaging, cellophane film, clean room personal equipment wastes ...	General and recycling trashes
Stainless steel excess	Stored to be recycled
Acid soaked cotton bud	To be defined
...	...

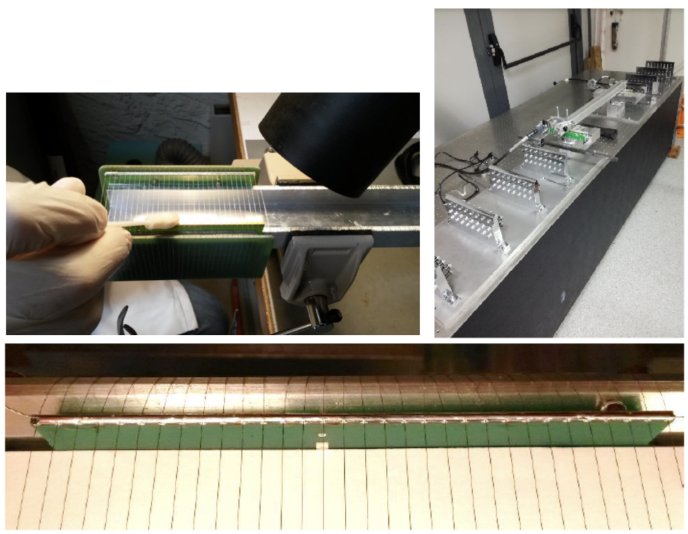


Figure 2.7: test of the 3 m grid wires soldering on the tooling

Chapter 3

Assembly of drift cage sub-modules in Clean Room Buffer

The protoDUNE DP drift cage (DC) is designed to hang from the structure at the top of the cryostat as described in chapter 1. Therefore, the total weight of DC must be light yet sturdy in order to maintain the functionality in the cryostat in LAr for a long time. In order to take full advantage of synergy, the DC utilizes a modular structure, as in the single phase (SP) design which uses fiber reinforced plastic (FRP) I-beam frames with extruded aluminum profiles with a center rib for further strengthen the structure. The University of Texas at Arlington (UTA) group has been working together with the ETH group responsible for the mechanical design and CERN group for the profile and clip production to construct the DC, including the production of the high voltage divider boards (HVDB). UTA group has undergone and passed the production review conducted by the team from the DUNE project management May 24, 2017, has received the FRP parts for the construction of the entire DC and is in the process of preparing the parts for preassembly. The DC consists of eight 6.3mx3.1m modules, two covering each face, as shown in Figure 1.3 in Chapter 1. Each module consists of three sub-modules with 33, 33 and 32 profiles, as shown in Figure 3.1 and thus the whole DC consists of a total of 24 sub-modules of dimension about 2mx3m. Each sub-module is assembled of two 6" I-beams with slots for aluminum profiles and two 3" I-beams for the mechanical connection. Unlike the SP DC cage, DP DC uses an electrically continuous field shaping ring by connecting all profiles between different modules with aluminum clips. To allow this continuity, the profiles are bent at 45 degree angle at one corner for a connection with a straight clip. The connection between two sub-modules modules in the same module are made by three flat FRP plates to ensure mechanical strength and the inter-module alignment.

The assembly procedure for a sub-module follows the steps below:

1. Connect two 6" I-beams with profile slots with two 3" cross I-beams using L-brackets, inserts, threaded rods and hex nuts all made out of FRP. Figure 3.2.a shows a photograph of such a connection using the L-bracket.

2. Insert the tapped slip nuts into the straight end of the profile and slide it all the way to the side with the 45 degree bent.

3. Insert the profiles until it touches the alignment bar at the other end.

4. Position the slip nut under the screw M4 holes on the 8" I-beam closer to the bent side of the profile.

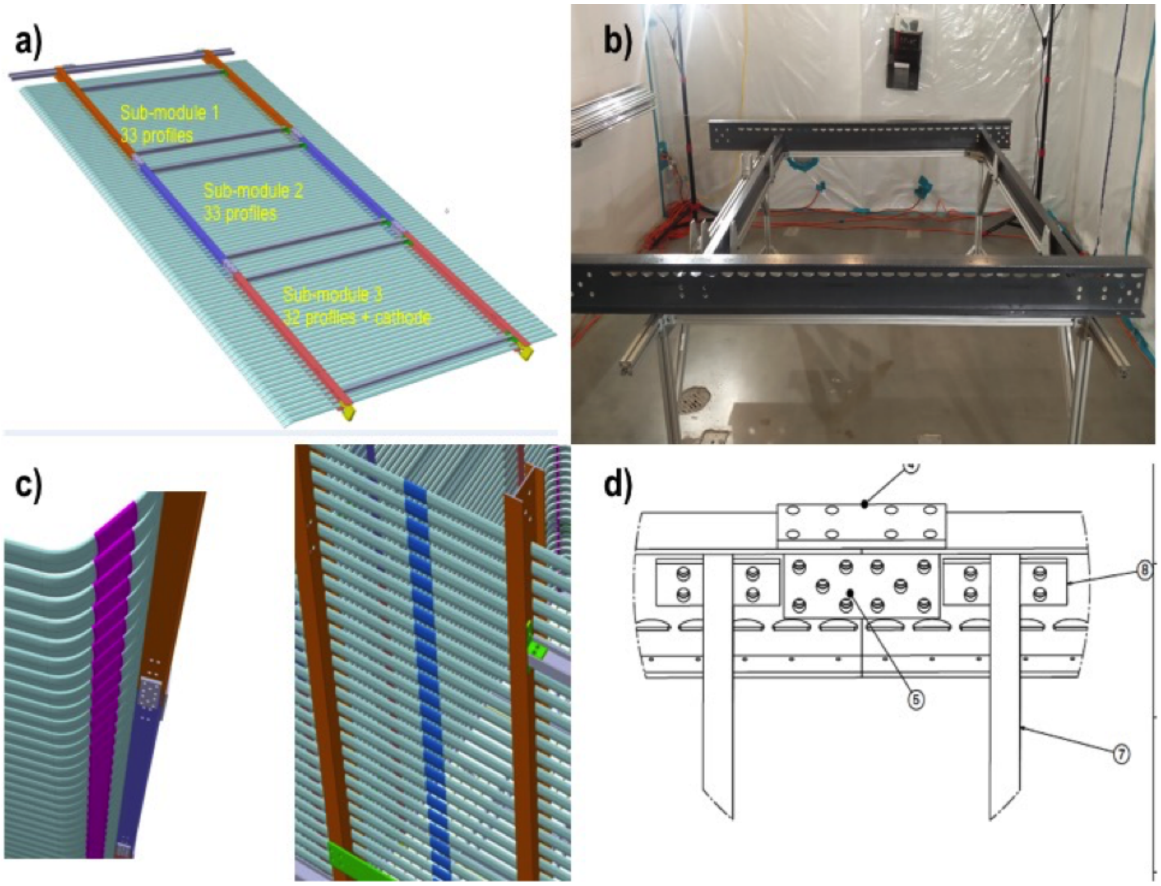


Figure 3.1: (a) Schematic drawing of a protoDUNE DP DC module which consists of three sub-modules with 33, 33 and 32 profiles each (b) An FRP frame of a top sub-module which consists of two 6" I-beams with the profile slots and two 3" cross I-beams connected via FRP L-brackets, threaded rods and hex nuts. The assembly table on which the frame sits is the actual assembly table to be used at CERN (c) Drawings of the profile connection using the aluminum clip for an electrical continuity of each field shaping ring (d) A excerpt from the engineering drawing which shows the inter-sub module connection in a module. Three flat FRP plates connected with inserts, threaded rods and hex nuts provide mechanical strength and the inter-module alignment

5. Tighten each profile to the I-beam using two M4 screws with the Dewalt 12V screw driver torque set to 10, making sure that the flatness of each profile is maintained.

The UTA team has assembled one each of three different types of sub-modules and packaged two of them as an exercise for shipping. Figure 3.2.b is a photograph of a completed sub-module hung from a crane to test the mechanical stability in as close a situation as in the actual installation in the protoDUNE DP cryostat. In order to test inter-module connections prior to shipping sub-modules, the UTA team has recently connected three 6" I-beams using the flat FRP plates, inserts, threaded rods and hex nuts. Figure 3.2.c shows the joint connected by the three flat plates which provides mechanical strengths and inter-module alignment. Figure 3.2.d shows a 6m long I-beam out of three 6" I-beams. The laser level beam shows an excellent inter-sub module alignment of the aluminum profile slots. This exercise gives confidence on the precision of the machining and the soundness of

Figure 3.2: (a) A photo of a connection between 6" and 3" I-beams with an L-bracket, inserts (unseen since they are in the screw holes), threaded rods and plastic nuts. (b) A photo of a completed sub-module hung from a crane (c) a photo of an inter-module connection using flat FRP plates, inserts (unseen), threaded rods and hex nuts (d) a 6m long connection of three 6" I-beams. The laser level beam line shows an excellent alignment of the profile slots across the three different beams.

the mechanical design.

Chapter 4

Cryostat roof and installation of suspension feedthroughs

4.1 Suspension Feed-Through (SPFT) for the CRPs

Each of the four CRP of ProtoDUNE-DP will be suspended by three cables to a motorised system allowing to control their vertical positions to better than 0.1 mm accuracy. The goal of this automatism is to keep the 3 meter long grid wires always at the same position, just below the liquid argon surface. The main requirement for the module structure is to hold precisely the LEM plates, the anode planes and the extraction grid wires at a fixed position with a well understood behaviour under the action of gravity and temperature gradients during operation in cryogenic conditions. The ability of the frame to stay as planar as possible with respect to the LAr level is a key ingredient for the best physics reach of the WA105 detector. In order to insure those requirements, the choice of the frame structure material went to INVAR which has a thermal expansion coefficient one order of magnitude less than stainless steel. A refined decoupling system with the G10 structure has been designed to eliminate the bi-material contraction effect. The drive system is controlled through a Siemens PLC interfaced to the PVSS slow control system that ready the liquid argon level with precise capacitive level meters. The CRP modules are to be suspended and motorized along the vertical axis. The suspension wires goes through the roof insulation and structure thanks to so called crossing pipes whose inner diameter is 59 mm. These crossing pipes allow to fine tune the position of the suspension axis within ± 25 mm range in horizontal plane in case of production deviation inside of tolerances. This functionality is illustrated in the figure below:

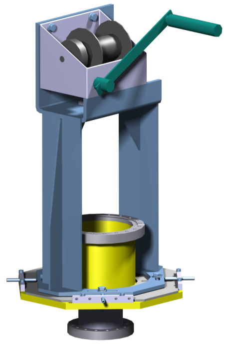


Figure 4.1: SPFT in installation configuration (Winch)

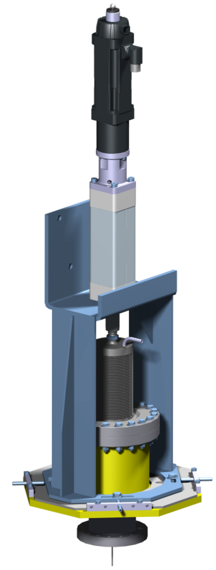


Figure 4.2: SPFT in operation configuration (Motor)

The yellow part is welded on a standard Vacom flange, used to ensure the sealing of cryostat. Mewasa bellow is used to achieve both vertical and lateral displacements. Indeed bellow is not strength by lifting consideration given motor and ball-screw are taken all the lifting load because they are directly fixed on the stainless steel upper termination of bellow.
Note that the stroke of ball-screw and bellow are the same (no possibility to break the bellow with a wrong command to the motor). In addition the motor is equipped with brakes to fix ball-screw in position in case of problem[4].

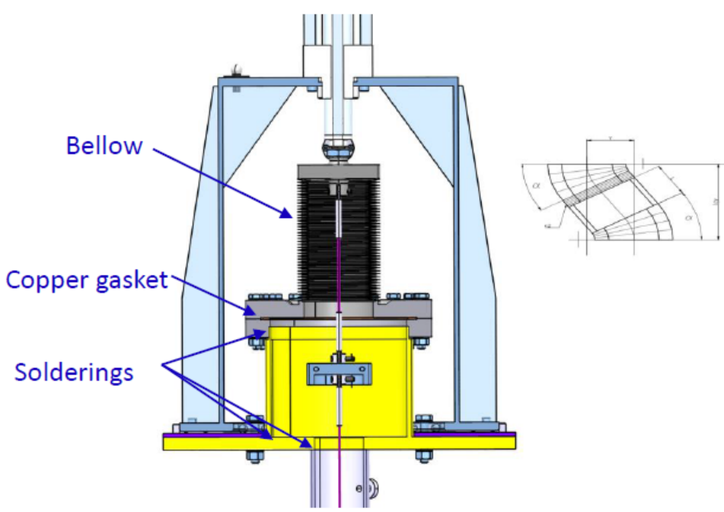


Figure 4.3: SPFT design overview

4.1.1 Switching sequence from manual winch to motor

The final lifting wires, whose length is roughly 2m, designed to place modules at proper altitude will be fixed to the XY anchoring device on module. Given the module will be in bottom position inside the cryostat we plan to use a lifting hand winch (CE certified) with reverse position and automatic brake to lift module in upper position under the roof. The hand winch reference is LEVAC-6411-C equipped with 5mm diameter steel cable. This winch is not reversible (no brake is required), it has a ratio of 11mm/lap, and the maximal load to apply on the crank is 12kg. The kit is suitable for a 250kg SWL[12].

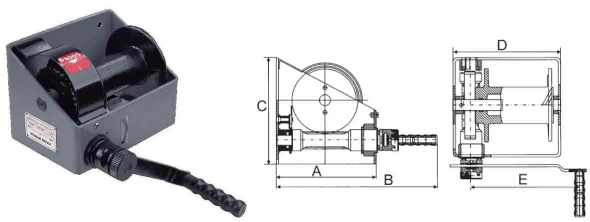
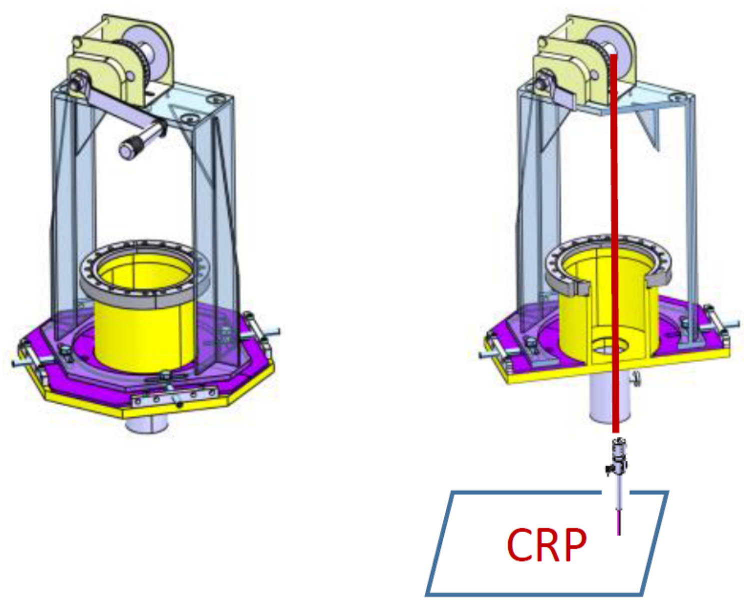


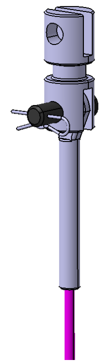
Figure 4.4: Levac 6411-C manual winch

The SPFT is assembled on the top cap in winch configuration. The CRP is then connected to the winch's cable

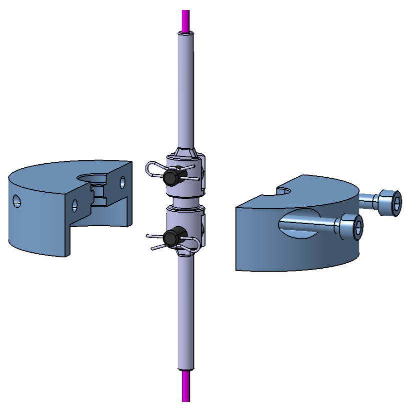


Note that final cable on module and winch cable are connected by a specific part allowing us to fix a mechanical stop before removing winch cable.

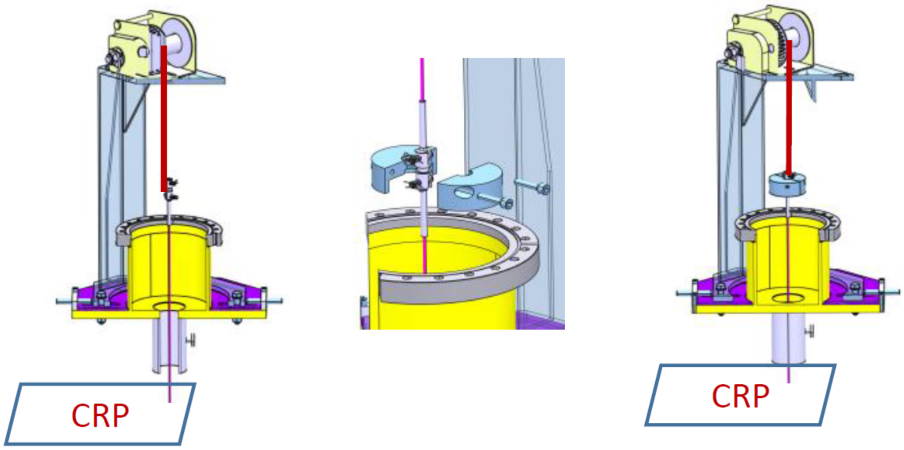
The picture below shows the specific part with the final lifting wire (fixed to module) and before having coupled the hand winch wire.



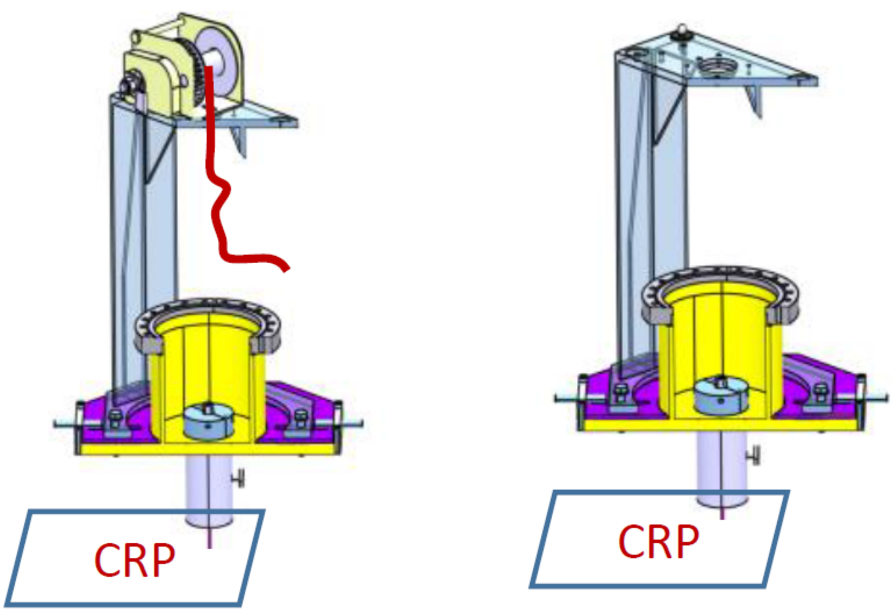
In addition this 2-wires interfacing part is shaped in a manner that the mechanical stop (2 parts tightened with screws) works with shearing loads thanks to the circumferential groove.



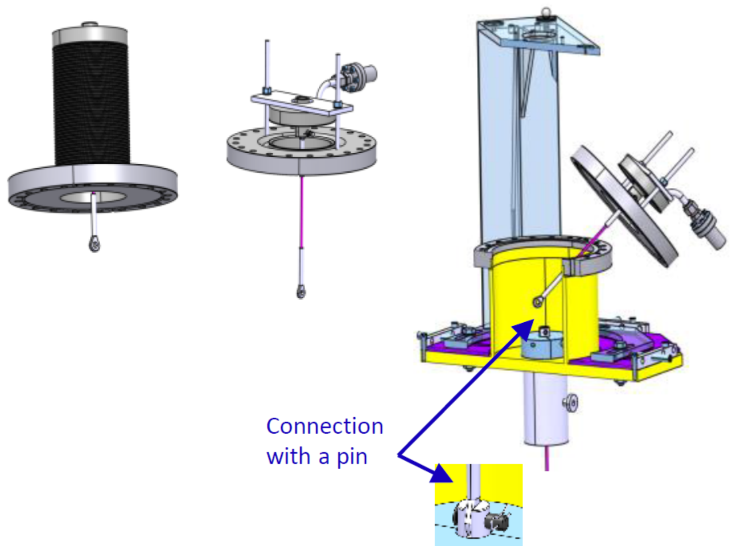
The CRP is lifted, and when the junction part is accessible from the top, the mechanical stop is assembled.



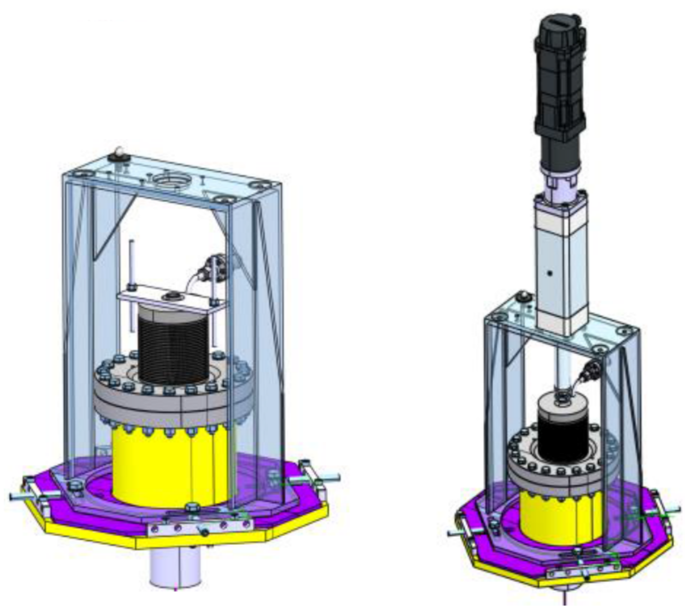
Once mechanical stop is fixed, the CRP is lowered until mechanical stop is in contact with yellow flange. The cable from the winch is then disconnected and the winch is removed.



Then we are able to mount the bellow already equipped with intermediate wire (same technical characteristics and performance than 2m long suspension wires described earlier) to link motor with module.



The bellow is placed with its copper gasket, the compression tooling is removed, and the motor is placed. The SPFT is then ready for operation.



4.2 Suspension Feed-Through (SPFT) for the Drift Cage

Field Cage consists of 8 modules and each module is suspended with two Suspension Feed-Throughs. Each suspension FT is used for Drift Cage installation and for the the final configuration of the Modules. Once the Drift Cage is installed and in his final configuration there is no possibility for any additional vertical regulation. During the installation the Modules are lifted using a manual winch in order to bring the Drift Cage from the Bottom of the Cryostat up to the Top. After that the suspension FT has an additional connection point where the final stainless steel wires are installed and the wires for the installation can be removed. This functionality is illustrated in the figure below:

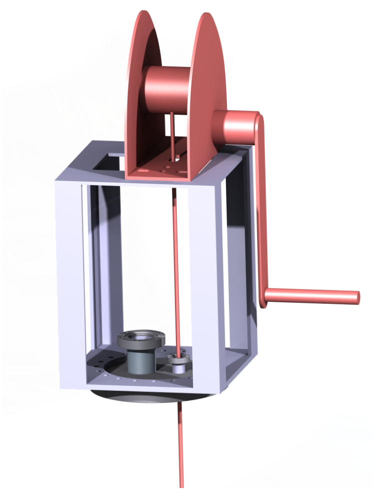


Figure 4.5: SPFT in installation configuration (Winch)

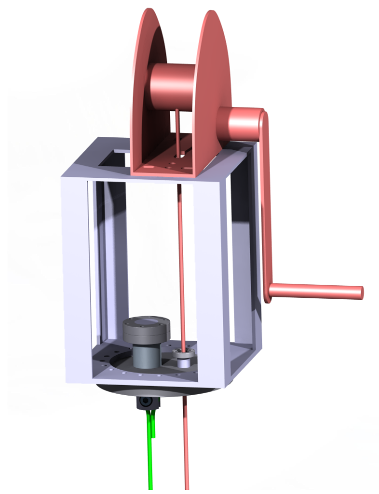


Figure 4.6: SPFT with additional connection for final configuration (Hook)

The SPFT is everything in Stainless Steel: CF160 Base Flange with 2 Half Nipples (CF40 for final configuration and CF16 where the 6mm wire go through for Installation) and Stainless steel support structure for the WInch. In the final configuration the CF16 Half Nipple will be used for the Gas Purge.

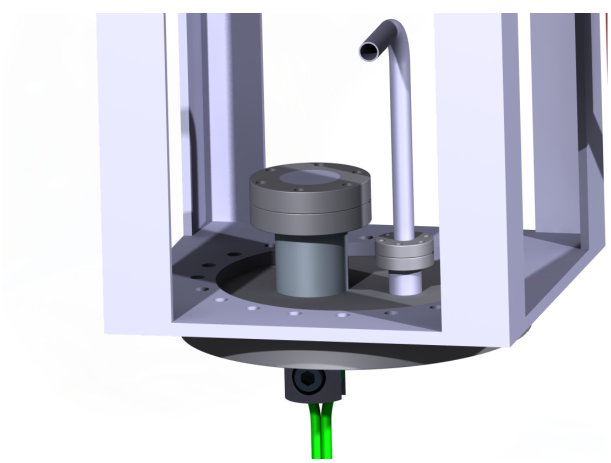


Figure 4.7: SPFT in Final Configuration

Chapter 5

Installation sequence inside cryostat and summary of all load cases

This section reviews the entire sequence of assembly inside the cryosat. A summary table is provided with the various load cases each of which are described in Part II of this document.

This section provides a summary of the assembly steps for which load calculation on various detector parts may be needed. Essentially three main detector parts have to be inserted. The 4 CRPs, the drift cage and then the cathode+ground grid modules. The main steps are summarized below and a view in image is provided in FIGs. 5.1, 5.2 5.3. A summary table containing the load cases for each step is presented in Table 5.1.

The detector assembly sequence starts once the cryosat interior is considered as a clean room (class 100'000) with the temporary floor in place and the two vertical cable trays installed (see Figure ??). Those cable trays host all the cables for the instrumentation that needs to be installed at the cryostat floor which consist of essentially the 36 photo multipliers and some cables for temperature sensors. A detailed list of all cables is provided here (CERNbox).

The CRP is assembled inside building 185 being suspended under an assembly frame (1). The assembly frame then serves as structural elements for the CRP transport box. The CRP inside the box is transported to EHN1 and inserted inside the clean room buffer (2), it is then placed on a troley (3) and hooked on the insertion I-beam (4). Once inside the cryostat the box is rotated and fixed onto wheeled feet that allow to place the CRP in position under its respective suspension cables (5,6,7). The box is then dismantled, the CRP is fixed to the cables and lifted to its nominal height (approx 6 meters from the temporary floor) (8) by the manual winches of the suspension feedthroughs located on the roof. Once at nominal height the manual winches are switched to the automated system (9). The CRP electronics are then connected to the relevant chimneys (signal feedthroughs for and CRP instrumentation feedthroughs for high voltages) all chimneys are located on the edges of the CRP frame for ease of cabling. The procedure (1) to (10) is repeated four times until all four frames are suspended at their nominal position (11). The drift cage sub-modules are then gradually brought inside the cryostat (12) and fixed on trolleys (13). The drift cage suspension stainless steel I-beams are connected to suspension feedthroughs cables ready to be lifted (14). The first sub-module (with its divider board if applicable) is then fixed below its suspension I-beam and lifted to allow fixing the second and third sub-modules (16). For this activity 2 persons are needed inside the cryostat and 2 on the roof to operate the manual winch for the lifting. Once 5 modules are in place (17) the aluminum clips and drift cage lateral reinforcements can be installed. This activity require one person on the inner-side of the drift cage and anther on the external side working at heights between

0 and 6 meters. The beam plug is then installed (18) and all the remaining drift cage sub-modules are brought inside the cryostat. Most are installed, apart from the last 5 sub-modules in order to leave sufficient clearance in front of the TCO (19). The very high voltage feedthrough with its extension is then installed (20). At this point the scissor-lifts and most large material is taken out from the cryostat(21). After that the cathode and ground grid modules are introduced in the cryostat and temporarily assembled on top of each other on trolleys. The trolleys allow to push the cathode and ground grid in one corner to finish the assembly of the drift cage and remove the insertion beam (22). The drift cage and ground grid (which are still attached together) are then lifted and fixed on the bottom of the drift cage (23). The temporary floor is then removed which allows for installation and cabling of the bottom temperature probes and photomultiplier tubes (PMT) on the membrane floor (24). The PMTs are delivered as pre-assembled modules with their mechanical bases; they only require to be placed at the appropriate position on the membrane floor and connected to HV cables (1 cable per PMT)

Main components	load cases	steps in Fig 5.3	Section for calculation in part II
CRP			
	CRP during assembly in 185 : suspended under supporting structure	1	7.3
	CRP suspended in transport box	2,3,4,5	7.2.3
	CRP in transportation box rotated and placed on table	6	7.2.4
	CRP in transport box on its wheeled feet	7	7.3
	CRP hooked on SPFT with manual which	8	7.4
	Winch/Motor switch	9	7.5
	CRP hooked on SPFT with motors	10, 11	7.6
Drift cage + cathode			
	Field Cage sub-Modules: Cryostat Insertion	12	8.2
	Positioning of the Sub-Modules inside the Cryostat (sub-modules on trolleys)	13	8.3
	FC suspended: calculation of stress on top suspension SS I-beam	15	8.4
	FC suspended (inc cathode): calculation of stress on top sub-module FRP I-beam	15	8.5
	FC one module suspended: suspension FT	16	8.6
	cathode and ground grid modules suspended and brought inside cryostat	21	9.2

	cathode and ground grid rotated and placed on wheeled trolleys	22	
	Fully assembled cathode and ground grid connected together on trolley	22	-
	during PMT installation: field cage suspended and all submodules connected with cathode and GND grid	23,24	-
	final configuration warm: drift cage + cathode suspended	24	9.2
	final configuration warm: ground grid on resting feet		9.4
	final configuration cold: DC + cathode suspended		8.7
	final configuration cold: ground grid on resting feet	-	9.4
CRP	CRP in cooling down conditions	N/A	7.7.2
	CRP in cold operating conditions	N/A	7.7.2

Table 5.1: Summary of load cases and references to calculations

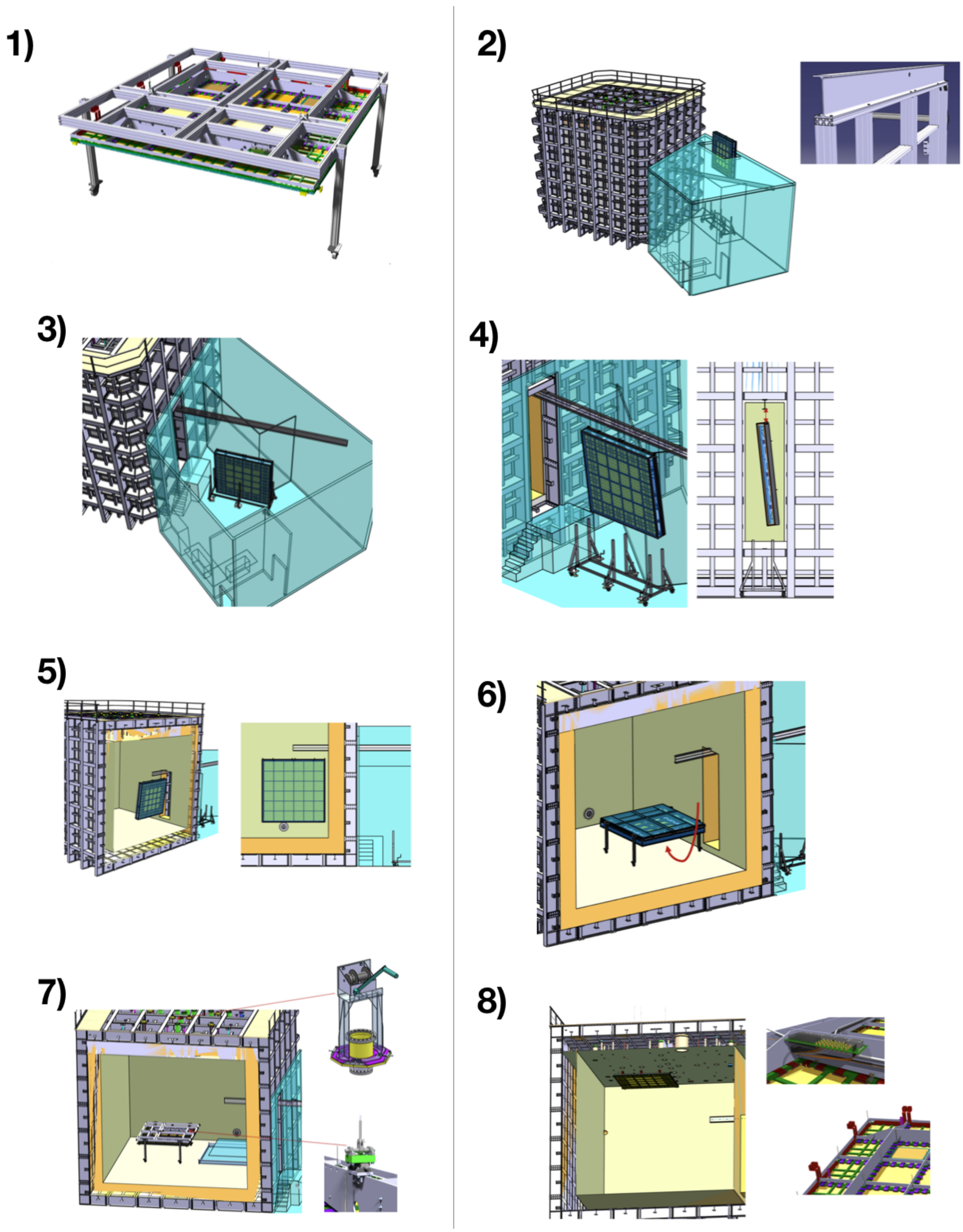


Figure 5.1: illustration of the mounting sequence in EHN1 (1)

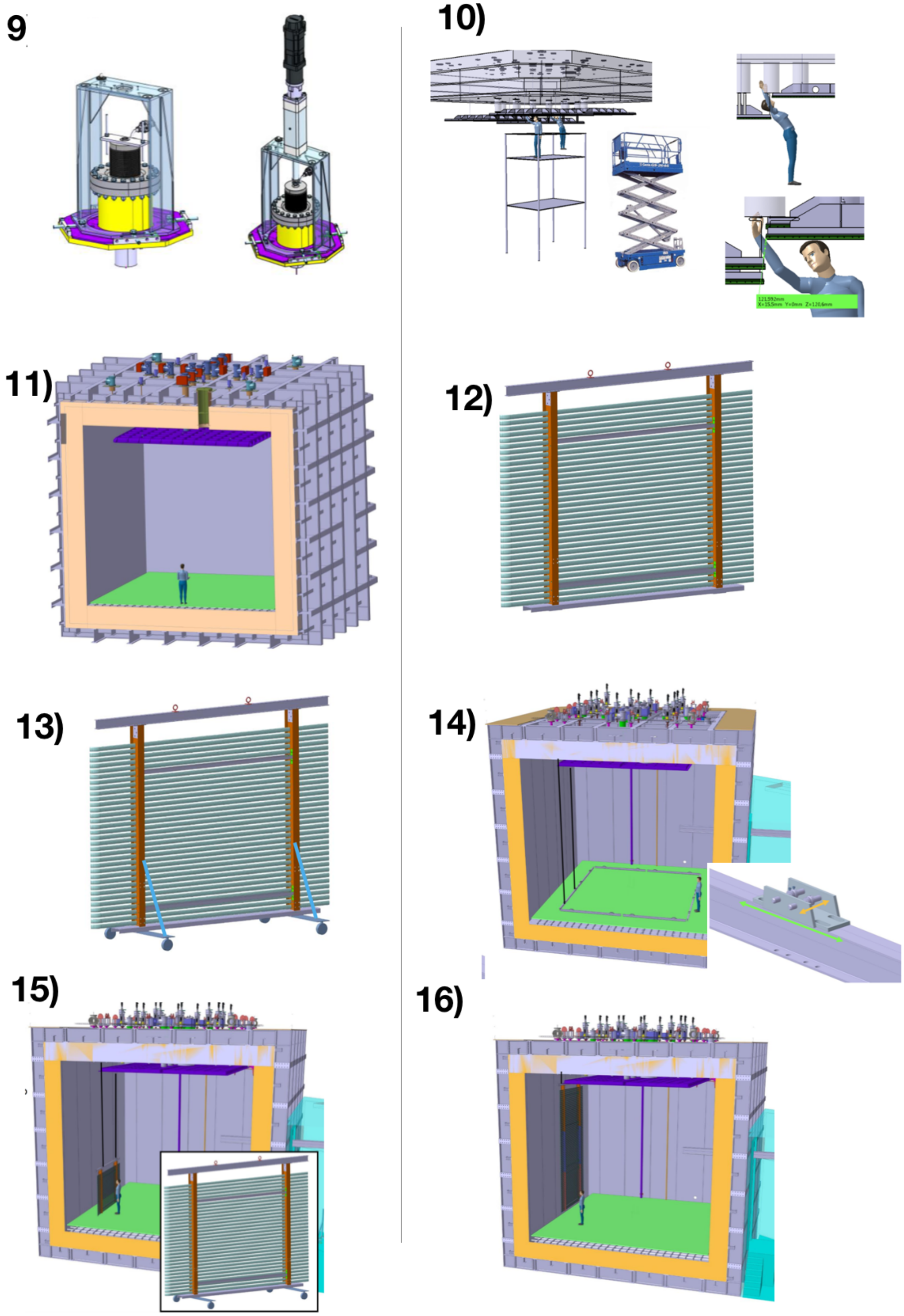


Figure 5.2: illustration of the mounting sequence in EHN1 (2)

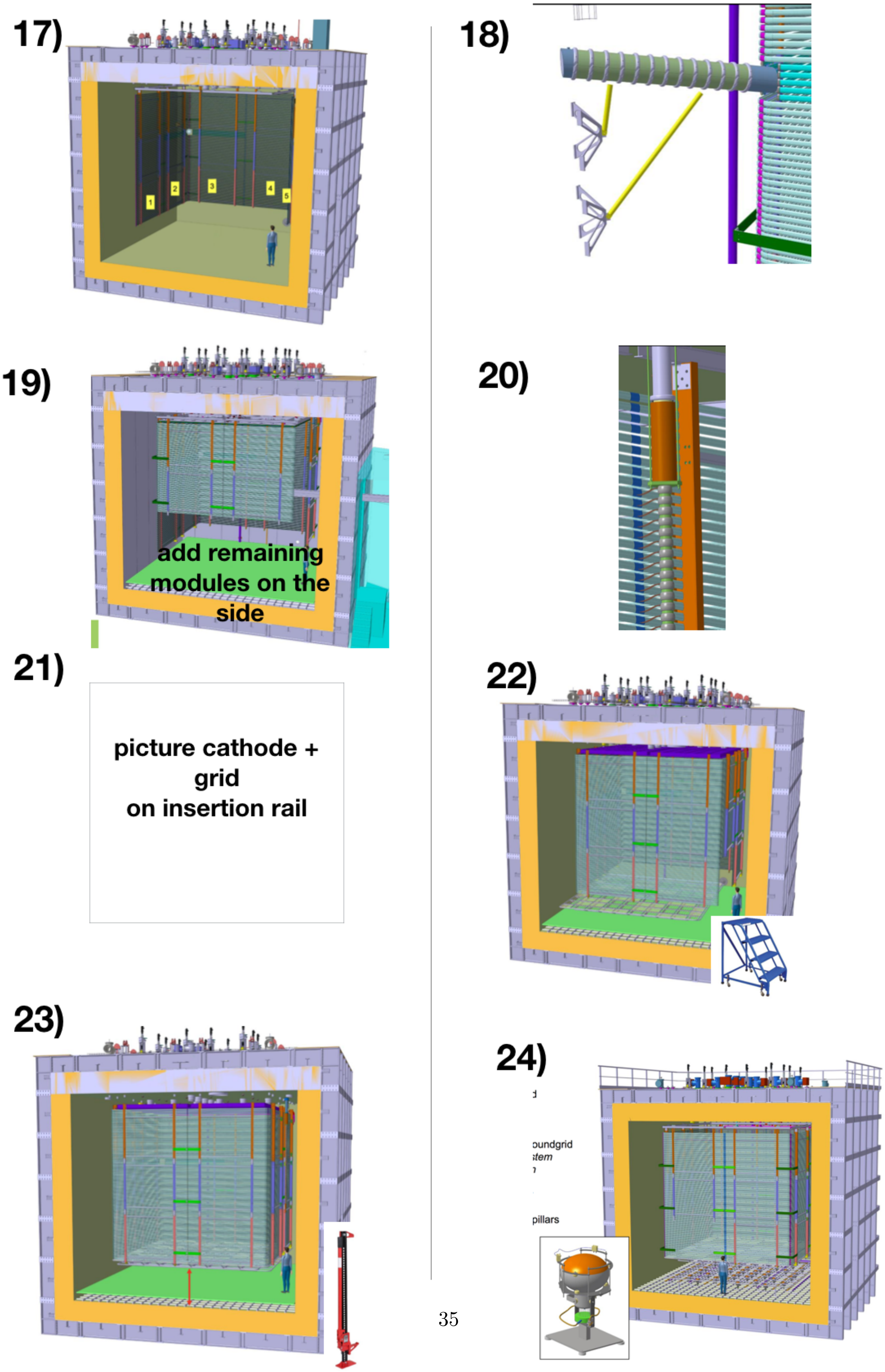


Figure 5.3: illustration of the mounting sequence in EHN1 (3)

Part II

Structural analysis and load calculation

Chapter 6

Common considerations for finite element calculations

The design situations described previously are validated by finite element methods. Prescriptions from annex C of NF EN 1993-1-5[3] are therefore applied :

Geometrical properties Following C.3, nominal geometrical properties have to be used. For assemblies, if applicable, nominal configuration and worst configuration will be both validated.

Software The software used for the validation is Ansys 18.0. Following C.4(1), the validation of each module is described in the "ANSYS Documentation, section "Workbench Verification Manual"[5].

Material properties Following C.6, the characteristic values are used for the materials. Certified or normative values of Young modulus (E), Yield strength at 0.2% (f_y) and Ultimate strength (f_u), at ambient and cold temperature if applicable, are detailed in dedicated sections of this document. Elastic-plastic laws with linear plasticity are used.

Material	**Designation**	**Volumic mass (kg/m^3)**	**Young Modulus E (MPa)**	**Yield strength 0.2% f_y (MPa)**	**Ultimate strength f_u (MPa)**
Invar	1.3912	8130	$193e^3$	220	400
	References :	*Invar Plates Standard Specification* [7]			
		NIST : Material Properties: Invar[15]			
Stainless Steel	304L / 316L	7900	$200e^3$	200	620
	References :	*APERAM - Offre Acier inoxydable de précision* [6]			
Steel	S235	7850	$210e^3$	235	360 - 510
	References :	*Aciers de construction non alliés suivant norme européenne* [13]			
Aluminium - Elcom Profiles[1]	3.3206.72	2700	$70e^3$	195	245
	References :	*Système de construction modulaire MB - Elcom* [11]			
G10[2]	Vetronit EGS102	1850	$24e^3$	–	–
	References :	*Stratifiés - VETRONIT EGS 102* [10]			
		Cryolab test report			
Teflon	PTFE	2160	550 (80000 PSI)	27 (3900 PSI)	–
	References :	Typical properties of PTFE [18]			
		NIST Material Properties: Teflon [16]			
Duplex Steel	Uranus 2205	7850	$200e^3$	460	680
	References :	*Arcelor Mittal - Uranus 2205* [14]			

Criteria relatives to Limit States

Following C.8(1), ultimate limit state is used for those FE calculations to insure the reliability of the whole installation.

Partial coefficients

As specified in C.9, partial coefficients are applied to the model through the load amplification coefficient at ultimate limit state α_u, constituted by two factors, α_1 and α_2, so that $\alpha_u > \alpha_1\alpha_2$.

α_1 is defined by NF EN 1990-1-1, Annex D [1]. Considering software used and the character of the different design situations, a conservative value is considered on the calculation : $\alpha_1 = 1.25$

As rupture is considered as dominant in the following FE calculations, α_2 is taken equal to γ_{M2}. γ_{M2} is given by NF EN 1993-1-8[2], section 2.2 (table 2.1 - Partial coefficients for assemblies). Recommended value is : $\gamma_{M2} = 1.25$[3]

Finally :

$$\alpha_u = 1.6$$

and $$\alpha_1\alpha_2 = 1.56$$

verifying $$\alpha_u > \alpha_1\alpha_2$$

The value of $\alpha_u = 1.6$ is thus used in the following calculations.

Loads

$\alpha_u = 1.6$, the "load amplification coefficient at ultimate limit state" is applied to loads. Unless specified, self weight is applied to the model as described in the next table. Considered masses are specified in the calculations sections, as specific other loads if necessary.

Load	**Type**	**Characteristic value F_K**	**Calculation value** [4]	**Unity**
Self-weight	Acceleration	9.81	15.7	m/s^{-2}

[3] No National Annex available for NF EN 1993-1-8[2], the common value of γ_{M2} is used

[4] Calculation value is obtained by multiplying the characteristic value F_K by the load amplification coefficient α_u, as described previously

Chapter 7

Charge Readout Plane and Suspension Feedthrough

7.1 Design situations overview

The following design situations, presented in the previous part are identified :

1. **Transport box suspension**
   The CRP is in its transport box, fixed to the aluminium supporting structure, suspended to the hall's crane through a stiffening steel IPE profile.

2. **Transport box on its wheeled feet**
   The CRP is in its transport box, fixed to the aluminium supporting structure, and the box is supported by its removable wheeled feet.

3. **CRP Winch suspension**
   The CRP is suspended by three cables from the SPFTs, in the manual winch configuration.

4. **Winch/Motor switch**
   The CRP is suspended by three final cables from the SPFT, on the mechanical stop, during exchange between manual winch and motor.

5. **CRP Motor suspension**
   The CRP is suspended by three final cables and the motor, in final configuration, in warm conditions during the installation of the others components of the detector.

6. **CRP in cooling down conditions**
   The CRP is still warm excepted the grid which is cold. This is the situation inducing the highest tension in the grid and the frame.

7. **CRP in cold conditions**
   Same like previous, in cold conditions during operations of the detector.

7.2 Design situation : Transport box suspension

In this section, the scoped assembly is the CRP in its transport box, fixed to the aluminium supporting structure, suspended to the hall's crane through a stiffening steel IPE profile.

7.2.1 Geometrical data

In this design situation, the geometry includes no moving part, and the deformations are expected to be very small.
During installation, two configurations are foreseen

Load case 1 The box is suspended by the IPE stiffener, in vertical position.

Load case 2 The box is suspended by the IPE stiffener and lying on the opposite side during rotation procedure, before wheeled feet assembly.

7.2.2 Note on model construction

In order to process stress values in the assembly, the model is cut in parts, and stress probes are added at contacts to calculate torsors. Those values are then compared to screws strength or manufacturers values (especially for aluminum profiles).

7.2.3 Load case 1 - FE calculation and verification

Model	To be filled in.
Boundary conditions	The whole model is suspended to the anchoring holes on the IPE profile.
Loads	The model is only suspended, the gravity including amplification factor α_u is applied.
Stress results	To be filled in.

7.2.4 Load case 2 - FE calculation and verification

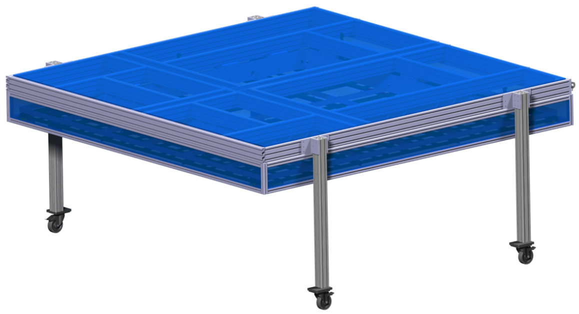
Model	To be filled in.
Boundary conditions	The whole model is suspended to the anchoring holes on the IPE profile. On the other side, the box rests on its edge. The worst case is reached the box in horizontal position.
Loads	The gravity (with amplification factor α_u) is applying along vertical axis
Stress results	To be filled in.

7.3 Design situation : Transport box on its wheeled feet

The CRP is in its transport box, fixed to the aluminium supporting structure, and the box is supported by its removable wheeled feet.

7.3.1 Geometrical data

Feet having an adjustable height, the maximal height inducing the highest stresses is considered.



7.3.2 FE calculation and verification

Analysis in static and buckling conditions, considerations about assemblies of Elcom profiles.

To be filled in.

7.4 Design situation : CRP Winch suspension

In this section, the scoped assembly is the CRP is suspended by three cables from the SPFTs, in the manual winch configuration.

7.4.1 Geometrical data

The configuration is the following :

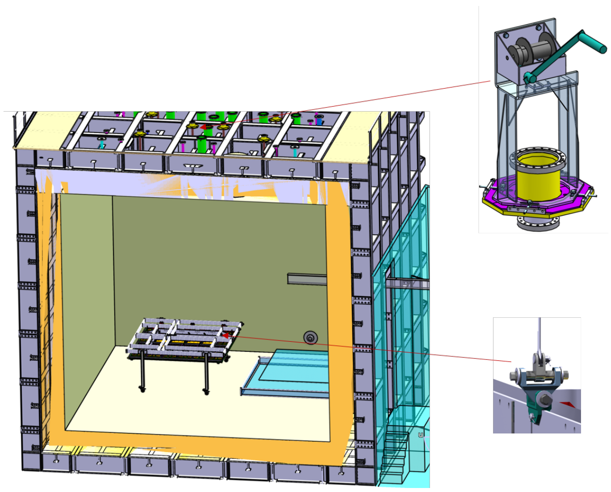


Figure 7.1: The CRP suspended by the three SPFT (CRP is not linked to the supporting frame on during this design situation).

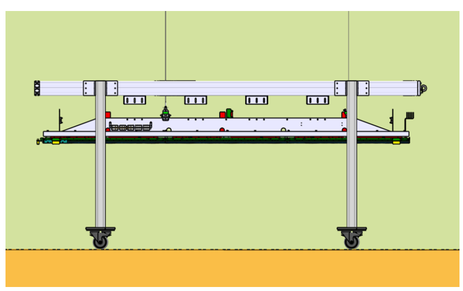


Figure 7.2: The CRP suspended by three cables, with supporting structure disconnected.

The suspension chain is constituted, form the top to the bottom, by :

- The SPFT in winch configuration
- The cable junction (which is supporting the mechanical stop on the next design situation)
- The anchoring system on the CRP
  1. centered position
  2. off-centered position
- The CRP itself

7.4.2 Certificated standard parts

For this design situation, the certificated standard parts are the winches and the cables. Information about the certification are given in section 7.8

7.4.3 SPFT in winch configuration - FE calculation and resistance verification

Model For this design situation the support will be equipped with the manual winch. The support is in stainless steel.

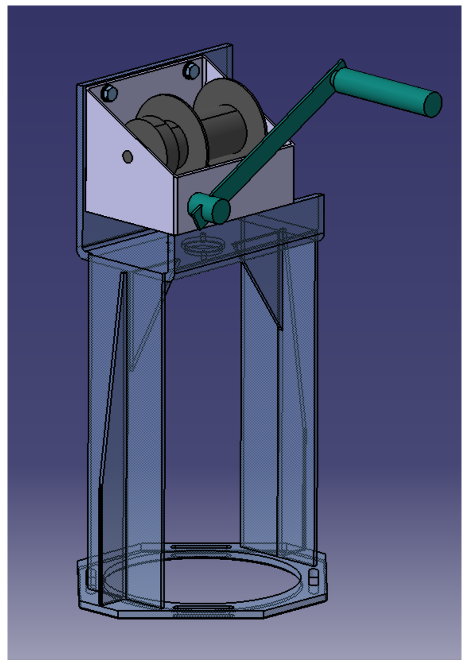


Figure 7.3: SPFT in installation configuration

Boundary conditions Bottom surface is clamped.

Loads

The load is distributed on the 4 holes for fixation screws (vertical plate) and the thickness of the plate for the contact of the other side of the winch. The loads to be applied to the model are constituted by the weight suspended to the cable. Here is the mass breakdown entering in the weight calculation :

Component	Mass (kg)
Invar frame	140
Decoupling systems	1
G10 frame	67.25
Detection plane	90
Transportation squares	2.5
Screws	3
Cables and ribbons	5
Anchoring systems (x3)	3
Cable junction with mechanical stop	3
Suspension cable	2
Total mass	316.75 kg
Weight	3107 N
Applied weight, by cable	**1657.7 N**

Displacements results

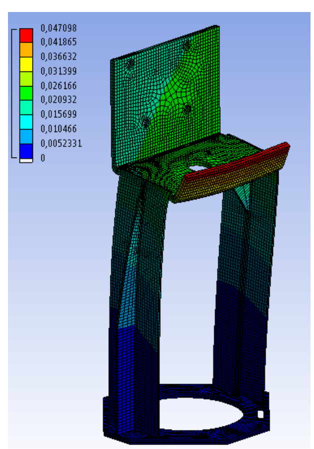


Figure 7.4: Displacement results on SPFT in installation configuration

Stress results

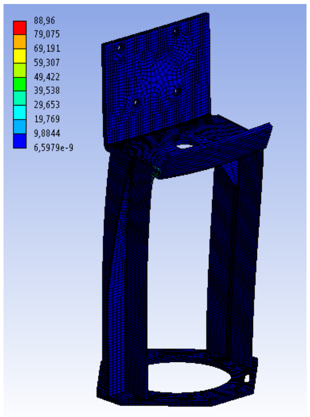


Figure 7.5: Stress results on SPFT in installation configuration

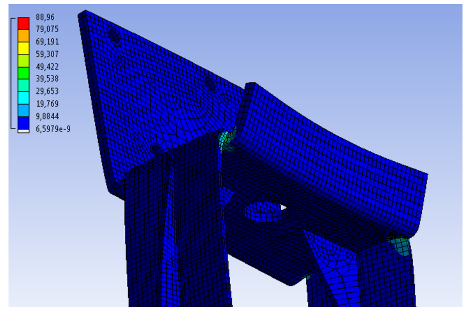


Figure 7.6: Detailed view on stress results on SPFT in installation configuration

Buckling Analysis results A buckling analysis has been performed. The load factor is 66. This value takes into account not only the suspended weight, but also lateral loads which could occur while acting the manual winch (maxi 12ON).

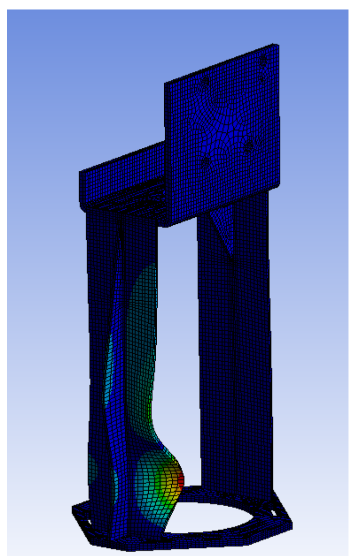


Figure 7.7: Buckling results on SPFT in installation configuration

7.4.4 Cable junction - FE calculation and resistance verification

Model

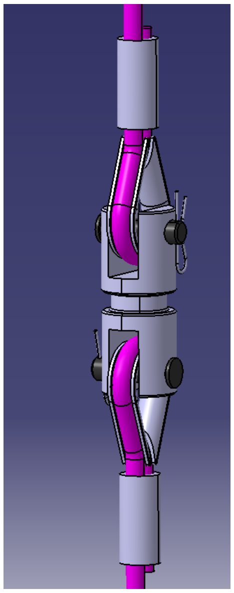


Figure 7.8: Cable junction geometry

Figure 7.9: Cable ending geometry

Thanks to its symmetric design (3 planes of symmetry), simplifications have been done to model this part.

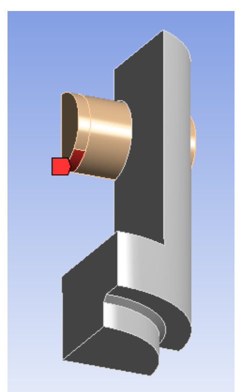


Figure 7.10: Model for cable junction calculation

Boundary conditions

Boundary conditions have been applied in a way that the cut sections can slide along their corresponding symmetry plane but cannot leave this plane (classical symmetry boundary conditions).

In addition the force corresponding to the quarter of the third of the weight of the suspended structure (with $\alpha = 1.6$ coefficient) is applied to the shear pin on a surface assumed to be 2mm wide over 90 degrees angle. This assumes to model the surface in contact between shear pin and metallic wires termination (standard, not modelled).

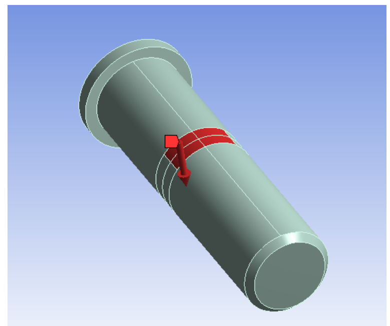


Figure 7.11: Surface for load application

Contact connection (0,2 friction coefficient) is applied between the shear pin and the 2-wires interfacing part.

Regarding the materials, the 2-wires interfacing part is in stainless steel and the shear pin is in Duplex steel.

Meshing

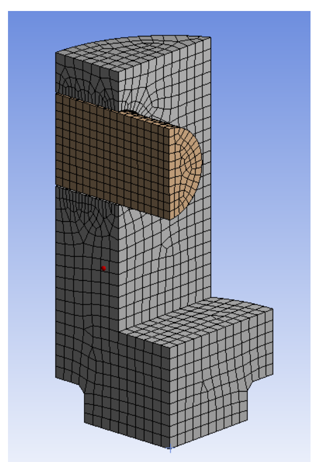


Figure 7.12: Detail on meshing used for calculation

Loads The loads to be applied to the model are constituted by the weight suspended to the cable. Here is the mass breakdown entering in the weight calculation :

Component	Mass (kg)
Invar frame	140
Decoupling systems	1
G10 frame	67.25
Detection plane	90
Transportation squares	2.5
Screws	3
Cables and ribbons	5
Anchoring systems (x3)	3
Cable junction with mechanical stop	3
Suspension cable	2
Total mass	316.75 kg
Weight	3107 N
Applied weight, by cable	**1657.7 N**

Displacements results

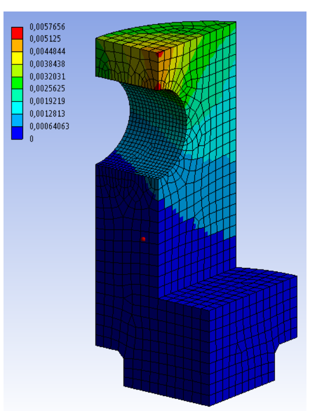


Figure 7.13: Displacement results on the cable junction

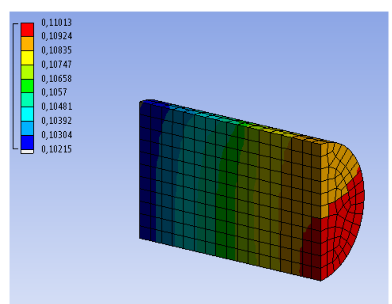


Figure 7.14: Displacement results on the shear pin

Note that 0.1mm rigid body motion is included in the scale in order to get contact with the 2-wires interfacing part. Indeed the shear pin diameter is 0.2mm smaller than the hole in the interfacing part (clearance for insertion). Thus 0.1mm has to be removed from this scale values to get the displacement due to the load (here 0.01 mm max displacement).

Stress results

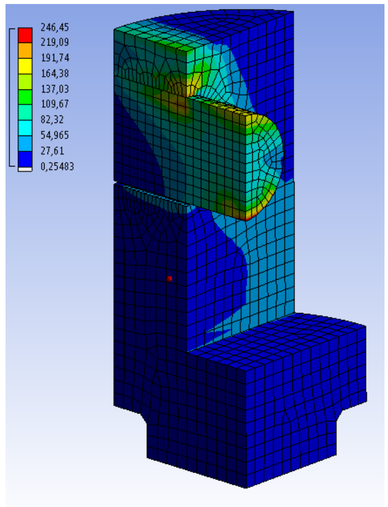


Figure 7.15: Stress results on the cable junction

The maximal peak stress of 246MPa stay low compared to the 460MPa $Rp_{0.2}$ yield stress f the duplex steel used.

7.4.5 Anchoring system - FE calculation and resistance verification

Model

This system is used to fine-tune the position of the CRP anchoring point, on the CRP frame.
It can be completely centered or off-centered.

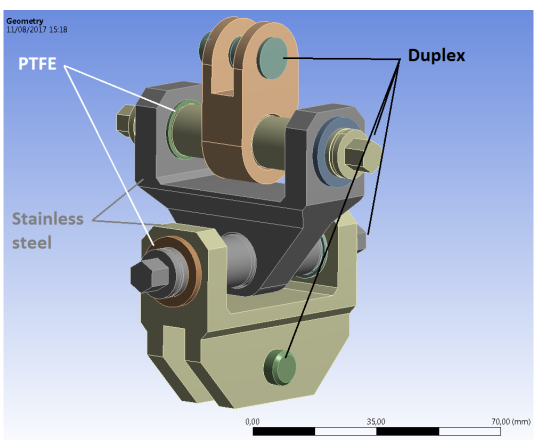


Figure 7.16: Hanging system model in centered configuration

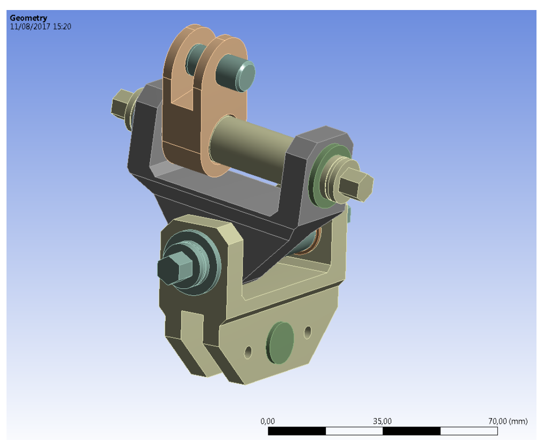


Figure 7.17: Hanging system model in off-centered configuration

Boundary conditions On the upper part, the anchoring system is suspended to the suspension cable. On the lower part, it is pinned to the CRP's invar frame.

Loads The loads to be applied to the model are constituted by the weight suspended to the lower part of the anchoring system. Here is the mass breakdown entering in the weight calculation :

Component	Mass (kg)
Invar frame	140
Decoupling systems	1
G10 frame	67.25
Detection plane	90
Transportation squares	2.5
Screws	3
Cables and ribbons	5
Anchoring systems (x3)	3
Cable junction with mechanical stop	2
Suspension cable	1
Total mass	314.75 kg
Weight	4910 N
Applied weight, by cable	**1637 N**

Stress in centered system

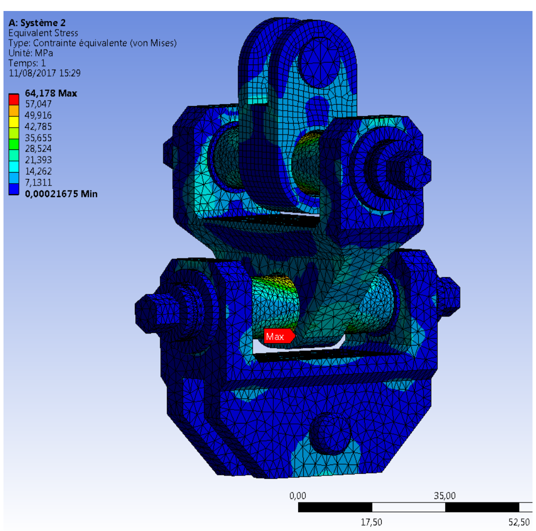


Figure 7.18: Stress in the centered system

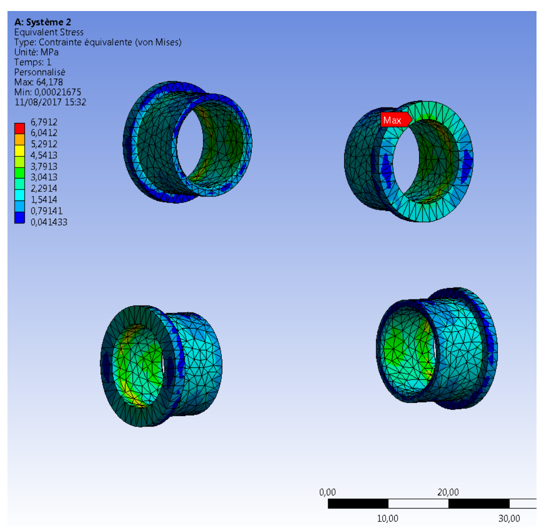


Figure 7.19: Stress in the PTFE parts of the hanging system

Stress in the PTFE parts are low compared to yield stress of PTFE.

Stress in off-centered system

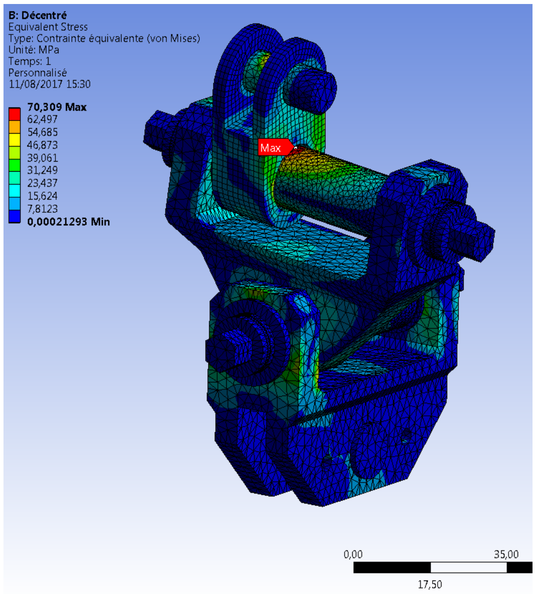


Figure 7.20: Stress in the centered system

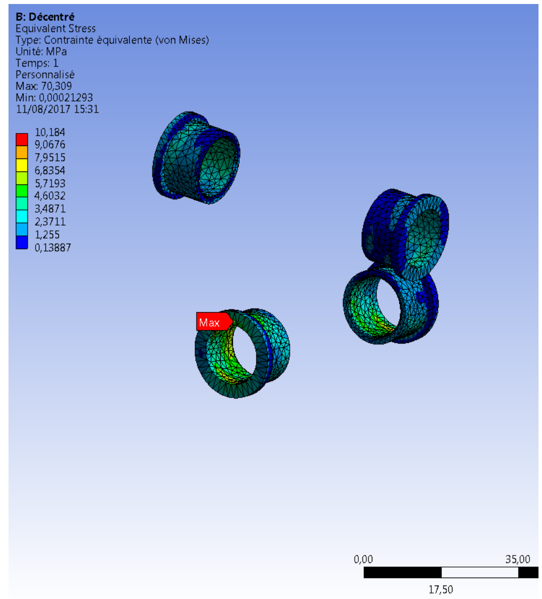


Figure 7.21: Stress in the PTFE parts of the hanging system

Stress in the PTFE parts are low compared to yield stress of PTFE.

7.4.6 CRP suspended by three points - FE calculation and resistance verification

The calculation performed for this design situation is a static analysis.

Model and Boundary Conditions

Overview

The model is constituted by the invar frame, the whole G10 frame, and the fifty junction parts

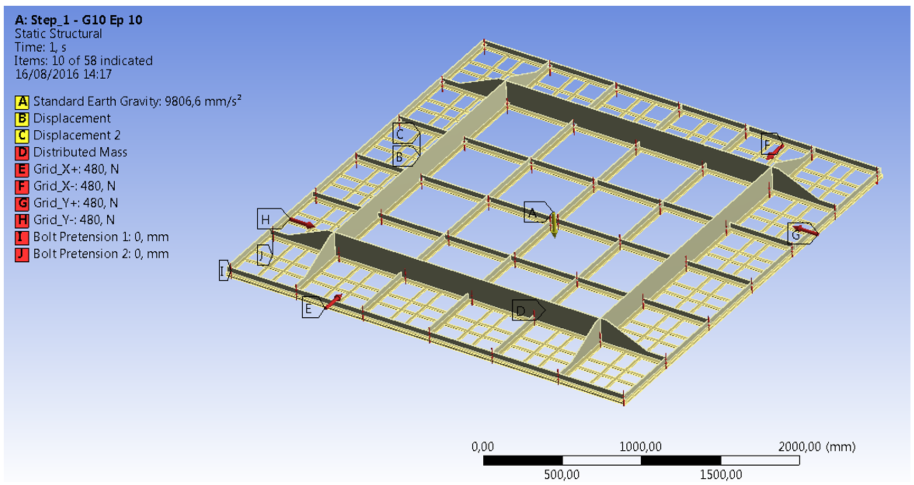


Figure 7.22: Overview of the model, with the fifty junction part in red at each cross of the frame

Junction parts for thermal shrinking

Junction parts insure only a vertical link between invar and G10 frames. Special contact elements allow both frame to slide horizontally to absorb thermal shrinking.

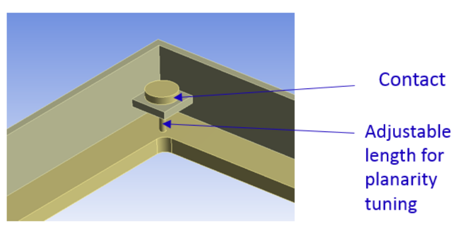


Figure 7.23: Detailed view of a junction part model

Only the two junction parts at the center of the module avoid lateral sliding, in order to lock both frames together.

Instrumentation added mass

To take in account the mass of the instrumentation, LAS , cables... a distributed mass of 150 kg is added below the G10 frame.

Extraction grid

To model the extraction grid tension below the module, special spring elements are added.

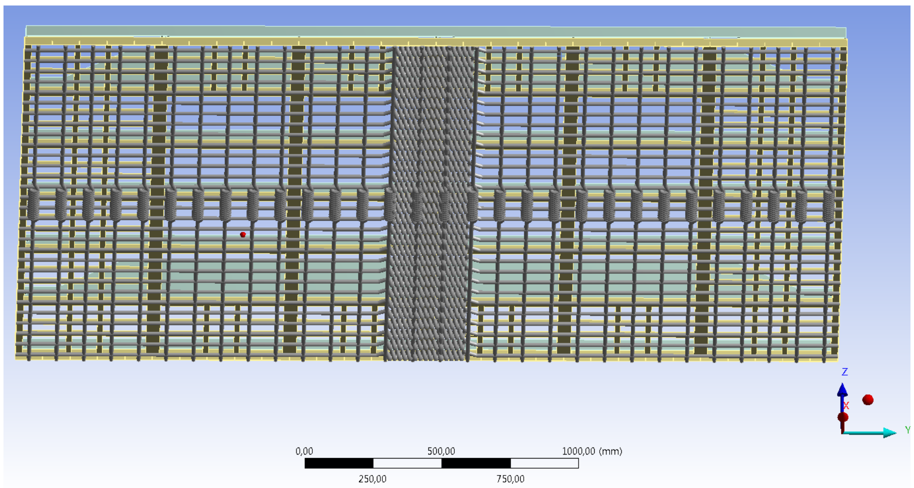


Figure 7.24: Springs below the module to model the extraction grid tension

Boundary conditions

The CRP is suspended by the three anchoring system pins.

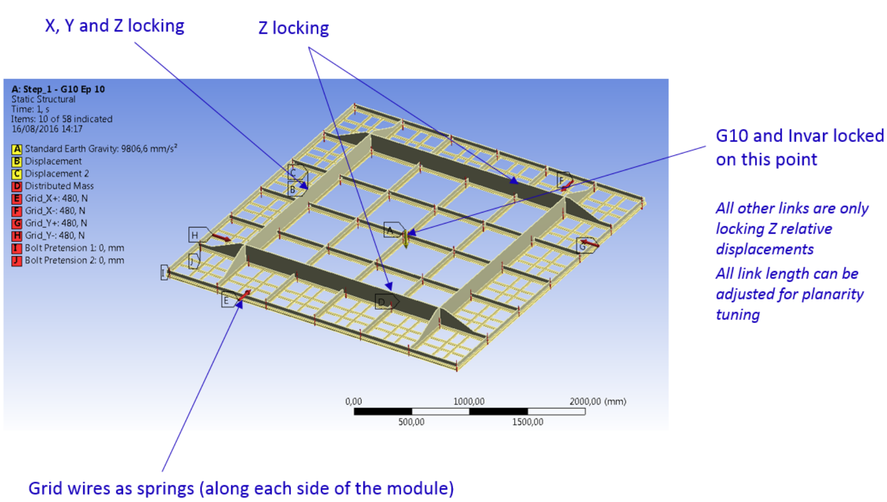


Figure 7.25: Overview of the boundary condition

Loads The CRP is only suspended, thus the gravity is applying along vertical axis.

Displacement results

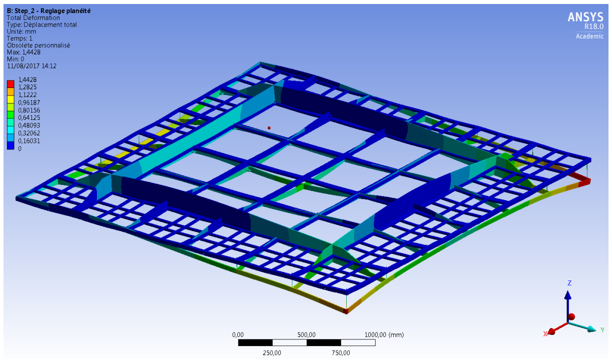


Figure 7.26: Displacements of the module under gravity, after planarity tuning

The displacement of the Invar frame is acceptable while the displacement of the G10 frame is adjusted thanks to metrology operation and tuning of the fifty junction parts. This operation is detailed in section 7.7.

Stress results

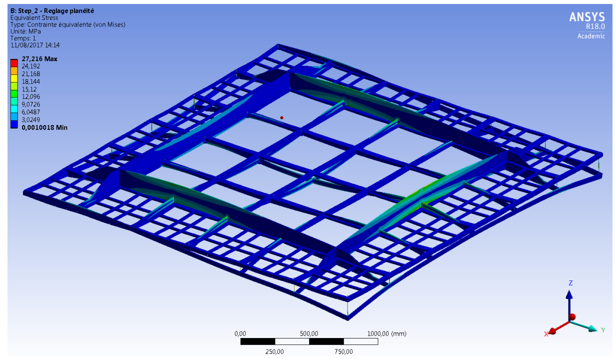


Figure 7.27: Stress in the whole structure

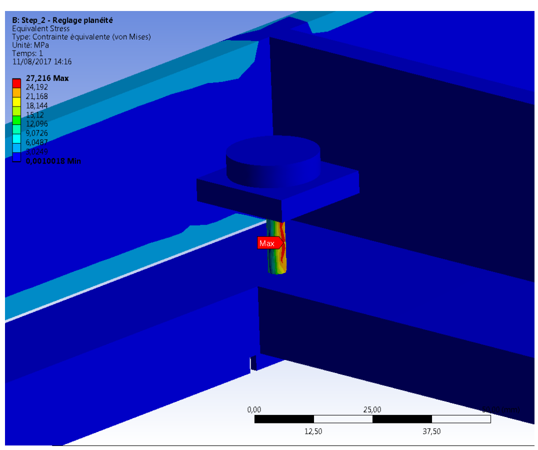


Figure 7.28: Highest stress in a junction part

All the junction parts are in Stainless steel, so the highest stress of 27 MPa has to be compared to the $RP_{O.2}$ of this material.

7.5 Design situation : Winch / Motor switch

7.5.1 Geometrical data

In this configuration, the suspension chain is constituted, form the top to the bottom, by :

- The bottom of the SPFT
- The cable junction with the mechanical stop
- The anchoring system on the CRP (validated in section ??)
- The CRP itself (validated in section ??)

Thus, only the bottom of the SPFT and the junction with its mechanical stop have to be validated.

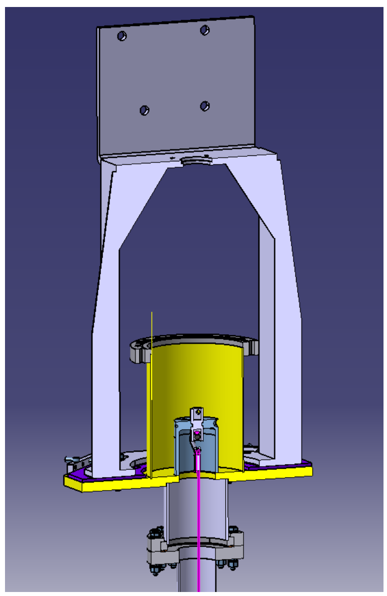


Figure 7.29: Upper part of the suspension chain to be validated for winch/motor switch

7.5.2 Certificated standard parts

For this design situation, the certificated standard parts are the cables. Information about the certification are given in section 7.8

7.5.3 SPFT - FE calculation and resistance verification

Meshing

Boundary conditions

Loads The loads to be applied to the model are constituted by the weight suspended to the cable. Here is the mass breakdown entering in the weight calculation :

Component	Mass (kg)
Invar frame	140
Decoupling systems	1
G10 frame	67.25
Detection plane	90
Transportation squares	2.5
Screws	3
Cables and ribbons	5
Anchoring systems (x3)	3
Total mass	343 kg
Weight	5383 N
Weight by cable	**1794 N**

To be filled in.

Stress results

7.5.4 Mechanical stop - FE calculation and resistance verification

Model

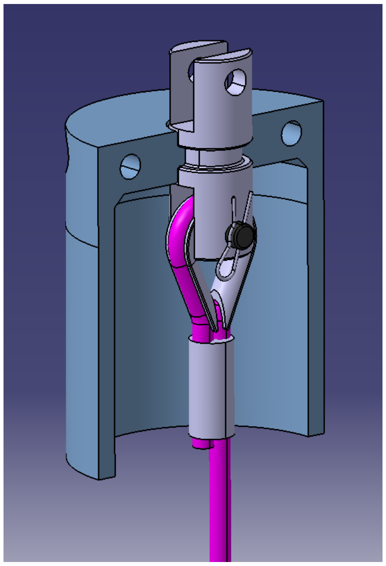


Figure 7.30: Mechanical stop

For the FEA modelling, planes of symmetry are used to simplify the model. Moreover the cable will not be explicitly represented: the mass will be modeled as a load acting directly on the shear pin thanks to the same method than above (surface whose width is 2mm with an angle of 90 degrees on pin).

Boundary conditions

The connection between parts are modeled by classical contact with 0.2 friction coefficient.
Boundary conditions are the ones in agreement with planes of symmetry (only sliding along the plane) and the bottom surface of the mechanical stop is fixed in the vertical direction.
All components are in stainless steel except the shear pin which is in Duplex steel.

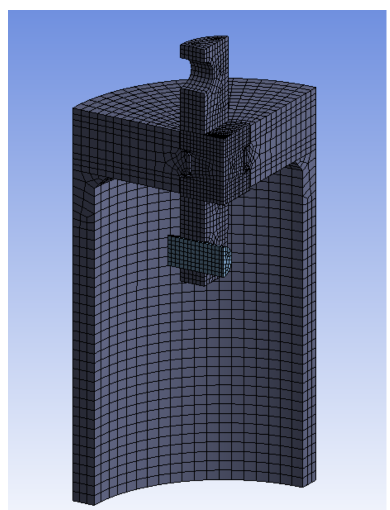


Figure 7.31: Mechanical stop meshing

Loads The loads to be applied to the model are constituted by the weight suspended to the cable. Here is the mass breakdown entering in the weight calculation :

Component	Mass (kg)
Invar frame	140
Decoupling systems	1
G10 frame	67.25
Detection plane	90
Transportation squares	2.5
Screws	3
Cables and ribbons	5
Anchoring systems (x3)	3
Total mass	343 kg
Weight	5383 N
Weight by cable	**1794 N**

Displacements results

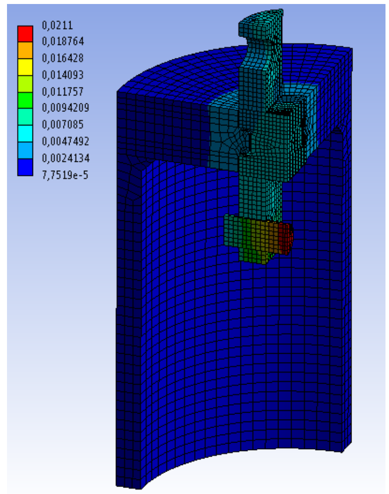


Figure 7.32: Displacement results on the mechanical stop

Stress results

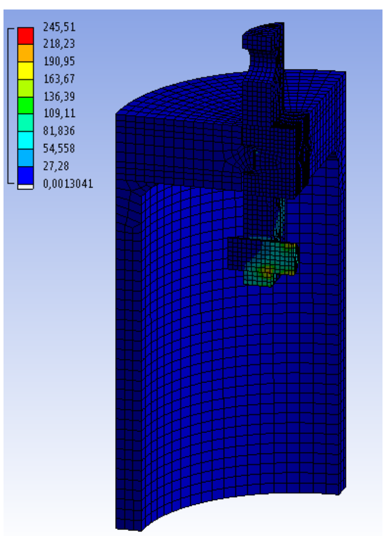


Figure 7.33: Stress results on the shear pin

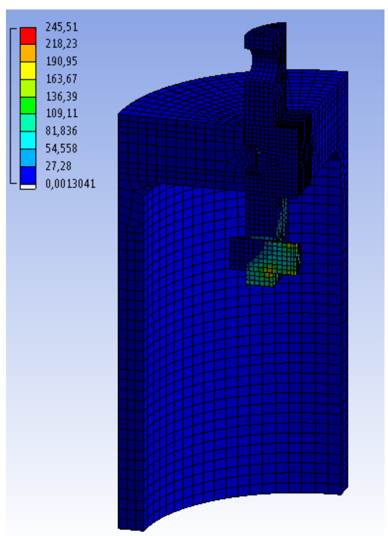


Figure 7.34: Stress results on the cable junction

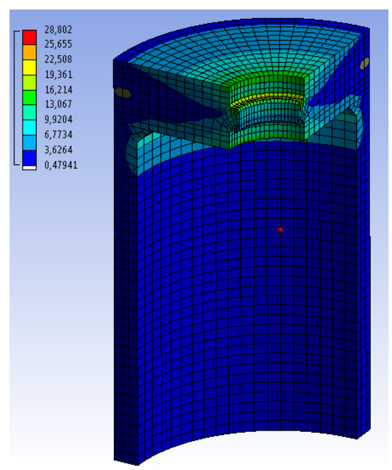


Figure 7.35: Stress results on the mechanical stop

7.6 Design situation : CRP Motor suspension

7.6.1 Geometrical data

In this configuration, the suspension chain is constituted, form the top to the bottom, by :

- The SPFT in Motor configuration, including the bellow termination part
- The cable junction (validated in the section 7.4.4)
- The anchoring system on the CRP (validated in section ??)
- The CRP itself (validated in section ??)

Thus, only the SPFT in motor configuration and the bellow termination part have to be validated in this section.

7.6.2 Certificated standard parts

For this design situation, the certificated standard parts are the cables and the motors. Information about the certification are given in section 7.8

7.6.3 SPFT in Motor configuration - FE calculation and resistance verification

Model	During standard operation mode, the motor will position the CRP at the desired altitude in the cryostat. For this a final short suspension cable links the cable junction and the upper bellow termination.

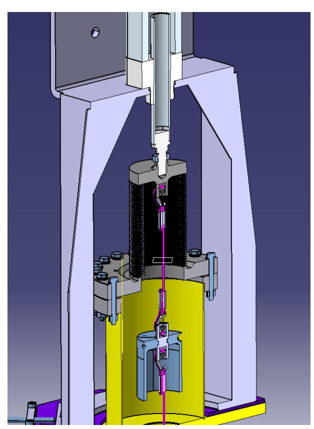


Figure 7.36: SPFT in motor configuration

Boundary conditions / Bellow termination part The upper bellow termination is in stainless steel and the shear pin in Duplex steel. The bellow termination is clamped in the thread dedicated to the motor connection.

Boundary conditions / SPFT shape The load is applied on the hole dedicated to center the motor on the support. Like the previous model in the case of the manual winch, the support is in stainless steel and the whole lower surface if fixed.

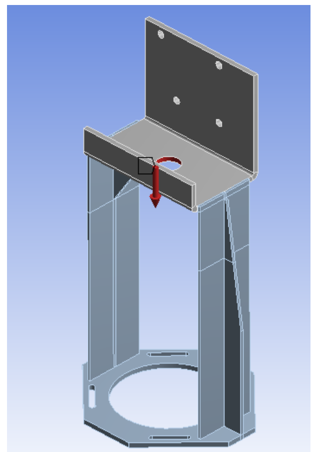


Figure 7.37: Load application on the SPFT shape model

Loads The loads to be applied to the model are constituted by the weight suspended to the cable. Here is the mass breakdown entering in the weight calculation :

Component	Mass (kg)
Invar frame	140
Decoupling systems	1
G10 frame	67.25
Detection plane	90
Transportation squares	2.5
Screws	3
Cables and ribbons	5
Anchoring systems (x3)	3
Total mass	343 kg
Weight	5383 N
Weight by cable	**1794 N**

Stress results / Bellow termination part

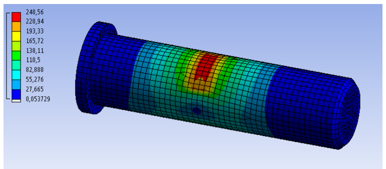


Figure 7.38: Stress level on the shear pin of the bellow termination part

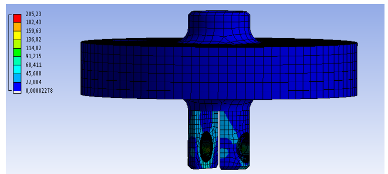


Figure 7.39: Stress level on the bellow termination part

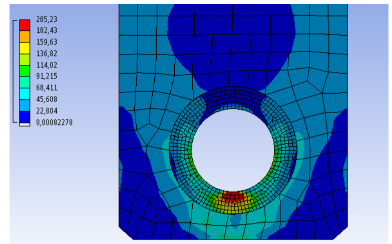


Figure 7.40: Stress level on the bellow termination part

Stress results / SPFT in motor configuration

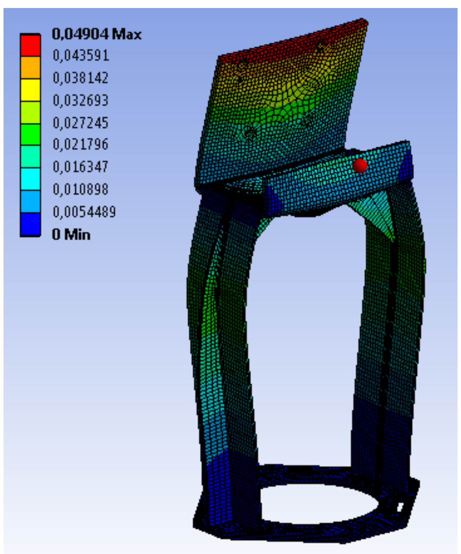


Figure 7.41: Stress level on the SPFT shape

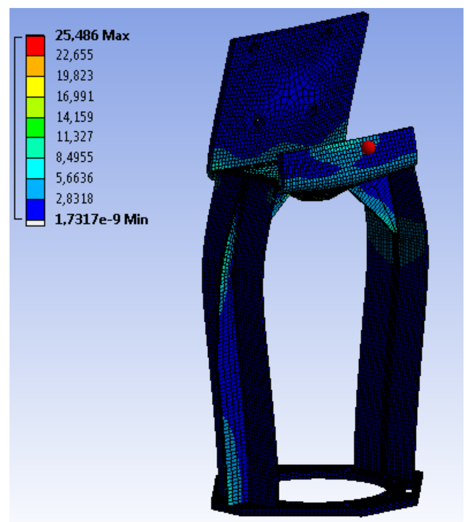


Figure 7.42: Stress level on the SPFT shape

Buckling Analysis

Buckling analysis has been performed and gives a higher load multiplier (525) than with manual winch configuration given in the latest configuration extra lateral load have been taken into account to represent loads applied to activate the handle.

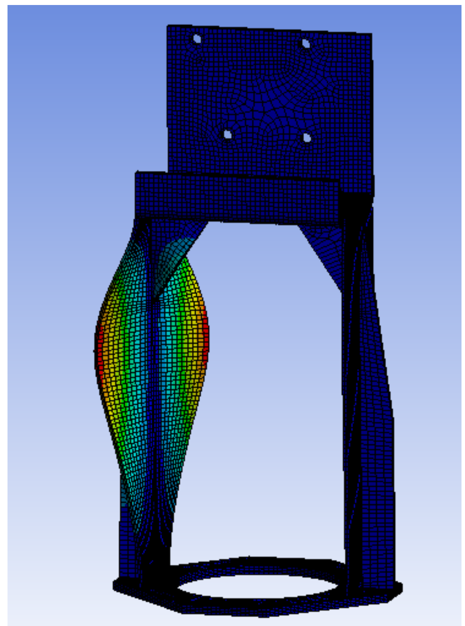


Figure 7.43: Buckling mode of the SPFT shape

7.7 Design situation : CRP in cooling down and cold conditions

7.7.1 Geometrical data

In this configuration, the suspended parts to be validated in cold conditions are :

- The stainless steel cables. Given the mechanical properties variation of stainless steel from ambient to cold temperatures, the cables are considered as suitable for operating in cold temperatures.
- The anchoring system on the CRP. Given the mechanical properties variation of stainless steel and PTFE from ambient to cold temperatures, and the small dimensions of the system making it little impacted by thermal contraction, the anchoring systems are considered as suitable for operating in cold temperatures.
- The CRP itself, during cooling down and in cold conditions.

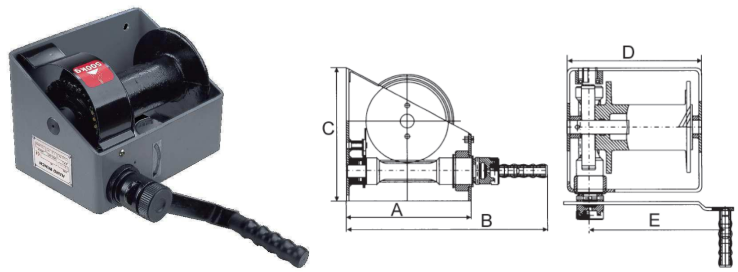
The experience of the 3x1x1 prototype has shown that cable junction and SPFT are not subject to cold conditions. The insulation thickness of the cryostat keep those systems to ambient temperature.

7.7.2 CRP in cold conditions - FE calculation and resistance verification

To be filled in.

7.8 Certificated standard parts

Manual winch The manual winch reference is LEVAC-6411-C, equipped with a 5mm diameter steel cable. This set is certified[12] by the manufacturer for 250kg SWL.



Suspension cables The suspension cables are certified[9] stainless steel lifting wires, from SCS company. They are standard lifting slings with ∅ 5mm seamings. The SWL (Standard Working Load) is 0.28 ton with a safety factor of 5.

Motor The axis of the motor is rated to support the load of the suspended CRP, until 15900N by motor for the EMC63 ball-screw model. For more information, see the manufacturer documentation[4]

Chapter 8

Field Cage & suspension

8.1 Design situations overview

The following design situations are considered under stress analysis during installation in order to verify that no issues was found from the point of view of safety:

1. **Field Cage sub-Modules Cryostat Insertion**
   The Sub-Modules are assembled in the CRB and suspended vertically at the I-Beam Crane.
2. **Positioning of the Sub-Modules inside the Cryostat**
   Sub-Modules are positioned in the cryostat in the correct place by using simple wheeled structure
3. **Field Cage Hanging System**
   The Hanging system of the Field cage consist of stainless steel I-Beams that will sustain the weight of the entire Field Cage and Cathode.
4. **Field Cage FRP first Sub-Module**
   The first Sub-Module of the field cage is the one that need to support all the weight of the entire module plus part of the weight of the Cathode.
5. **Field Cage Suspension Feedthrough**
   The Suspension system is used for installation and for final fixing. During the Installation a Manual lifter will be used to raise the Field Cage in his final position
6. **Overall Field Cage simulation in cold**
   This Simulation will study the behaviour of the complete Field Cage and Cathode for the additional stresses that will be induced by the cooling shrinkage

8.1.1 General weight calculation of the Field Cage

In order to simplify and better understand the various FE Calculation, the weight of the Field Cage is calculated here. This section explain also how the weight is divided according to the modules and suspension FTs.

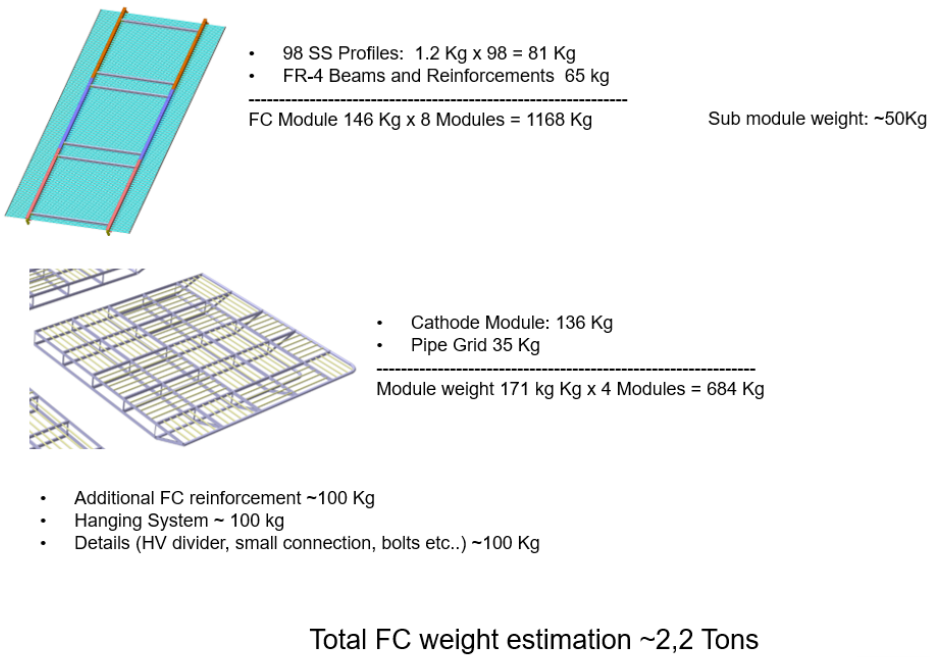


Figure 8.1: Field Cage Weight without Hanging System

Component	Mass (kg)
Field Cage	2200
additional 0.1 factor (bolts and small items)	2420
Conservative adjustement	2500
amplification factor α_u	4000
Total mass	4000 kg
Weight	40000 N
Weight by Module	**5000 N**
Weight by single FRP I-Beam	**2500 N**
Weight by single hanging wire	**3000 N**

The weight at the wire is 50Kg more than at the FRP I-beam because of the SS hanging system I-Beam.

8.2 Design situation : Field Cage sub-Modules Cryostat Insertion

Field Cage Sub-Modules will be assembled in the Clean Room Buffer. Once assembled they will be inserted in the Cryostat suspended at the I-Beam Crane.

8.2.1 Geometrical data

Since this is a procedure during Installation load case will be in warm. Weight of the Field Cage Sub-Modules is very low (60kg). Hanging system will not require particular calculation

8.2.2 Note on model construction

Hanging system will consist mainly in a reinforcement for the Field Cage Sub-Modules will be over constraint.

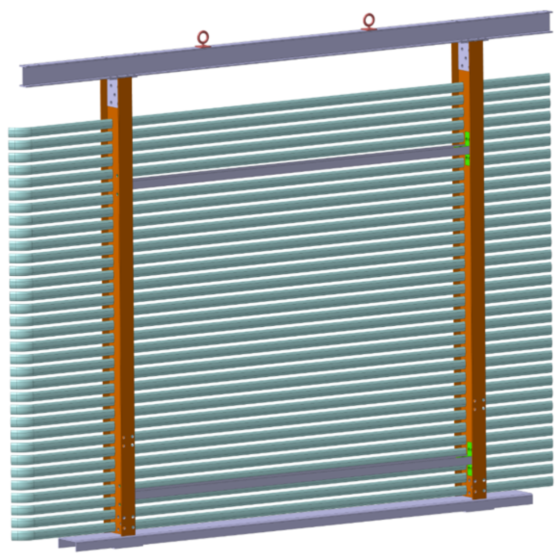


Figure 8.2: Field Cage Sub-Module reinforcement for Insertion inside the Cryostat.

8.2.3 FE calculation and verification

At the moment no FE calculation are foreseen. If required it will be done

8.3 Design situation : Positioning of the Sub-Modules inside the Cryostat

Sub-Modules has to be Transported from the TCO to the final position in order to be hung at the Field Cage Hanging System

8.3.1 Geometrical data

Since this is a procedure during Installation load case will be in warm. Weight of the Field Cage Sub-Modules is very low (60kg). Hanging system will not require particular calculation

8.3.2 Note on model construction

Hanging system will consist mainly in a reinforcement for the Field Cage Sub-Modules will be over constraint.

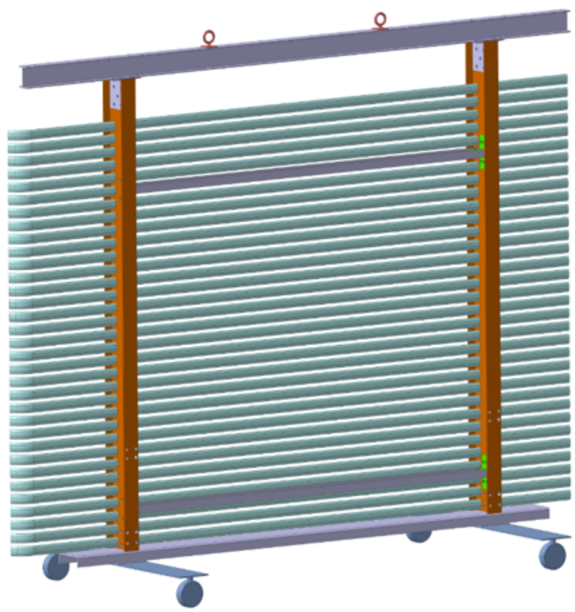


Figure 8.3: Sketch of additional Plates under the reinforcement in order to add wheels.

8.3.3 FE calculation and verification

At the moment no FE calculation are foreseen. If required it will be done

8.4 Design situation : Field Cage Hanging System

Hanging system is a stainless steel structure that will hold the entire Field Cage.

8.4.1 Geometrical data

It consist of a Stainless Steel I-Beam, a pin connected to the hanging wires and Stainless Steel L-profiles are connected to the FRP I-Beams of the Field Cage Modules. The stainless steel pin, where the wire is connected, is studied separately since it is the weak point of the system

Case 1 Hanging System without Pin.

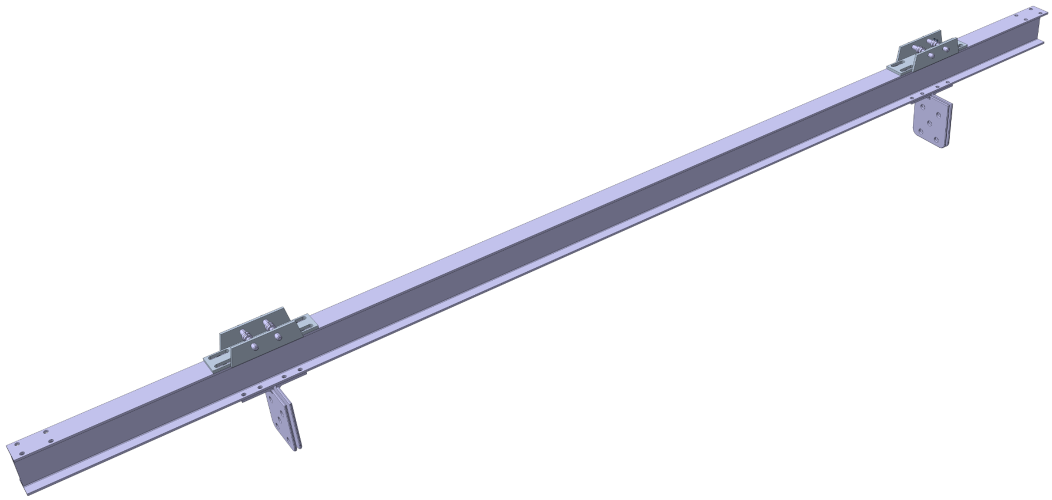


Figure 8.4: Hanging System for each Field Cage Module.

Case 2 Hanging Pin.

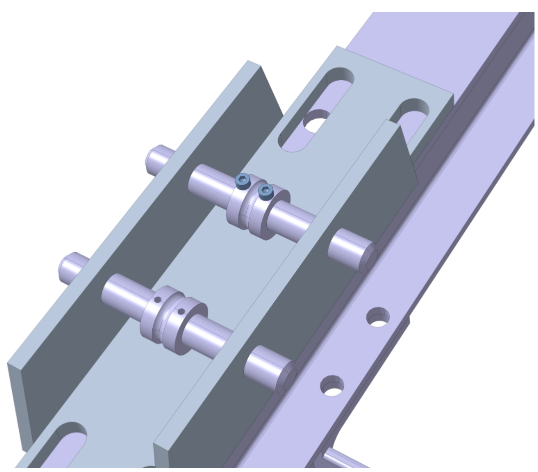


Figure 8.5: Hanging Pin for wire connection.

8.4.2 Note on model construction

As for the other cases a 1.6 safety factor at the load will be applied and the calculation will be considered in warm condition during the installation.

8.4.3 Case 1 - FE calculation and verification

Boundary conditions Hanging system is connected with two Stainless Steel wires of 6mm diameter.

Loads The Load consist of the self weight with amplification factor α_u at the Gravity with an additional Weight of 5000 N applied to the Stainless steel L-Profile where the Field cage is connected.

Stress results As a results of the simulation the Maximum stress is 93.5Mpa.

Additionally to the amplification factor already applied at the weight, there is still a safety factor of 2.

Deformation are very small and largely inside the elastic range of the material

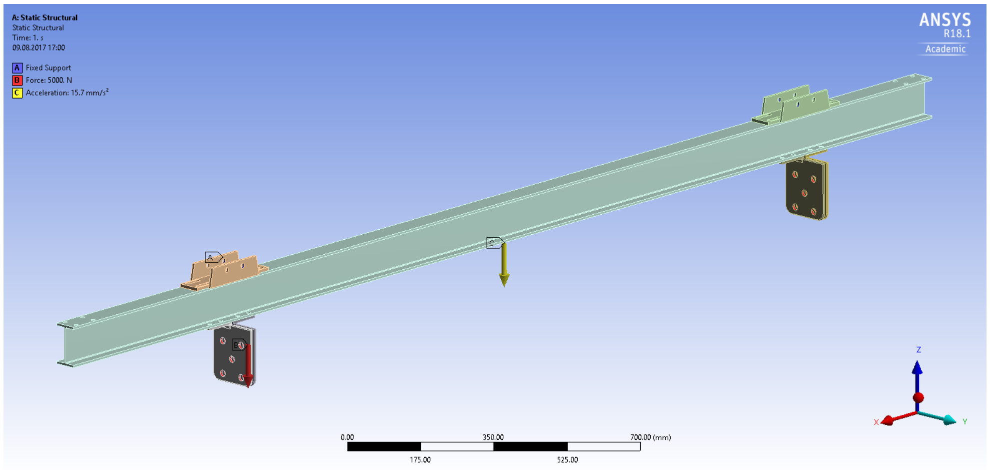


Figure 8.6: Load Case for the Hanging System - Load of 5000N

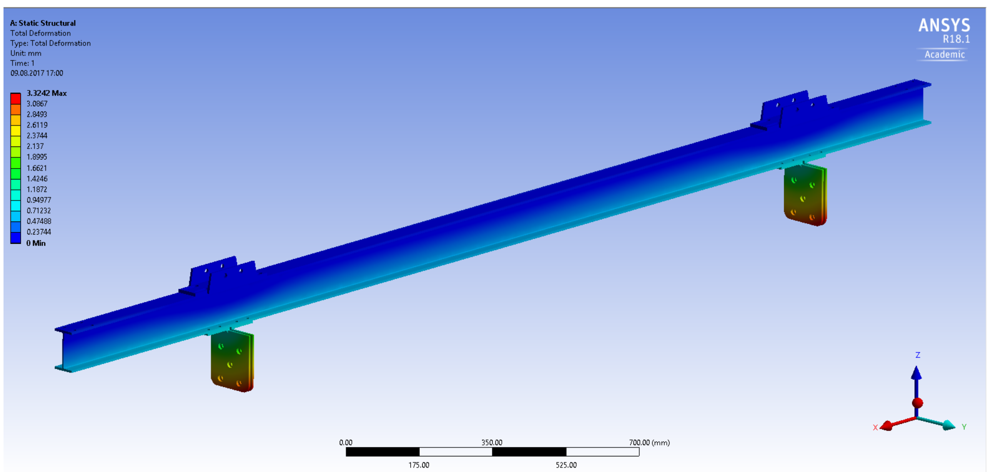


Figure 8.7: Deformation for the Hanging System - Max Deformation 3.32mm

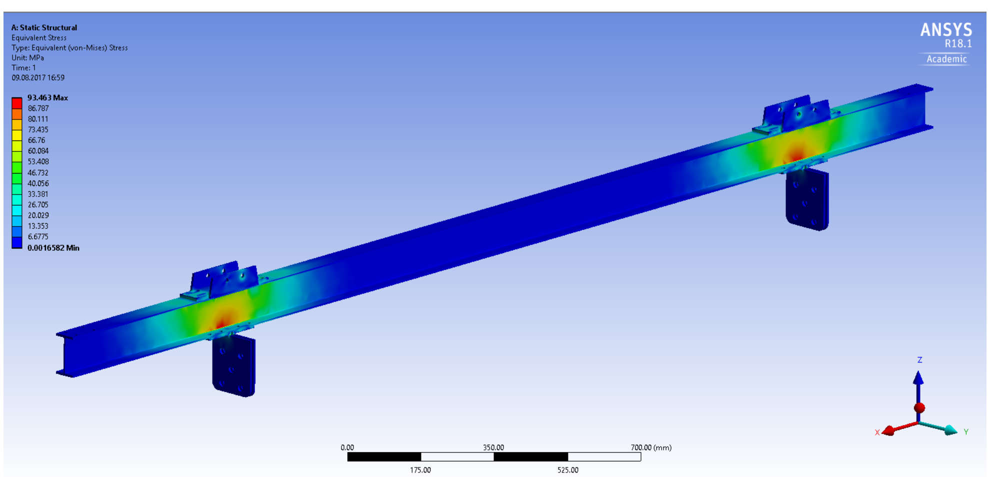


Figure 8.8: Stress for the Hanging System - Max Stress 93.5Mpa

8.4.4 Case 2 - FE calculation and verification

Boundary conditions Pin is the connection to the 6mm diameter Hanging wire.

Loads Loads is including the weight of the Stainless Steel I-Beam of the Hanging System. A Weight of 3000N is applied to the Pin .

Stress results Maximum Stress at the Pin is 140Mpa. Additionally to the amplification factor applied still there is a safety factor of 1.4.

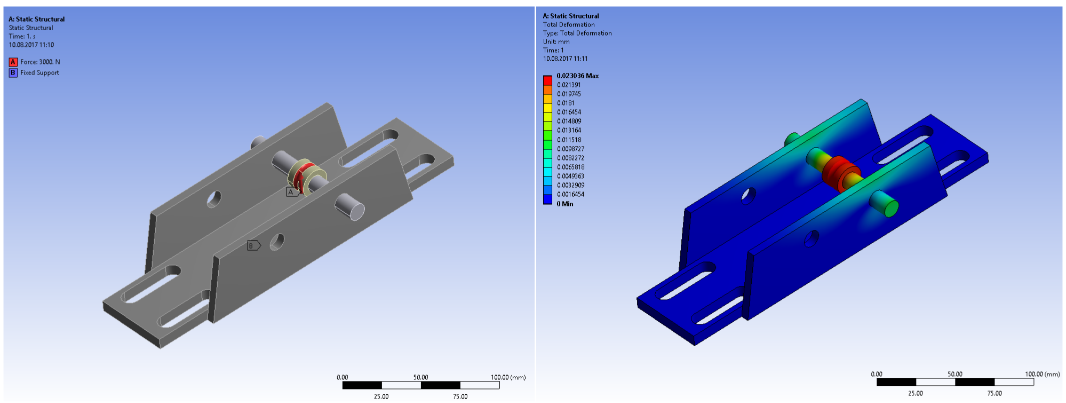


Figure 8.9: Load Case (3000 N) and Deformation for the Hanging Pin - Max 0.3mm

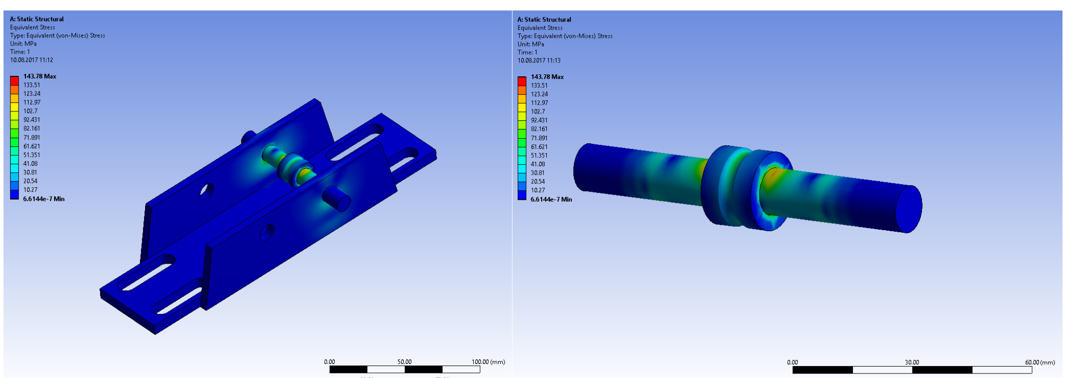


Figure 8.10: Stress at the Hanging Pin - Max Stress 140Mpa

8.5 Design situation : Field Cage FRP first Sub-Module

Top Sub-Module of the Field Cage is connected to the Stainless Steel Hanging System and the FRP I-Beam has to sustain all the weight of the Field Cage with Cathode included

8.5.1 Geometrical data

Stress is only vertical through the FRP I-Beam. Stress and Deformation are expected to be very small since the weight of the entire Field Cage is divided in 16 I-Beam

8.5.2 Note on model construction

No particular notes concerning this simulation. As for the other cases a 1.6 safety factor at the load will be applied and the calculation will be considered only in warm condition. Real Load Test was performed at the FRP I-Beam showing a large safety factor compared to the Detector situation. FE calculation are simply to show and confirm the real load test. Figure 8.11 Shows a load test of the FRP bars.

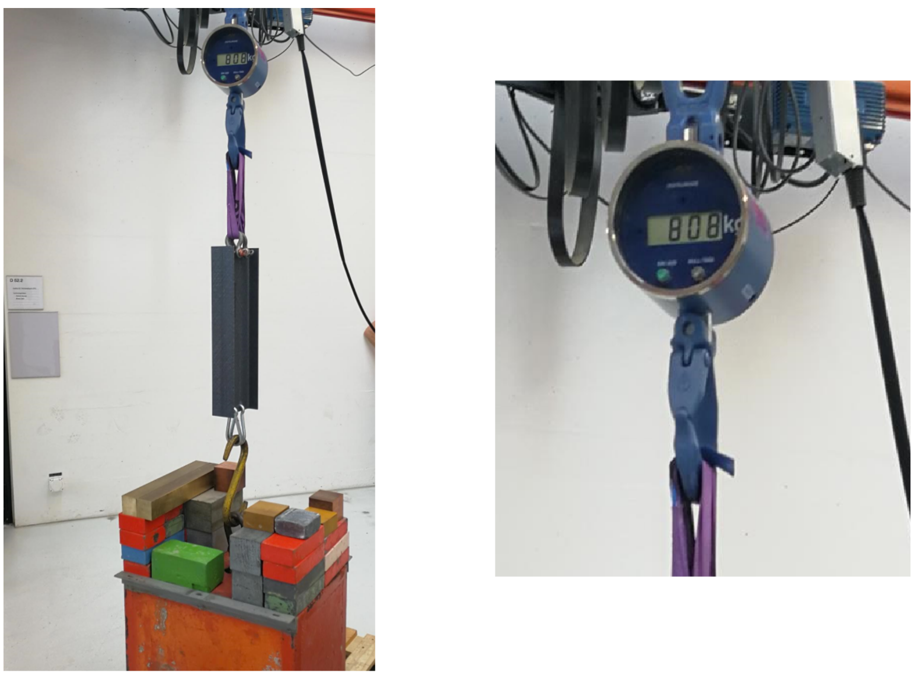


Figure 8.11: Load Test at 800kg the FRP sample used for the Field Cage

8.5.3 FE calculation and verification

Meshing

Boundary conditions Box is sitting at the cart with no particular fixing.

Loads Load applied at the holes of the top FRP I-Beam. Weight applied is 2500N. In this case the weight of the Stainless Steel Hanging System is not considered since the the FRP I-Beam is connected below it

Stress results As shown in the picture below the maximum stress is at the holes where the the FRP I-Beam is connected to the hanging system.

Stress is 21Mpa with 2500N weight divided in 5 holes.

The Load Test of 8000N was applied at only two holes showing no problem. In this case no additional simulation is needed. The FRP will sustain all the weight of the Field Cage without any issue.

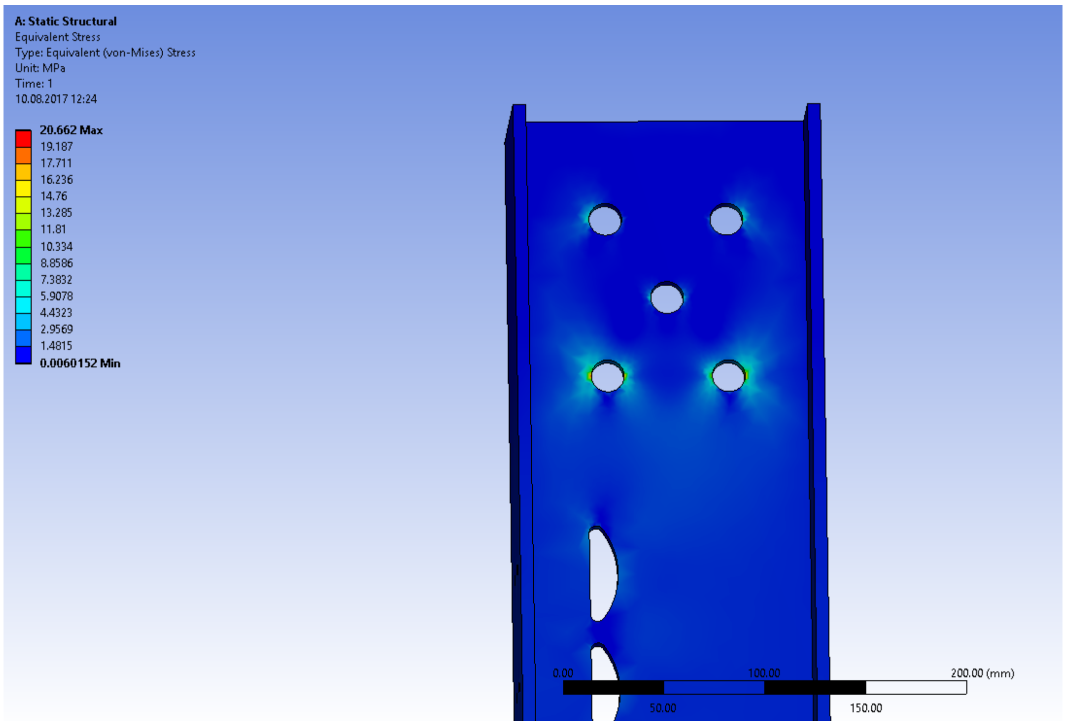


Figure 8.12: Stress at the Top holes of the Field Cage Modules that have to hold all the Field Cage Weight

8.6 Design situation : Field Cage Suspension Feedthrough

Suspension Feedthroughs are at the Top of the Cryostat. There are sixteen Fts that need to sustain the weight of the Field Cage. One Feedthrough per FRP I-Beam (2 Fts per Field Cage Module). During the installation a manual winch per each Fts will be used in order to lift the Field Cage Modules. When the Modules are in the nominal position the they are suspended to a CF40 Flange.

8.6.1 Geometrical data

Three Configurations are considered:

Load case 1 Suspension Feedthrough during installation.

Load case 2 Suspension Feedthrough in final configuration.

Load case 3 Suspension Feedthrough CF40 Hook.

8.6.2 Note on model construction

No particular note at the model. Material is Stainless for the entire structure.

8.6.3 Load case 1 - FE calculation and verification

Boundary conditions Suspension Feedthrough is Connected to CF200 Flange and the force is applied at the Manual winch where the Field Cage Modules will be lifted

Loads Load considered is 3000N. Weight of the Field Cage considering he additional weight of the Hanging System

Stress results Maximal stress is 92.8.3Mpa. There is an additional safety factor of 2,1

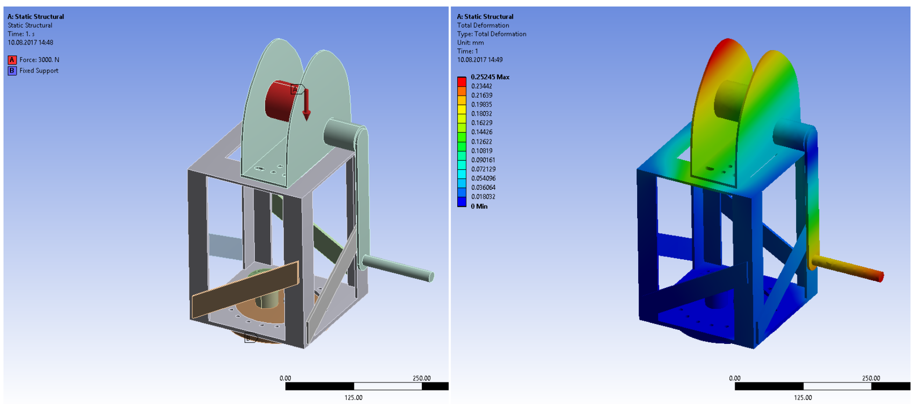


Figure 8.13: Load case with force applied at the Manual Winch during installation

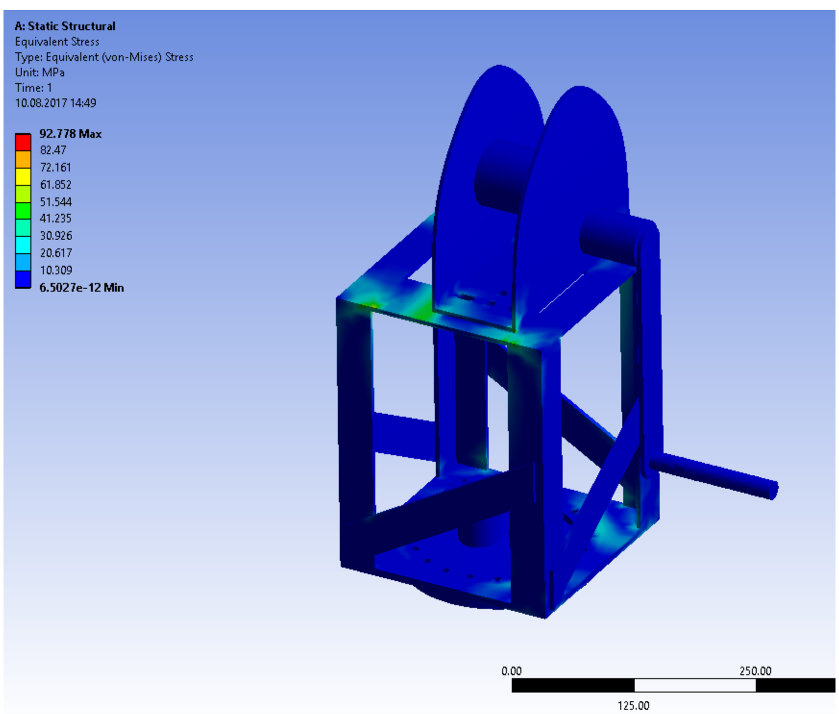


Figure 8.14: Stress at the Suspension Feedthrough - Max Stress 92.8Mpa

8.6.4 Load case 2 - FE calculation and verification

Boundary conditions Suspension Feedthrough is connected to CF200 Flange and the force is applied at CF40 where the Wire will be hooked in his final position.

Loads Load considered is 3000N. Weight of the Field Cage considering he additional weight of the Hanging System

Stress results Maximal stress is 52.3Mpa. There is an additional safety factor of 3,8

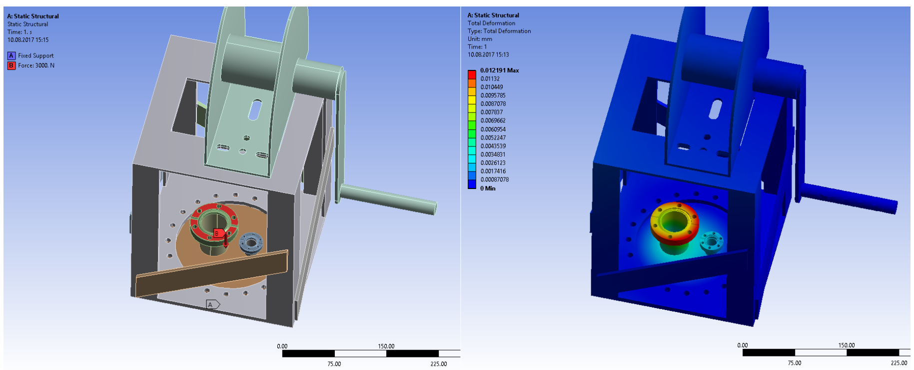


Figure 8.15: Force apllied at the CF40 in final configuration

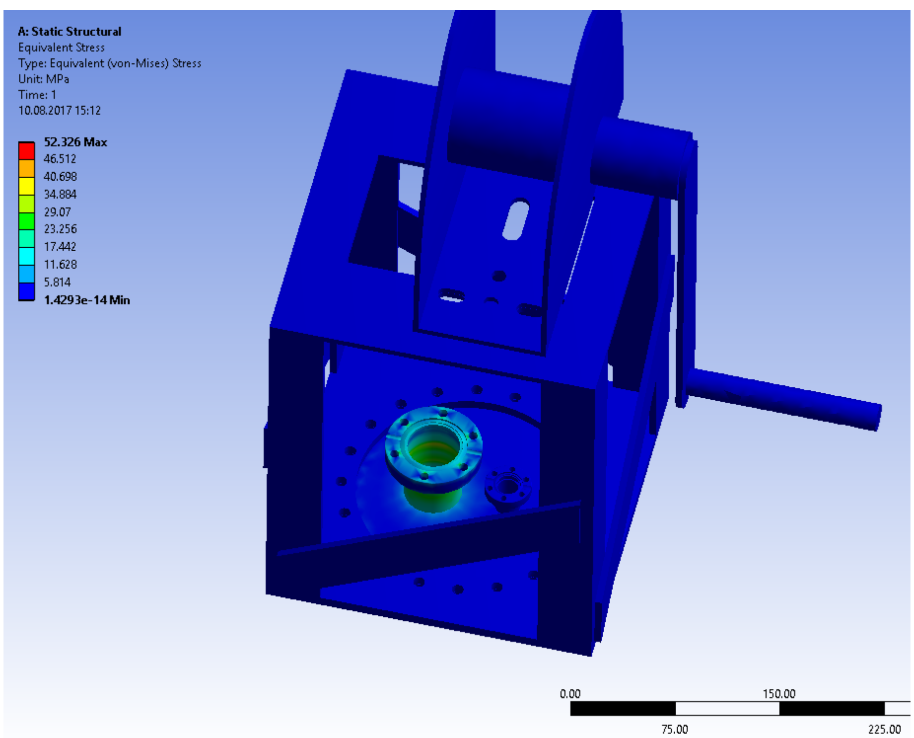


Figure 8.16: Stress at the CF40 chimmney where the Field Cage is suspended - Max Stress 52.3Mpa

8.6.5 Load case 3 - FE calculation and verification

Boundary conditions The Hook where the Drift Cage Modules are connected is welded at a CF40 Flange..

Loads Load considered is 3000N. Weight of the Field Cage considering he additional weight of the Hanging System

Stress results Maximal stress is 86.6Mpa. There is an additional safety factor of 2.3

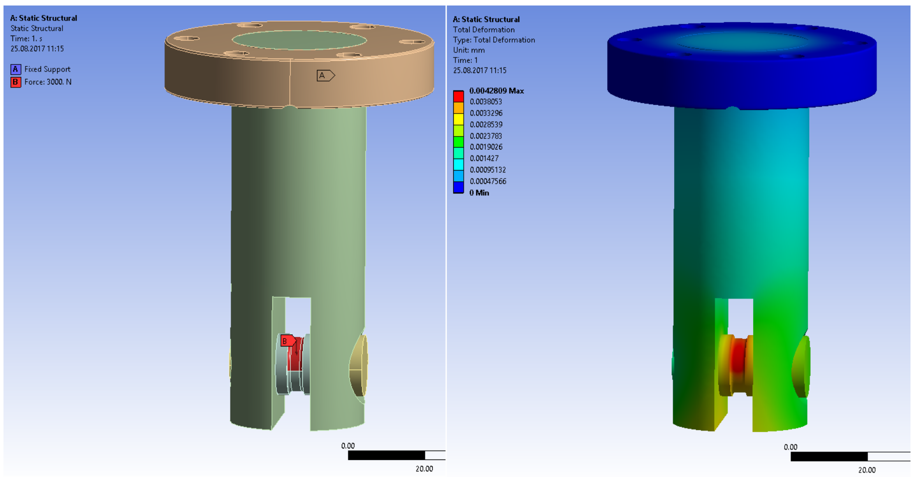


Figure 8.17: Load Case at the CF40 Hook

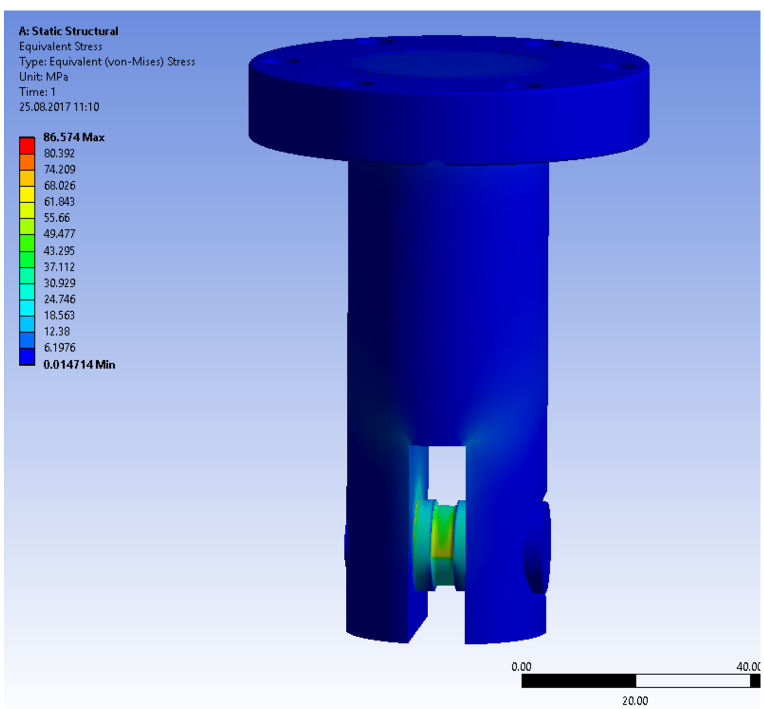


Figure 8.18: Stress at the CF40 Hook where the Field Cage is suspended - Max Stress 86.6Mpa

8.7 Design situation : Overall Field Cage simulation in Cold

The scope of this simulation is more for the functionality of the Detector, in order to verify after the shrinkage due to the cool down.

8.7.1 Geometrical data

Study is not yet performed

8.7.2 Note on model construction

Study is not yet performed

8.7.3 FE calculation and verification

Boundary conditions	Model hung at sixteen stainless steel wires.
Loads	The model is only suspended, the gravity including amplification factor α_u is applied.
Stress results	Study not yet performed.

Chapter 9

Cathode & ground grid

9.1 Design situations overview

The following design situations are considered under stress analysis during installation in order to verify that no issues was found from the point of view of safety:

1. **Transport box suspension and insert in the Cryostat**
   The Cathode and the GroundGrid are constructed in four modules each of 3.15mx3.15m. They are transported in a box suspended at the crane inside the Clean Room Buffer through the Hatch on the Top.

2. **Cathode at the Field Cage**
   Cathode is suspended with sixteen FR4 holders at his perimeter at the end of the Field Cage FRP I-beams. Structure of the Cathode is a self supporting structure

3. **Ground Grid positioned at the Membrane**
   The GroundGrid is supported by pillars that are positioned at the flat membrane. Pillars are free to move due to the shrinkage. Only the center pillar will be glued at the membrane to keep the Groundgrid centered with the Detector.

9.2 Design situation : Transport box suspension and Insert in the Cryostat

In this section the Cathode and GroundGrid modules are transported in their boxes suspended in the Hall's crane and inserted in the Clean Room Buffer Hatch. Boxes are opened in the Clean Room Buffer and the parts are inserted Vertically through the TCO.

9.2.1 Geometrical data

In this design situation, the Cathode and Groundgrid modules are not fragile. They are meant to sustain they self weight horizontally. The transportation to the Clean Room Buffer and the insertion through the TCO is vertically. The stress at the Modules is expected to be very low.

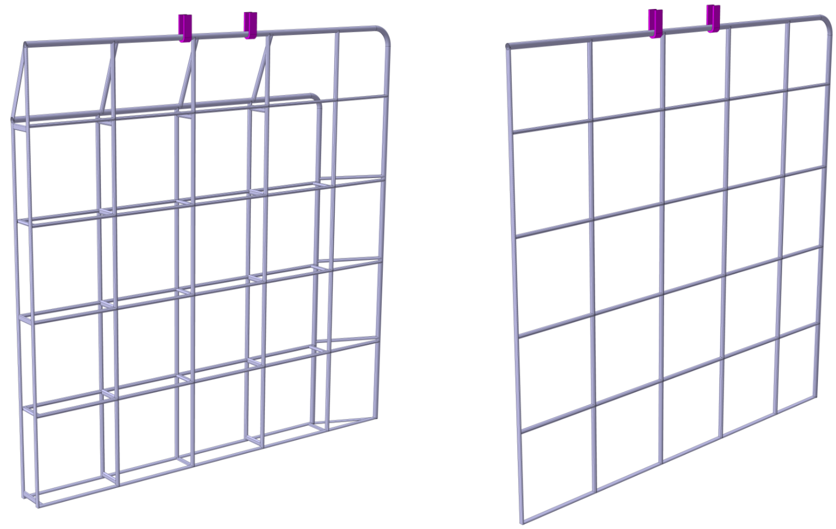


Figure 9.1: Cathode are simply inserted in the Cryostat with Slings

For this section the Structural Calculation is done exclusively for the suspended insertion through the TCO. The Transport Box will be manufactured by a specialized company for transportation. As soon as the Box will be designed and manufactured calculation as a verification will be done.

9.2.2 Note on model construction

No particular note for this simulation. The slings are modeled in order to give the stress at the connection points and the self weight is calculated with a safety factor α_u .
Material of Cathode and Groundgrid is Stainless Steel.

9.2.3 FE calculation and verification

Boundary conditions	The whole model is suspended to the slings at a distance of 500mm.
Loads	Self weight with amplification factor α_u .
Stress results	Maximal stress is in the Cathode Module of 34Mpa. The Stress in the Groundgrid is negligible.
	Considering the stress of 34Mpa there is still a safety factor of 5,8.

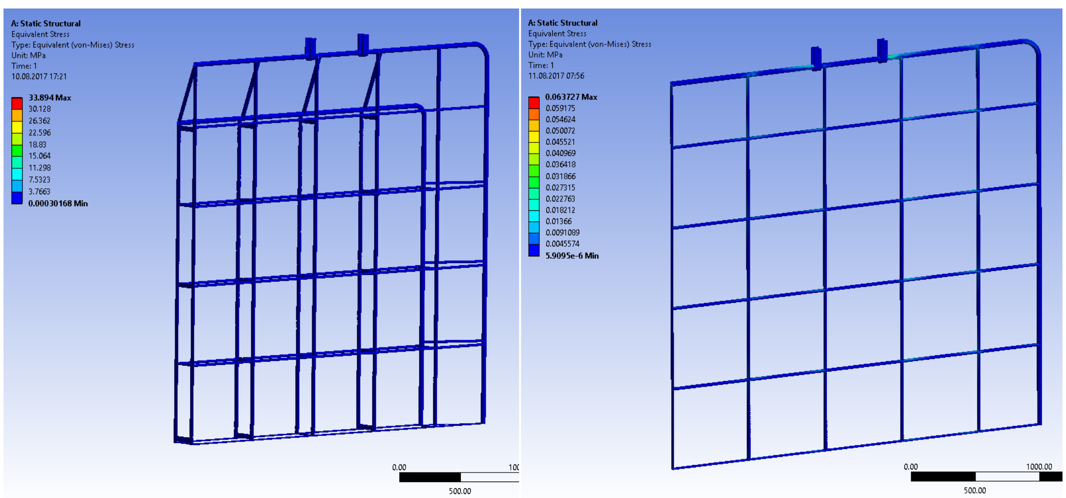


Figure 9.2: Stress at the cathode and the groundgrid suspended with Slings - Max Stress 34Mpa

9.3 Design situation : Cathode at the Field Cage

The Cathode is suspended at the bottom of the Field Cage in sixteen point. Hanging Points, so called Cathode Holders, are made by G10 Plate. This section consider the Cathode only in warm and dry condition which is the worst situation for the point of view of the stress. The Cold simulation is considered together with the Field Cage model in Chapter 8.7.

9.3.1 Geometrical data

The worst case loading occurs when the cathode is under gravity and dry. Three analysis were performed.

Load case 1 Module of the cathode was created using symmetric boundary conditions.

Load case 2 The full cathode was modeled and compared to the first analysis.

Load case 3 The full cathode was modeled but only supported at four points.

9.3.2 Note on model construction

At the moment the model is simplified in order apply symmetry boundary and in order to have a preliminary idea of the structure. A full study of the cathode will be done by middle of September.

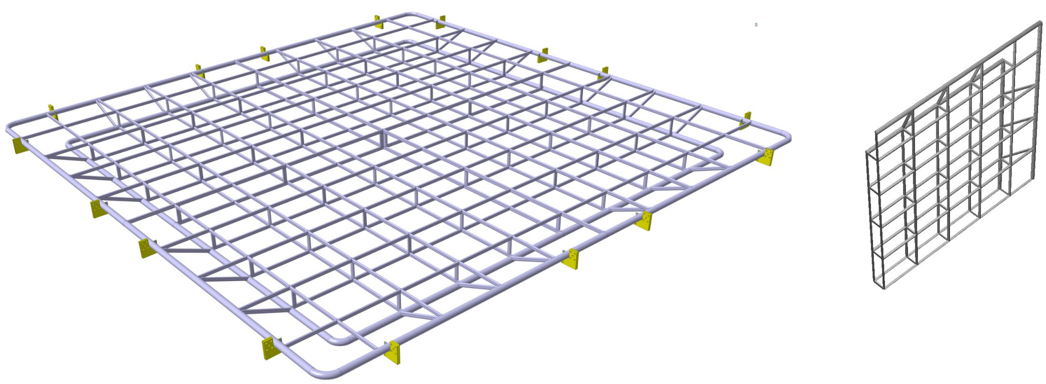


Figure 9.3: Geometry of Cathode complete and only one module

9.3.3 Load Case 1 : FE calculation and verification

Boundary conditions Cathode is connected to the sixteen G10 holder. Symmetric Boundary condition are used in order to simulate the entire Cathode

Loads The load consists of the selfweight. In this particular case no α_u value was applied to the acceleration but it will be applied at the stress result .

Stress results The center deflections is 1.93mm and the Maximal Stress is 30MPa.

Considering that no amplification factor to the Gravity was apllied there is a safety factor of 6,6.

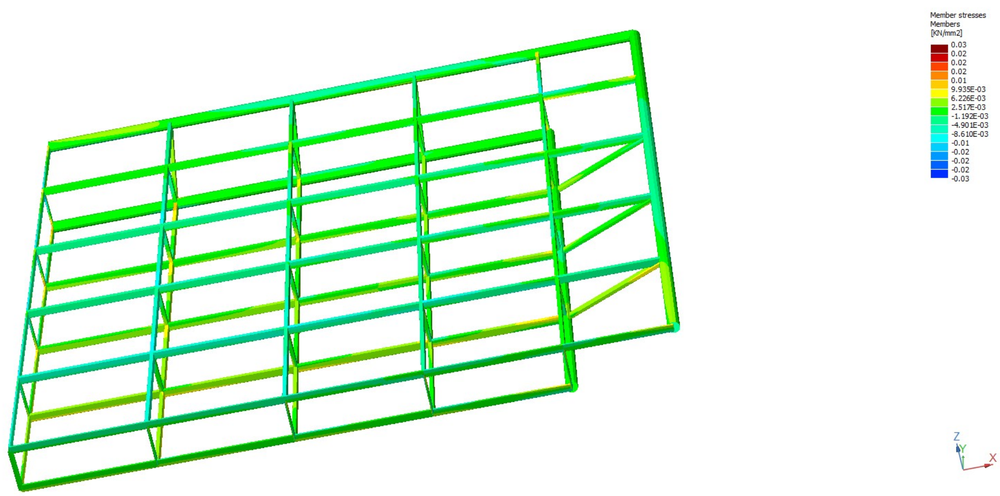


Figure 9.4: Stress result at one module - Max 30MPa

9.3.4 Load Case 2 : FE calculation and verification

Boundary conditions Cathode is connected to the sixteen G10 holder.

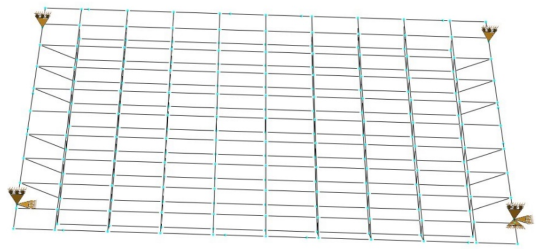


Figure 9.5: Cathode with reduced hanging points

Loads The load consists of the selfweight. In this particular case no α_u value was applied to the acceleration but it will be applied at the stress result .

Stress results As expected the Results match with the module study.

The center deflections remained 1.93mm and the stresses were below 30MPa.

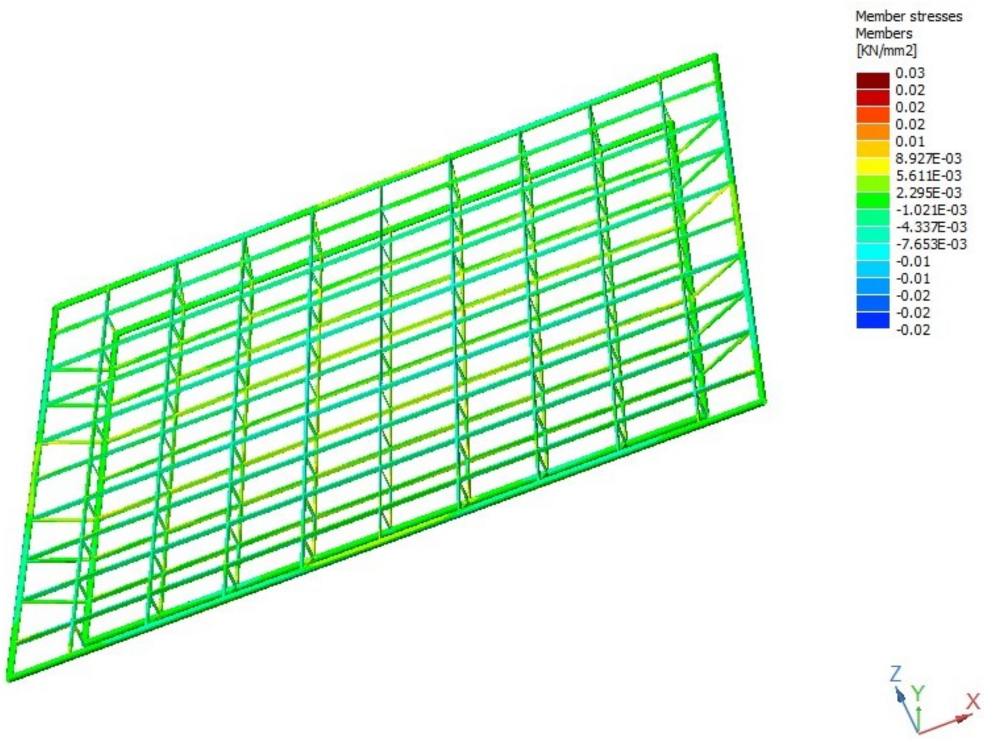


Figure 9.6: Stress result at the Cathode Complete - Max 30MPa

9.3.5 Load Case 3 : FE calculation and verification

Boundary conditions Cathode is connected to only four G10 holder.

Loads The load consists of the selfweight. In this particular case no α_u value was applied to the acceleration but it will be applied at the stress result .

Stress results The stresses are acceptable even when it is only partially supported. Maximal Stress is 130MPa.

Considering that no amplification factor to the Gravity was apllied there is a safety factor of 1.54.

In this particular case of only partial supporting, additional analysis is needed to be done on the bolted and welded connections.

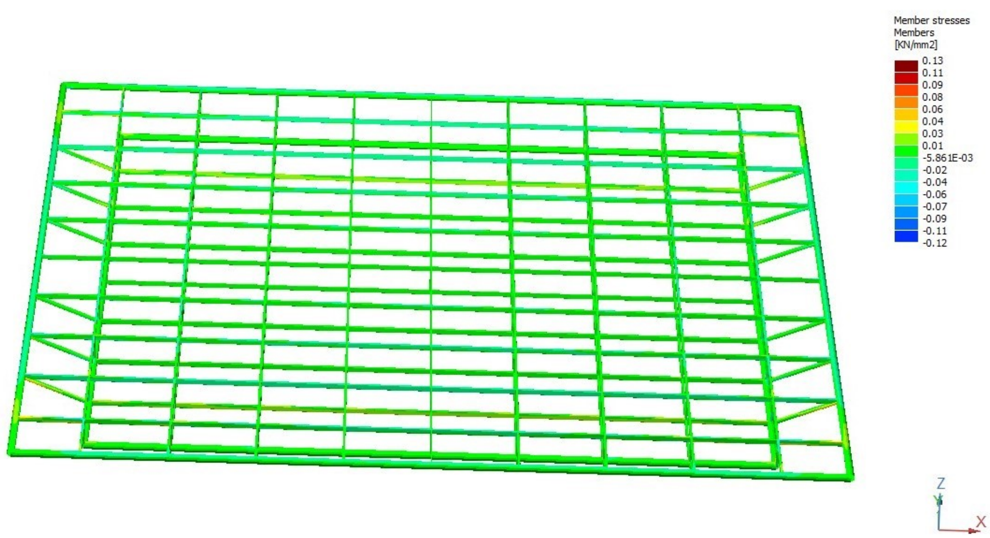


Figure 9.7: Stress result at the Cathode Complete supported in four point - Max 130MPa

9.4 Design situation : Ground Grid positioned at the Membrane

Ground Grid is placed at the membrane with nine Pillars. Center pillar will be point glued at the membrane in order to stay fixed. The other eight external Pillar have a Teflon sheet on their bottom in order to shrink freely during the cool down without inducing stress at the membrane

9.4.1 Geometrical data

Two load cases are considered. In warm and cold. FE calculation in warm is the worst case concerning the stress. Cold Calculation is mainly to verify the size of the pillar base in order that after the thermal shrinkage there will be no conflict at the membrane corrugation.

Load case 1 GroundGrid in warm and Dry.

Load case 2 Groundgrid in cold.

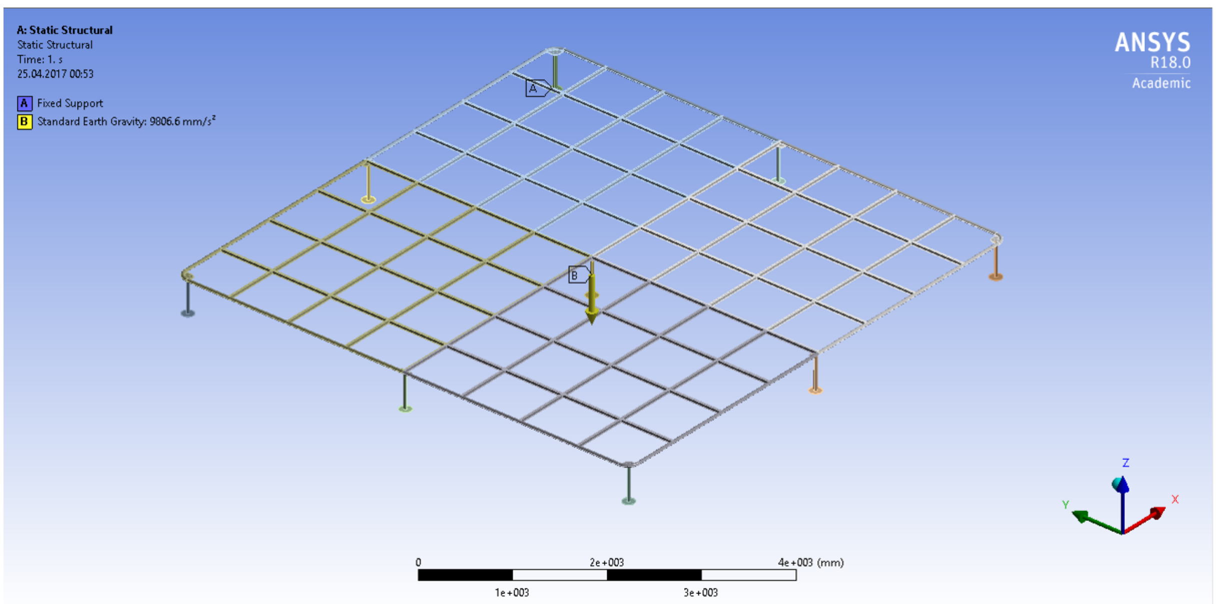


Figure 9.8: GroundGrid Geometry placed on his nine pillars

9.4.2 Note on model construction

At the moment the model is not at his complete final design. A full study of the GroundGrid will be done by mid of September.

9.4.3 Load case 1 - FE calculation and verification

Boundary conditions The whole model is placed at the membrane with 9 pillars.

Loads Gravity is applied to model. This Simulation doesn't include the amplification factor α_u . Safety factor will be calculated according to the stress result compared to the Yeld strengt in Chapter 7

Stress results Maximal Stress, thanks to the central Pillar, is 44,2 Mpa.

Considering that no amplification factor to the Gravity was apllied there is a safety factor of 4.5.

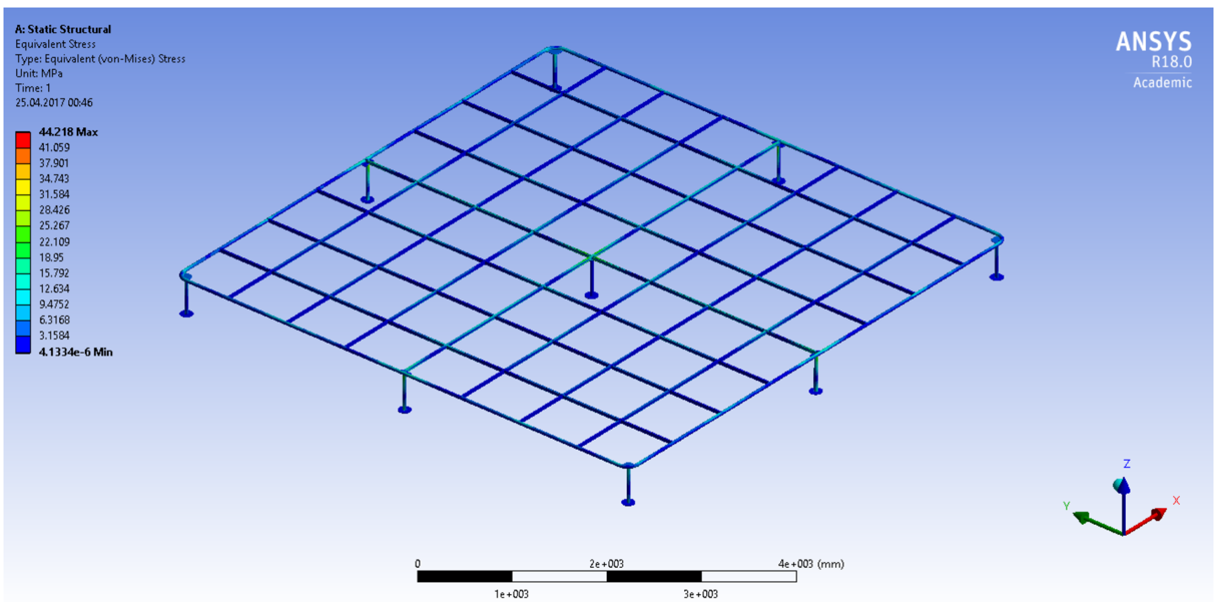


Figure 9.9: Stress at the Groundgrid - Max Stress 44,2Mpa

9.4.4 Load case 2 - FE calculation and verification

Boundary conditions The whole model is suspended to the anchoring holes on the IPE profile. On the other side, the box rests on its edge. The worst case is reached the box in horizontal position.

Loads The gravity (with amplification factor α_u) is applying along vertical axis

Stress results This Calculation in Cold is not yet performed

Bibliography

[1] AFNOR. *Eurocode: Basis of structural design NF EN 1990-1-1.* Paris, 2003.

[2] AFNOR. *Eurocode 3: calcul des structures en acier : partie 1-8 : calcul des assemblages : annexe nationale à la NF EN 1993-1-8:2005.* Paris, 2007.

[3] AFNOR. *Eurocode 3: design of steel structures : part 1-1 : general rules and rules for buildings.* BSI, 2015. Incorporating corrigenda February 2006 and April 2009.

[4] Bosch Rexroth AG. *Verins Electromécaniques EMC.* Bosch Rexroth AG, 2015.

[5] Inc. Ansys. *Ansys User's Guide, Release 18.0.* Ansys, Inc., 2017.

[6] Aperam. Aperam - offre acier inoxydable de précision, 2014.

[7] Aperam. Invar plates standard specification, 2014.

[8] Brabant. Fiche de données sécurité - acide phosphorique 25 à 85%, 2014.

[9] SCS Sangles et Cables Savoyards. Certification document of suspension cables - scs, 2017.

[10] Von Roll Deutchlant GmbH. Stratifiés - vetronit egs 102, 2014.

[11] item Industrietechnik GmbH. Système de construction modulaire mb - elcom, 2013. Material properties in the Technical Data (around page 600).

[12] Levac. Certification document of manual winch - ref 6411-c, 2017.

[13] Arcelor Mittal. Arcelor mittal - aciers de construction non alliés suivant norme européenne, 2017.

[14] Arcelor Mittal. Arcelor mittal - uranus 2205, 2017.

[15] NIST. Material properties: Invar, 2017. References are given following the URL.

[16] NIST. Material properties: Teflon, 2017. References are given following the URL.

[17] Stannol. Technical data sheet - stannol solder wire arax, 2013.

[18] Inc. WS Hampshire. Typical properties of ptfe, 2014.

Appendix A

Layout of the cryostat in EHN1 and naming convention for the feedthroughs

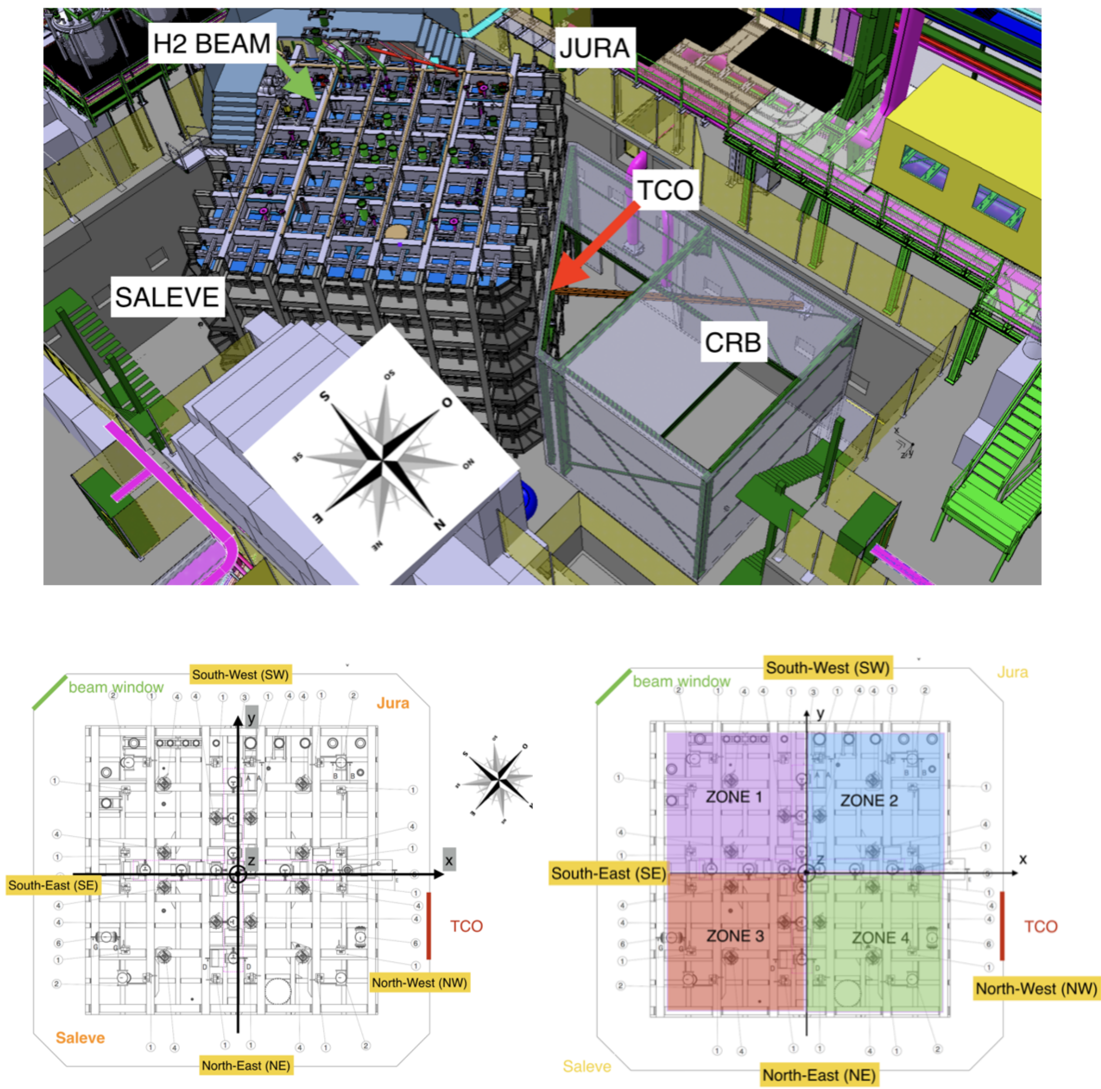


Figure A.1: 3D view in EHN1 and cartesian coordinate of the cryostat

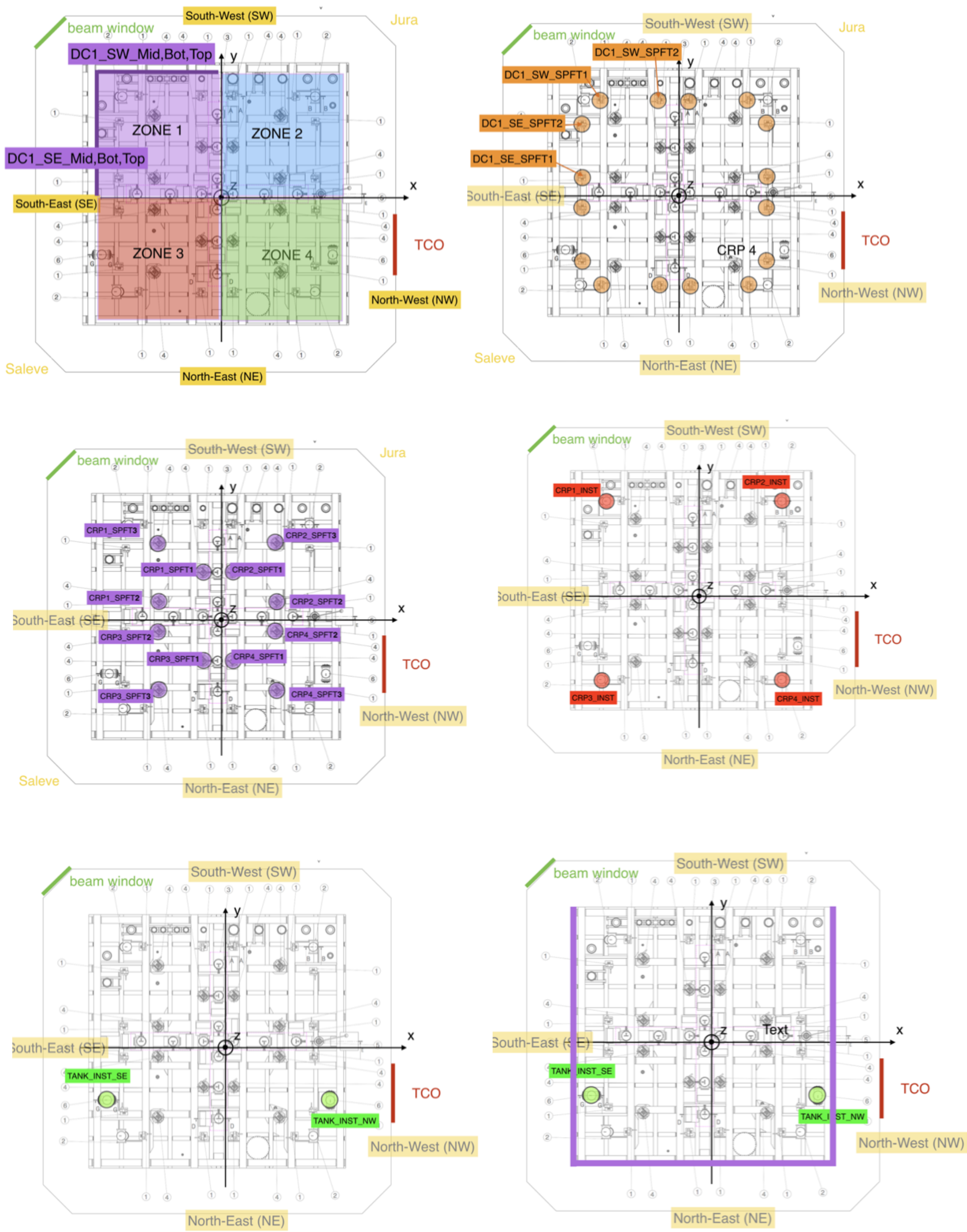
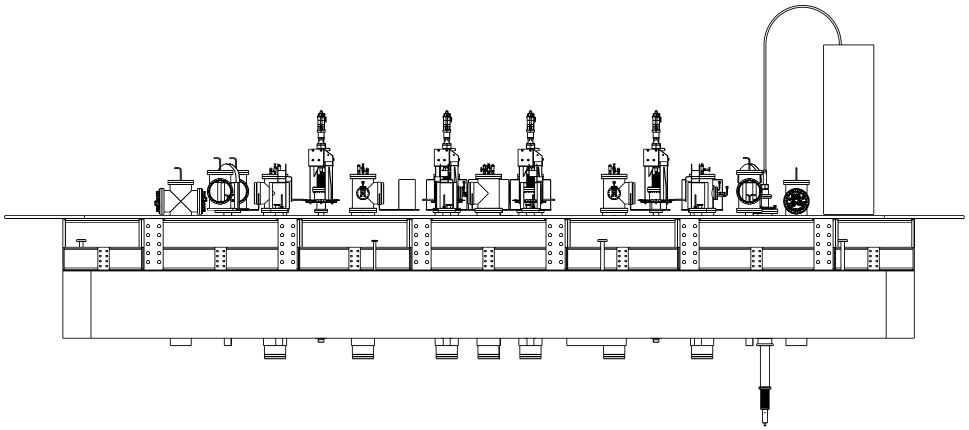
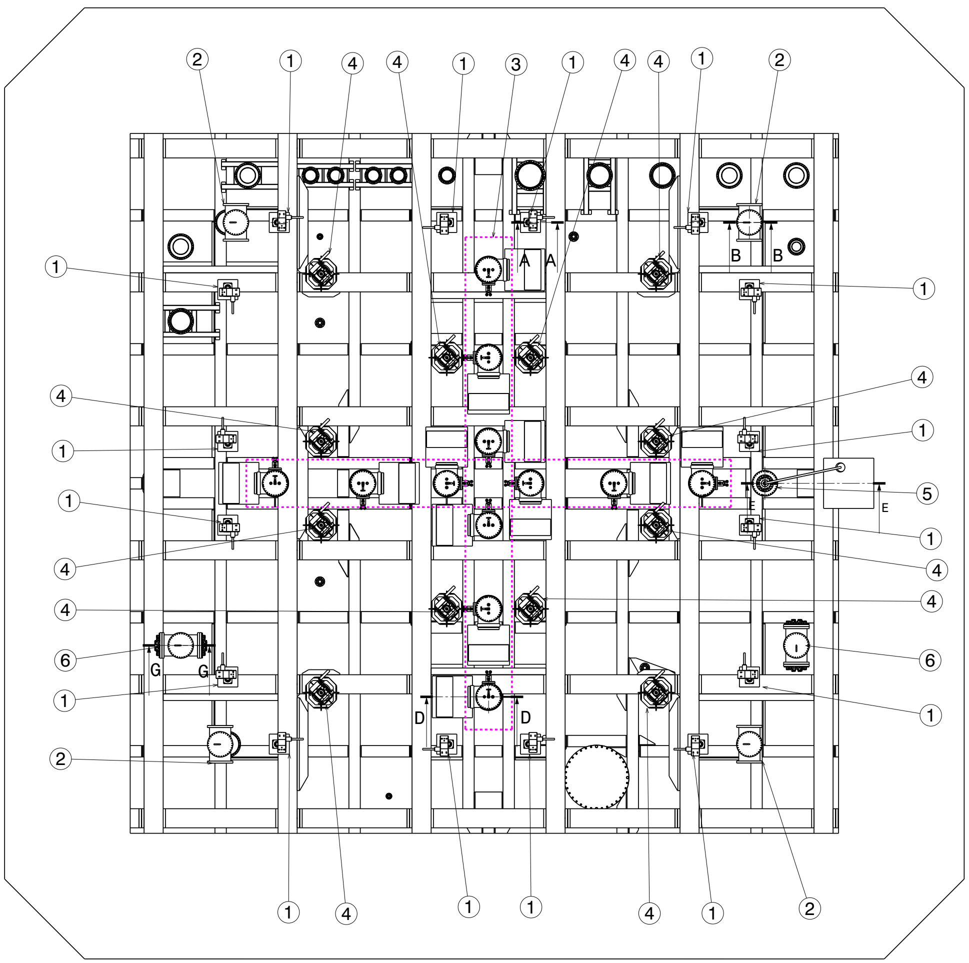


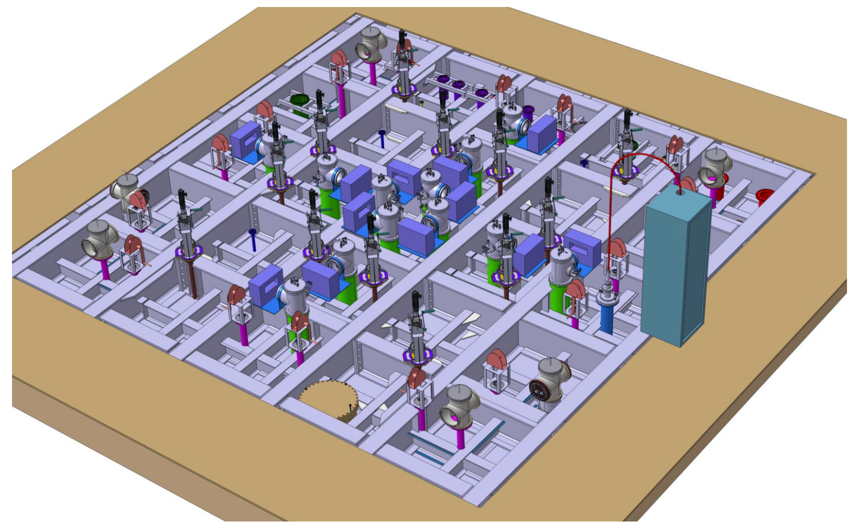
Figure A.2: 3D view in EHN1 and cartesian coordinate of the cryostat

Appendix B

Details of feedthroughs







Pos	Qty	FT Name	FULL NAME	COMMENT
1	16	FC SPFT	Field Cage Suspension FT	
2	4	CRP-INS	CRP-Instrumentation	
3	12	SGFT	Signal FT	together with Electronic Box
4	12	SPFT CRP	Suspension FT CRP	
5	1	HVFT	High Voltage Ft	High Voltage Power supply Rack near to the HVFT
6	2	TANK-INS	Tank-Instrumentation	

Project:	Project Name									Scale	Tot Pages
Sub-Proj.:	Sub-Project Name									1:25	1
Assembly:	Assembly Group Name										
Created:	DD.MM.YYYY	Name	Dimensions From	1	6	30	100	300	1000		Page N°
Last Mod.:	DD.MM.YYYY	Name	To	6	30	100	300	1000	2000		1
Constructed:	DD.MM.YYYY	Name	Tollerance	±0.1	0.2	0.3	0.5	0.8	1.2		

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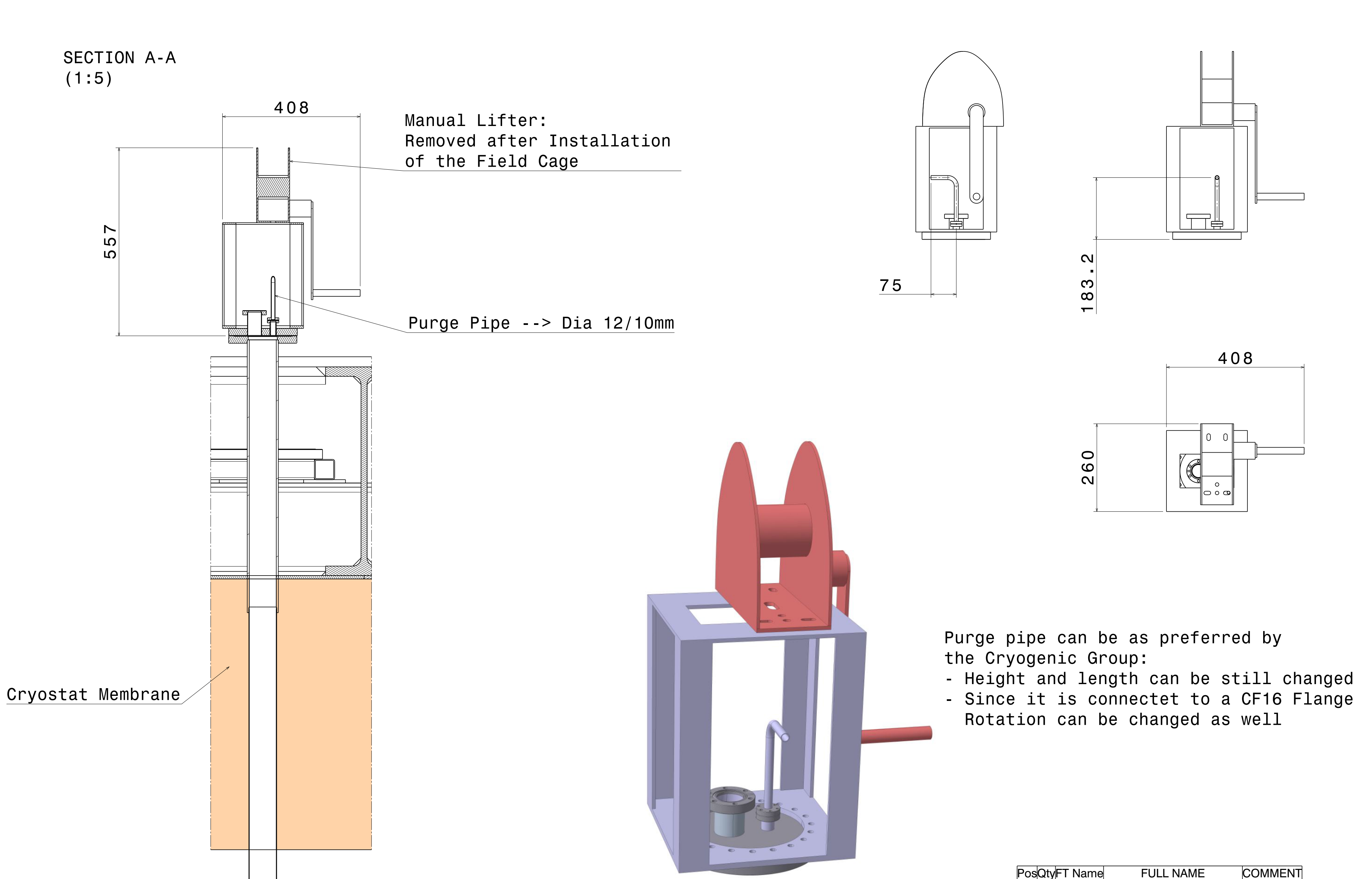
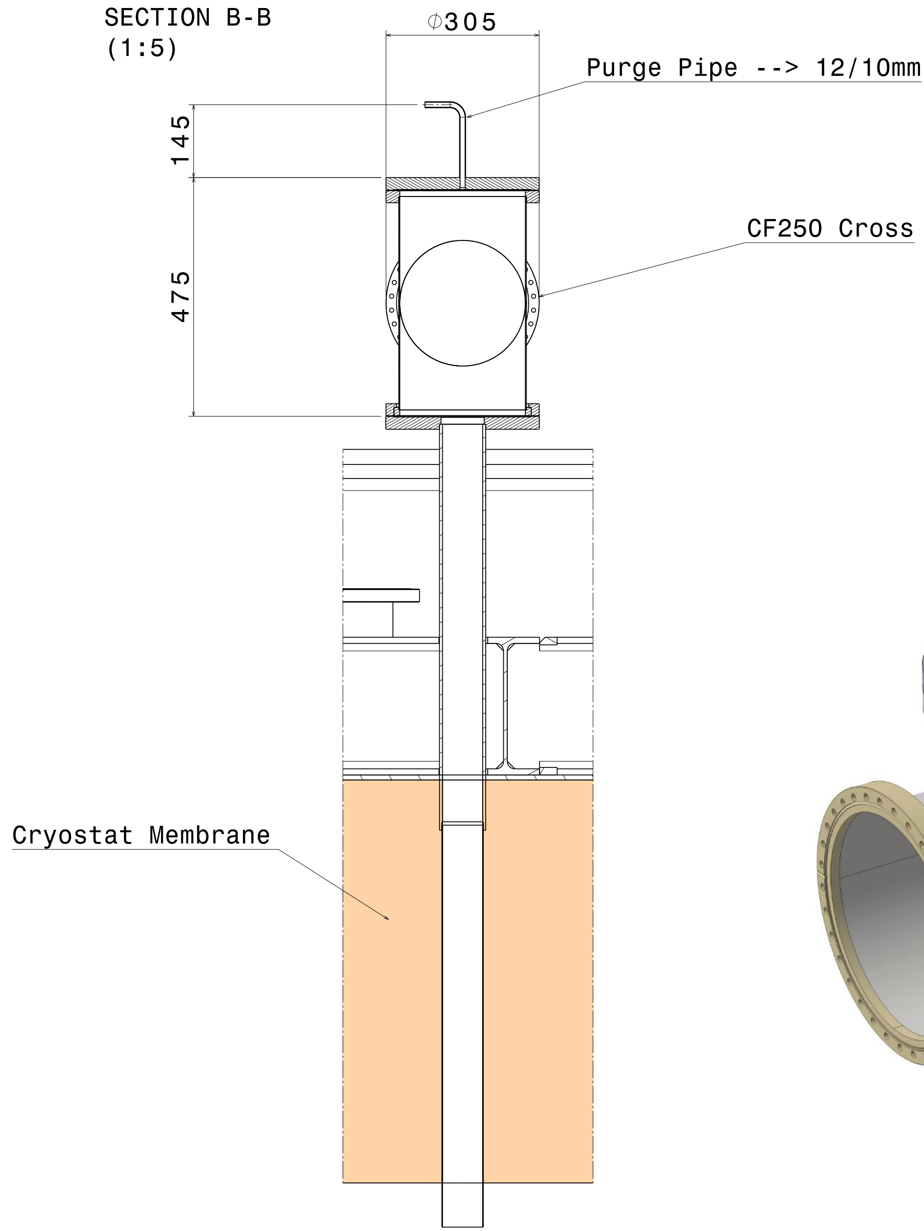
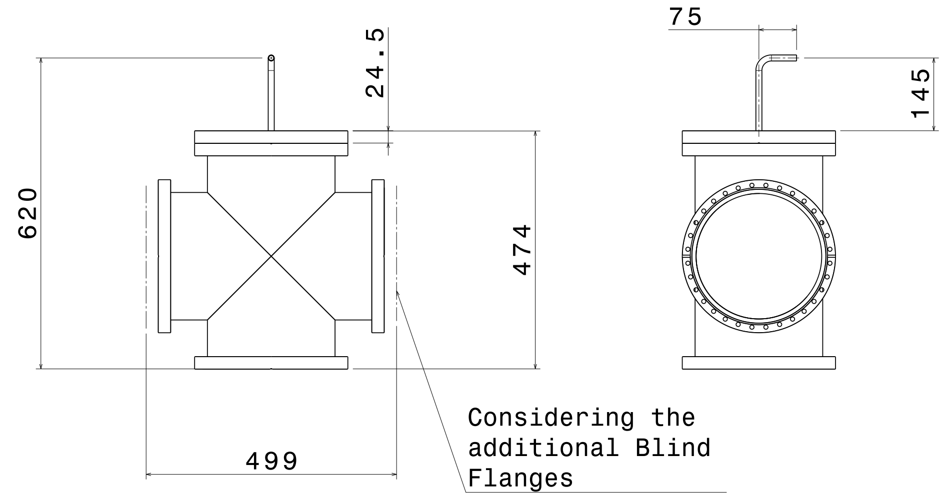
Top Cryostat FTs Overview — XX-XXXX

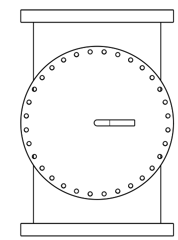


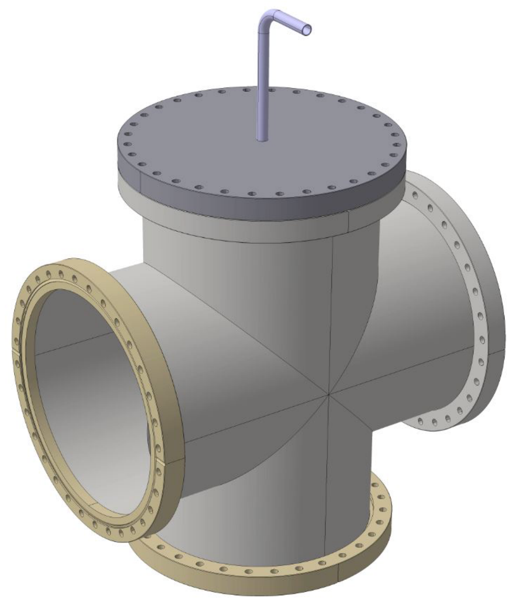
Pos	Qty	FT Name	FULL NAME	COMMENT
1	16	FC SPFT	Field Cage Suspension FT	

Project:	Project Name									Scale	Tot Pages
Sub-Proj.:	Sub-Project Name									1:5	1
Assembly:	Assembly Group Name										
Created:	DD.MM.YYYY	Name	Dimensions	From	1	6	30	100	300	1000	Page N°
Last Mod.:	DD.MM.YYYY	Name		To	6	30	100	300	1000	2000	1
Constructed:	DD.MM.YYYY	Name	Tollerance		±0.1	0.2	0.3	0.5	0.8	1.2	
ETH Institute for Particle Physics	FC SPFT									XX-XXXX	









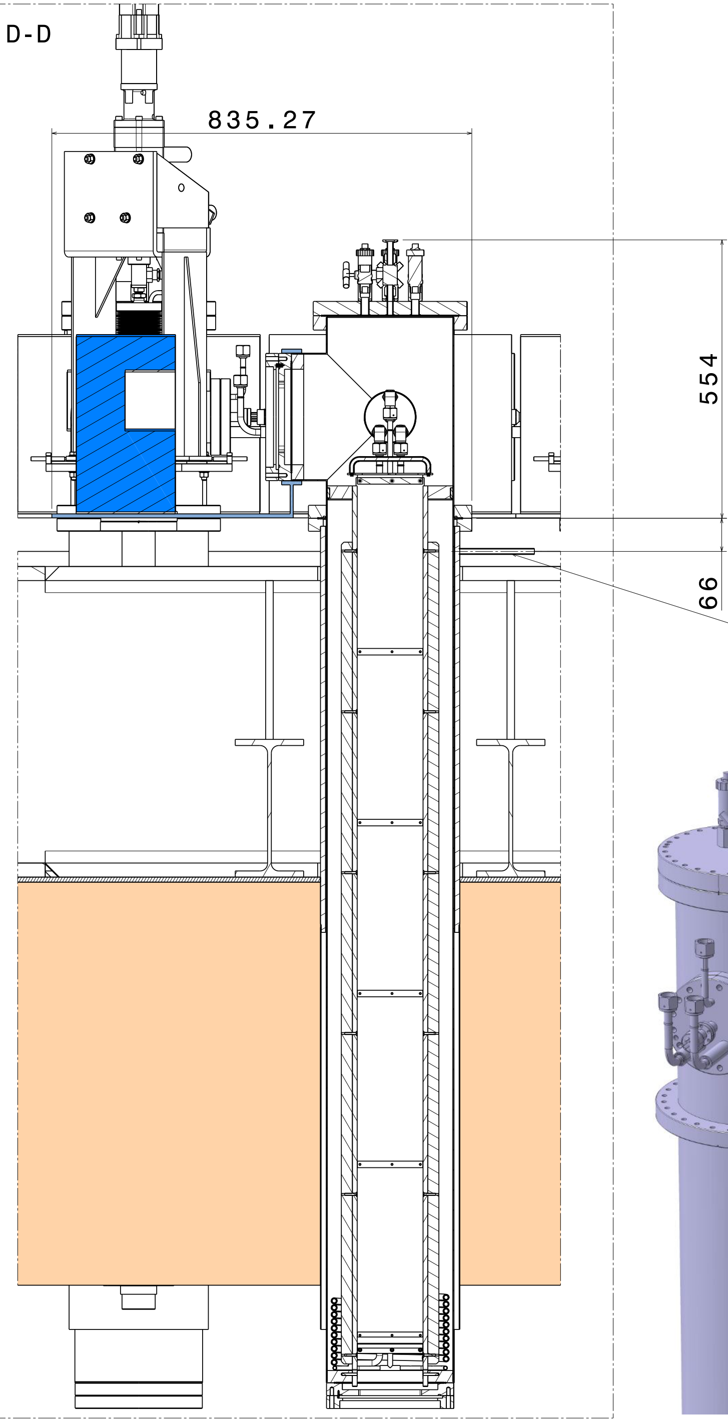
Purge pipe can be as preferred by the Cryogenic Group:

- Height and length can be still changed
- Since it is connectet to a CF250 Flange Rotation can be changed as well

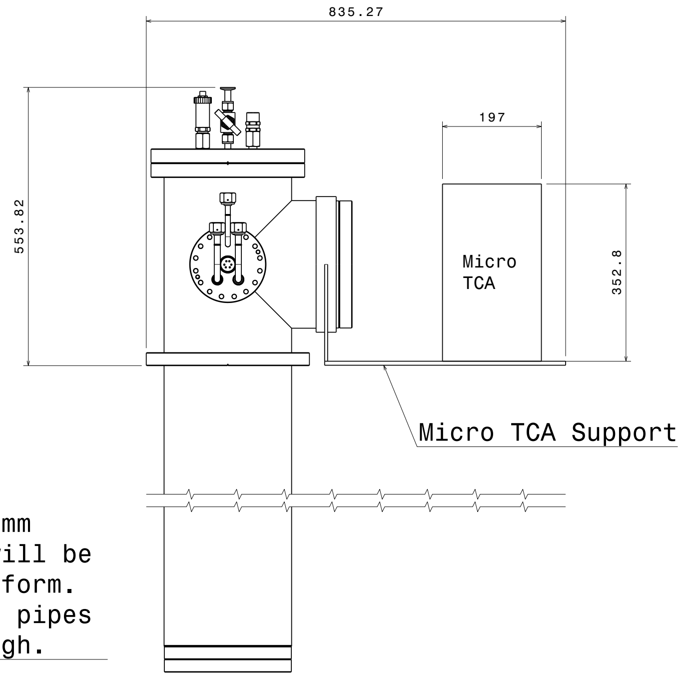
Pos	Qty	FT Name	FULL NAME	COMMENT
2	4	CRP-INS	CRP-Instrumentation	

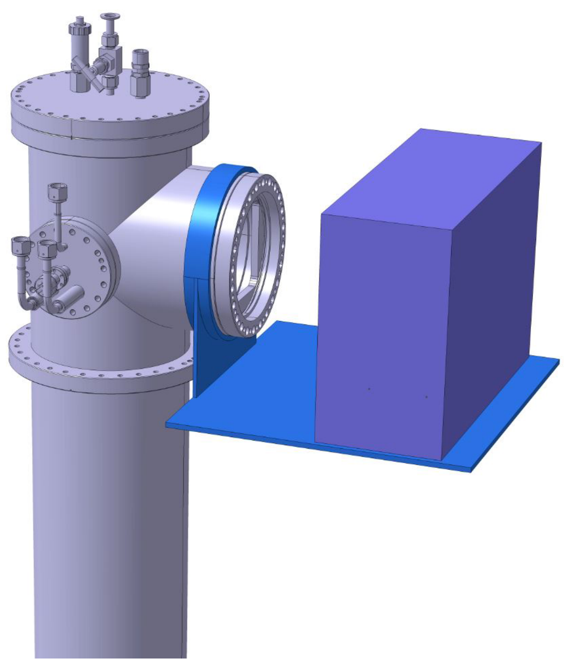
Project:	Project Name										Scale	Tot Pages
Sub-Proj.:	Sub-Project Name										1:5	1
Assembly:	Assembly Group Name											
Created:	DD.MM.YYYY	Name	Dimensions	From	1	6	30	100	300	1000		Page N°
Last Mod.:	DD.MM.YYYY	Name		To	6	30	100	300	1000	2000		1
Constructed:	DD.MM.YYYY	Name	Tollerance		±0.1	0.2	0.3	0.5	0.8	1.2		
ETH Institute for Particle Physics	CRP-INS										XX-XXXX	

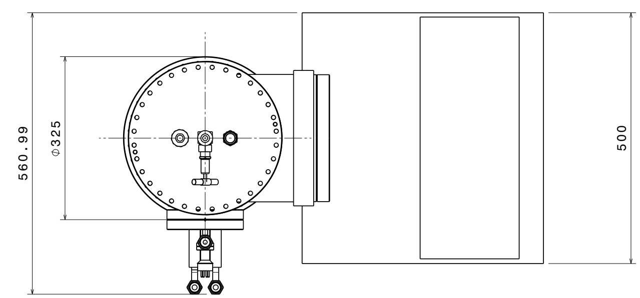
SECTION D-D
1:5



Purge Pipe --> Dia 12/10mm
Location and direction will be decided by Neutrino Platform.
Purge is at the Corssing pipes and not at the Feedthrough.







Pos	Qty	FT Name	FULL NAME	COMMENT
3	12	SGFT	Signal FT	together with Electronic Box
4	12	SPFT CRP	Suspension FT CRP	

Project:	Project Name									Scale	Tot Pages
Sub-Proj.:	Sub-Project Name									1:5	1
Assembly:	Assembly Group Name										
Created:	DD.MM.YYYY	Name	Dimensions	From	1	6	30	100	300	1000	Page N°
Last Mod.:	DD.MM.YYYY	Name		To	6	30	100	300	1000	2000	1
Constructed:	DD.MM.YYYY	Name	Tollerance		±0.1	0.2	0.3	0.5	0.8	1.2	

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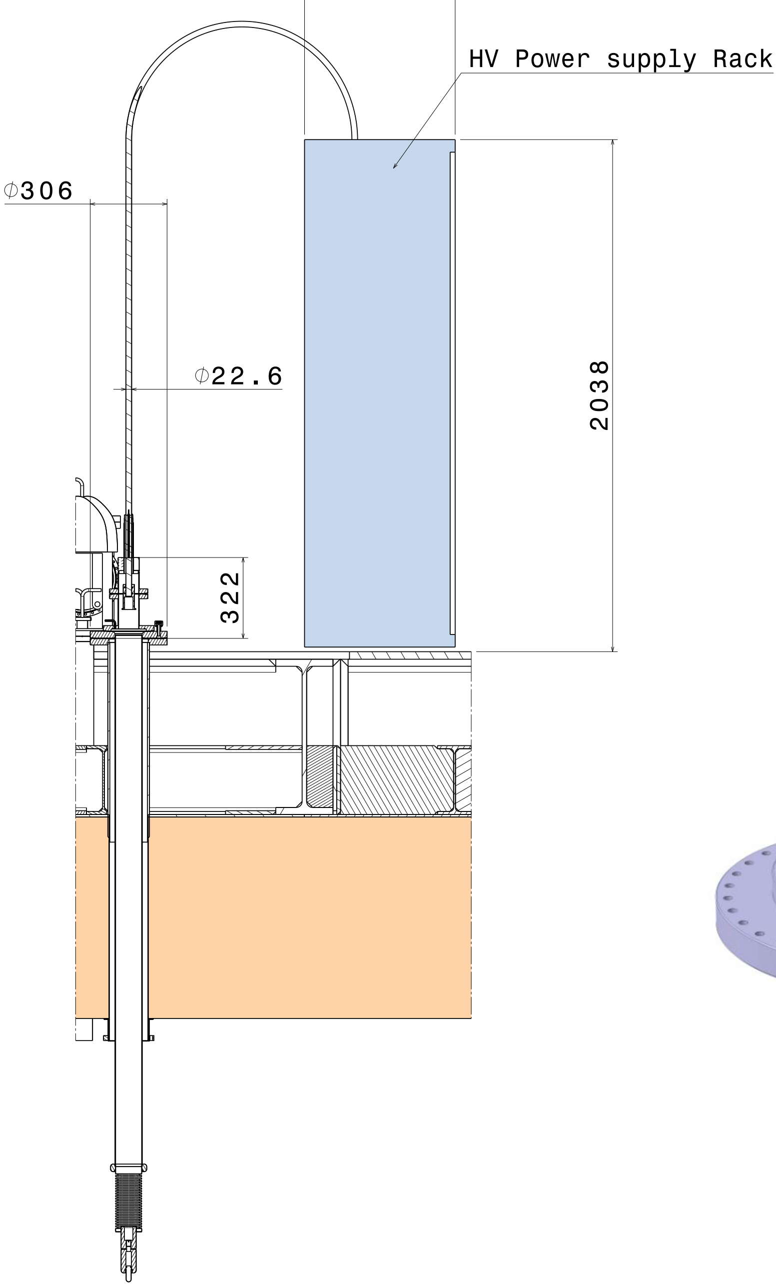
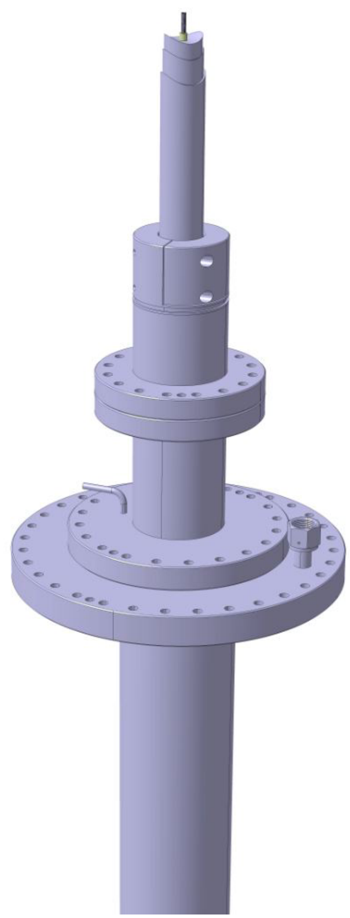
Signal Ft

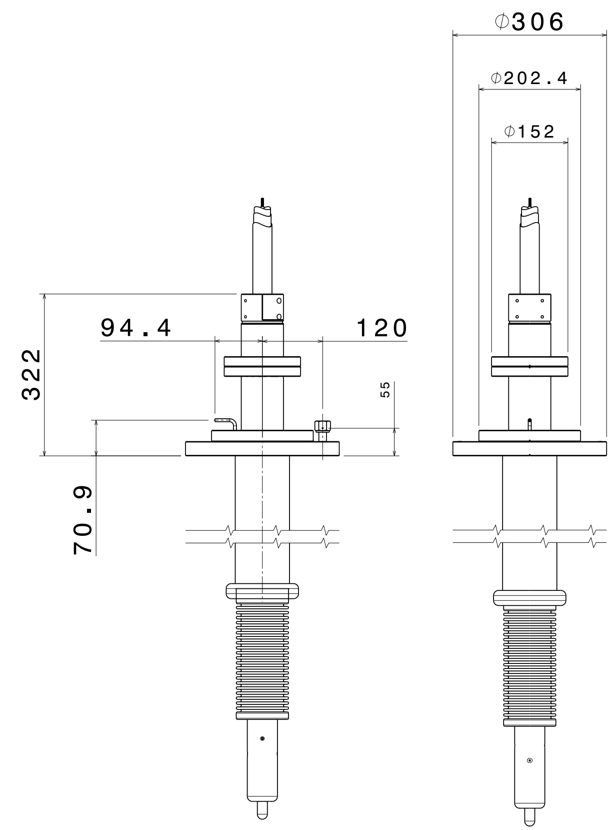
XX-XXXX

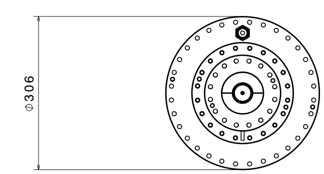
SECTION E-E
(1:10)





HFVT is rotational symmetric
in order to decide the best
position for the Purge



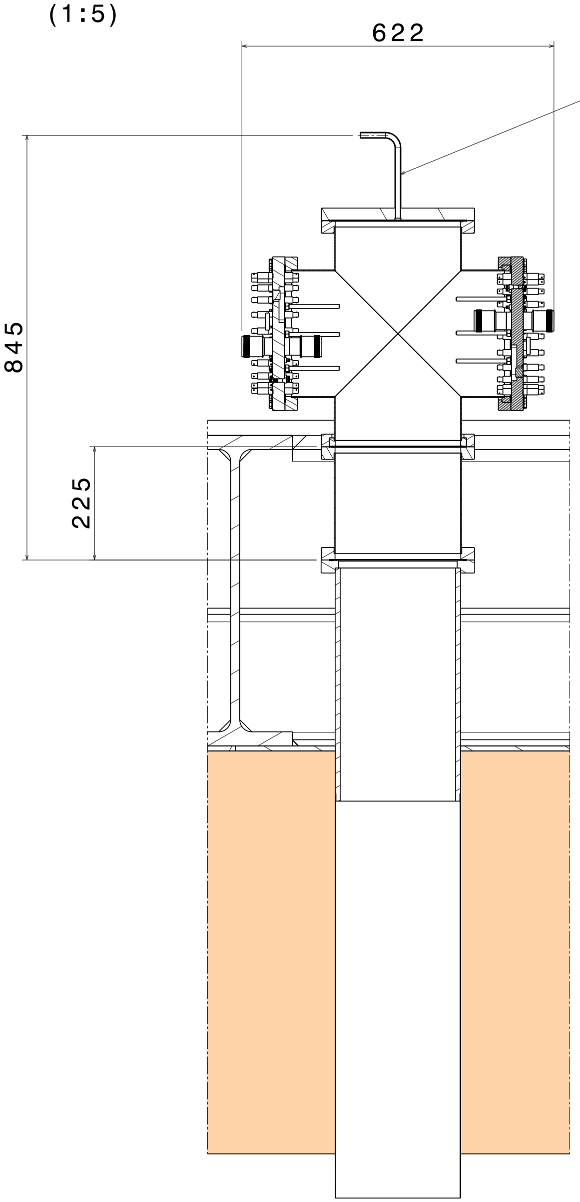


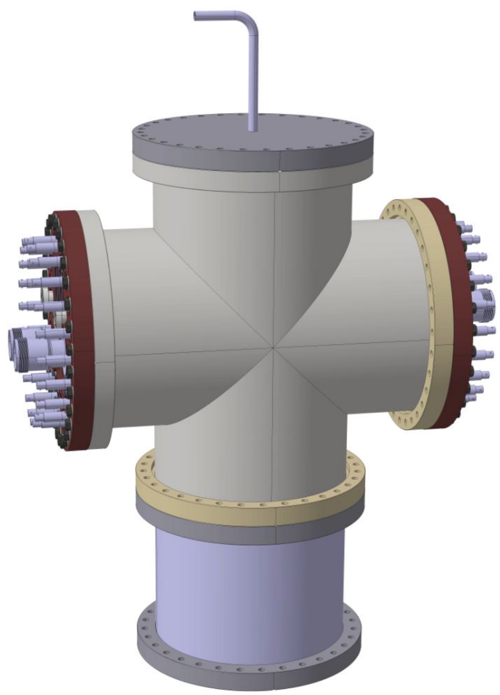
Pos	Qty	FT Name	FULL NAME	COMMENT
5	1	HVFT	High Voltage Ft	High Voltage Power supply Rack near to the HVFT

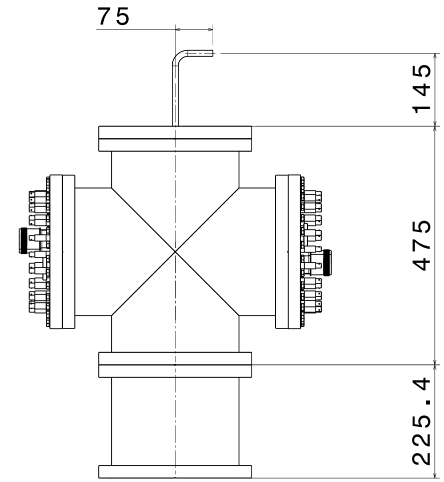
Project:	Project Name										Scale	Tot Pages
Sub-Proj.:	Sub-Project Name										1:10 (1:5)	1
Assembly:	Assembly Group Name											
Created:	DD.MM.YYYY	Name	Dimensions	From	1	6	30	100	300	1000		Page N°
Last Mod.:	DD.MM.YYYY	Name		To	6	30	100	300	1000	2000		1
Constructed:	DD.MM.YYYY	Name	Tollerance		±0.1	0.2	0.3	0.5	0.8	1.2		
ETH Institute for Particle Physics		HVFT									XX-XXXX	

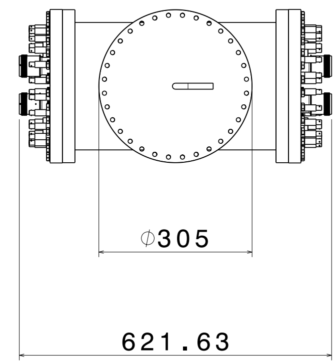
SECTION G-G
(1:5)

Purge pipe --> Dia 12/10mm









Purge pipe can be as preferred by
the Cryogenic Group:

- Height and length can be still changed
- Since it is connectet to a CF250 Flange
  Rotation can be changed as well

Pos	Qty	FT Name	FULL NAME	COMMENT
6	2	TANK-INS	Tank-Instrumentation	

Project:	Project Name											Scale	Tot Pages
Sub-Proj.:	Sub-Project Name											1:5	1
Assembly:	Assembly Group Name												
Created:	DD.MM.YYYY	Name	Dimensions	From	1	6	30	100	300	1000			Page N°
Last Mod.:	DD.MM.YYYY	Name		To	6	30	100	300	1000	2000			1
Constructed:	DD.MM.YYYY	Name	Tollerance		±0.1	0.2	0.3	0.5	0.8	1.2			

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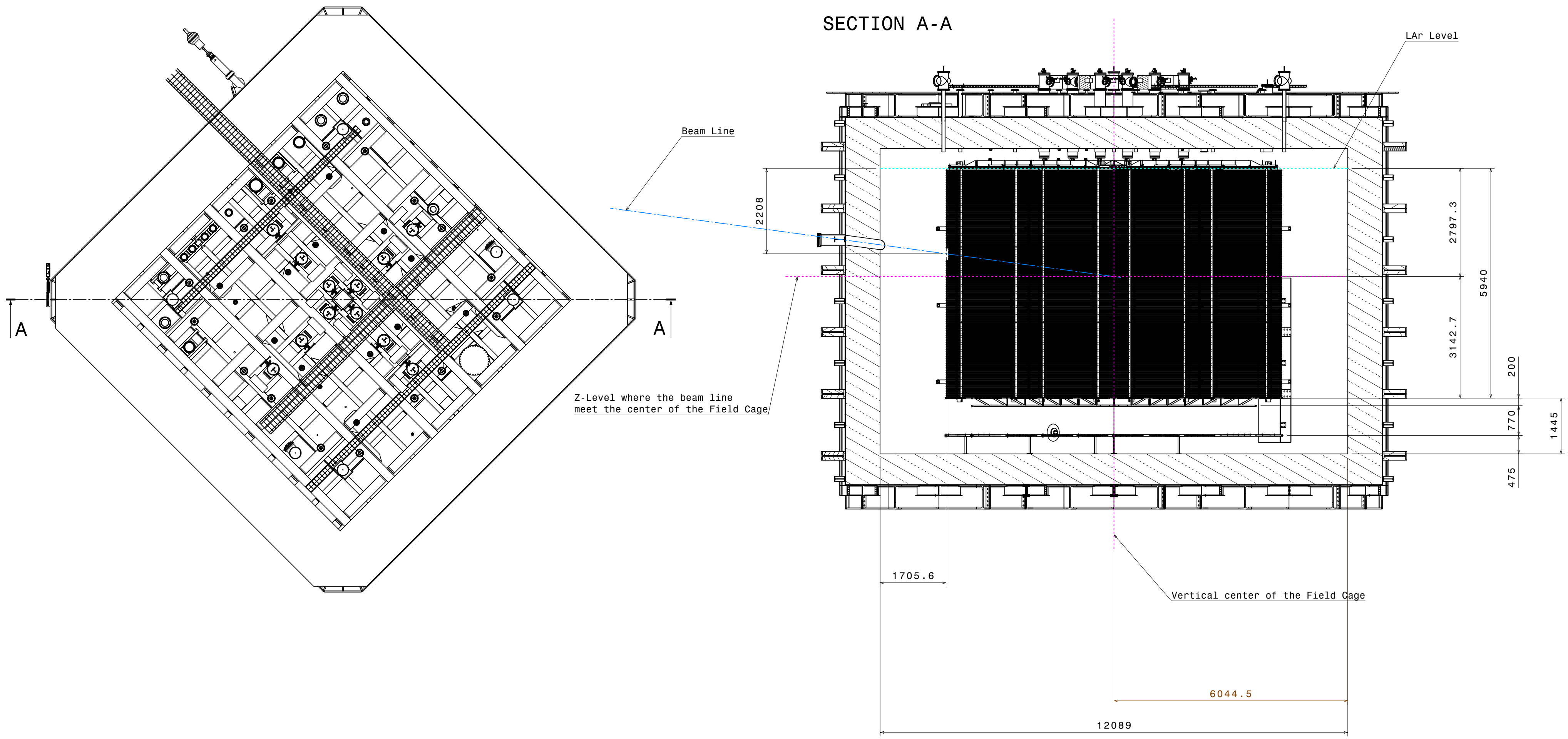
TANK Instrumentation

XX-XXXX

Appendix C

Detector cut view



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Sub-Proj.:	Sub-Project Name										1:50	1
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Created:	29.03.2017	Adamo Gendotti	Dimensions	From	1	6	30	100	300	1000		Page N°
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Constructed:	DD.MM.YYYY	Name	Tollerance		±0.1	0.2	0.3	0.5	0.8	1.2		

ETH zürich — WA105 6x6x6 Beam Position — XX-XXXX