2.12 BARREL ASSEMBLY

2.12.1 Overview, constraints, specifications

The HCAL barrel consists of two halves, HB+1 and HB-1 each weighing approximately 465 metric tonnes (510 English tons) each. The final assembly of these halves must reside within a dimensional envelope specified by the parameter drawing. A quarter view of HCAL is given in Fig. 2.39.

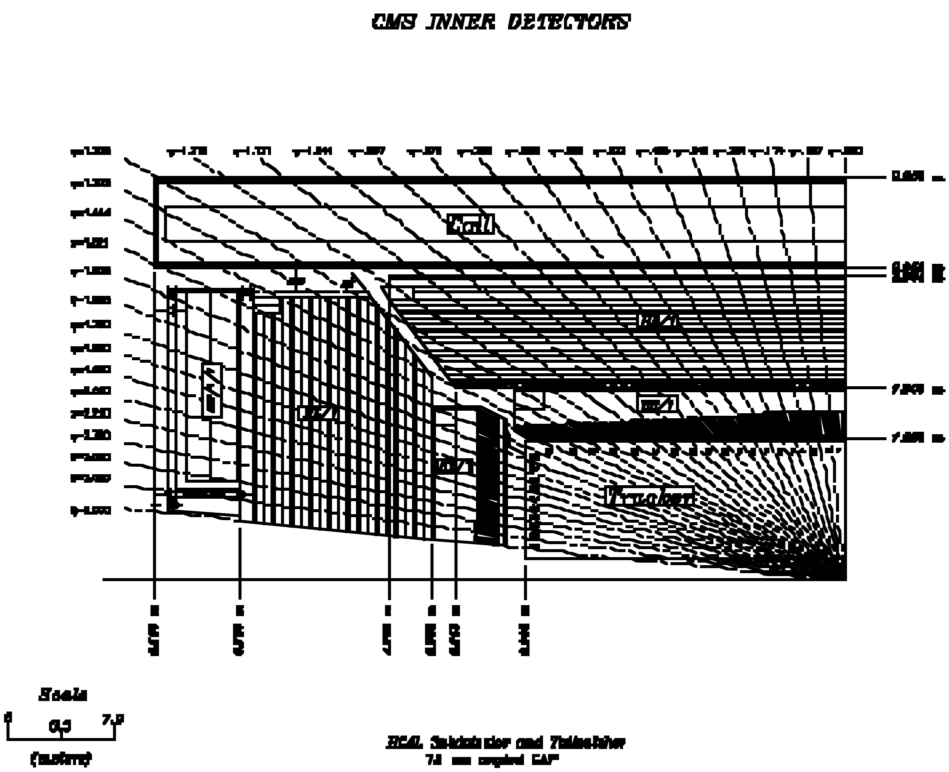

Fig. 2.39: CMS Inner Detector Parameters Drawing

Each barrel half, HB+1 and HB-1, is comprised of eighteen nominally identical wedges. Two of these eighteen wedges are the support or rail wedges. The wedges will be assembled at a factory whose site will be determined by competitive bid.

2.12.2 Assembly scenario

Factory assembly

Assembly at the factory of HB+1 and HB-1 is a necessary step in the QA/QC process to guarantee a suitable final product. Three months will be allowed for the factory assembly of HB+1, the first HCAL barrel half, and one month for HB-1.

The HCAL barrel wedges will be measured and dimensioned after final machining at the factory. After each wedge has been measured and verified, the wedges will then be "pre-assembled" in a CAD program to determine which order graphically provides the "best" fit when assembled. This order will be primarily dictated by the position of the support wedges in order to ensure that they will be located as close to their ideal position as possible.

Once the computer assembly model is complete, each physical HCAL barrel half will be assembled in its entirety. This procedure will mimic the planned assembly sequence that will take place in the surface hall SX5.

A tolerance study for the purposes of assembly was conducted using the allotted machine tolerances for the wedges. The machined tolerance of the wedge's inner and outer stainless steel plates, and hence its geometrical envelope is +/- 0.15 millimeters (+/- 0.006 inches). The study focused on a worst case scenario in which the inner radius chord of each wedge was +0.15 millimeters over its nominal dimension and conversely the outer radius chord was -0.15 millimeters under. In this case, the last wedge in the assembly must be machined out of nominal tolerances to fit. This case would require three different wedge sets of scintillator; One set for all the nominally identical wedges, and one set for each of the two special machined-to-fit wedges. This is necessary either to avoid gaps in the coverage or simply fit into the absorber structure, depending if the special wedge is oversized or undersized. In this case, the scintillator tile production for the special wedges must wait until both HB's are completed in the factory. The goal is to have all nominally identical wedges to avoid this. Tolerance buildup is indicated in Fig. 2.40.

To account for this variation in the wedges during to the manufacturing process, shims may be added between the wedges to ensure a better overall geometrical agreement with an ideal barrel shape. These shims, if necessary, would be used in wedges where the wedge to wedge connection stress is at a minimum. The support rail wedges would not be shimmed with respect to their neighboring wedges. This is done so as to maintain the best possible contact surface between the wedges in the region where the majority of wedge to wedge contact stress exists. Upon completion, the HCAL barrel halves will be surveyed and checked against the dimensional envelope parameter to make sure they satisfy all QA/QC requirements. Once these specifications have been met, the wedges will be marked in order to allow the procedure to be exactly duplicated in future assembly. This implies that the factory has access or must be provided with the necessary surveying equipment. Each of the barrel halves will then be disassembled for shipping to the temporary storage site at CERN, Building 168. Three months will be allowed for shipping time as the site of the factory is as of yet undetermined.

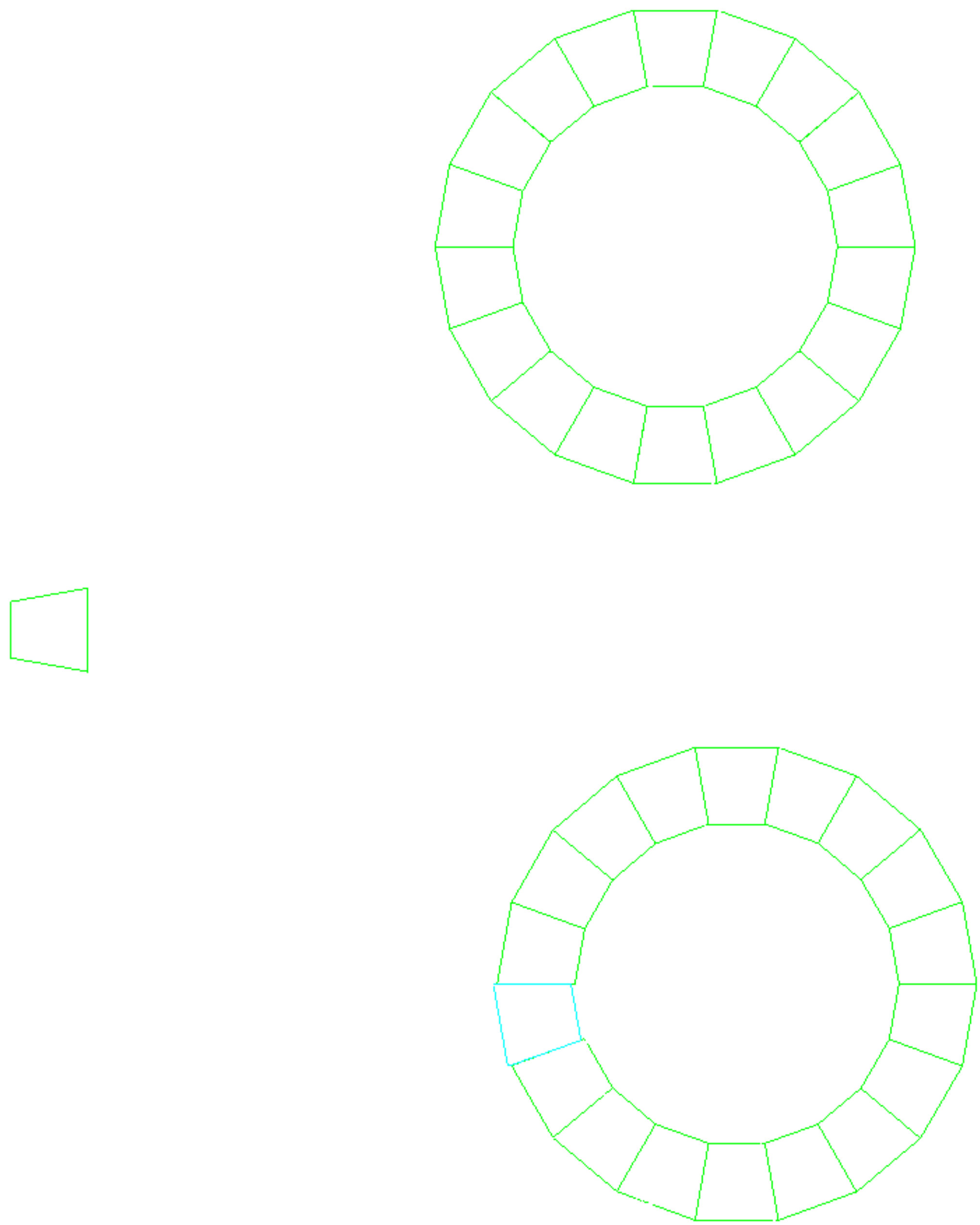

Fig. 2.40: Wedge tolerance buildup .

Building 168 at CERN, see Fig. 2.41, is where the HCAL barrel wedges will be instrumented with scintillator and stored until needed for barrel assembly in the surface hall SX5. The wedges arrive singly at Building 168 by truck. Spacers are then attached to the wedge to make it compatible with a wedge handling fixture. Each wedge weighs about 25.7 metric tonnes (28.3 English tons).

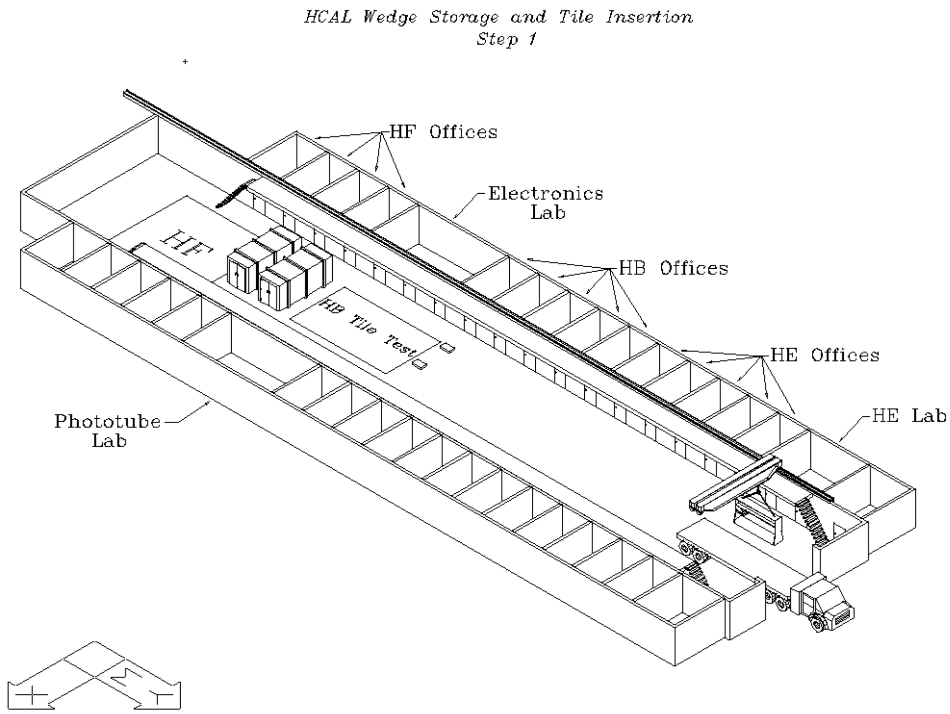

Fig. 2.41: First absorber wedge arriving in Bldg. 168.

A simplified wedge handling fixture is proposed to transport a completed wedge to its storage position on the floor. Since the wedges don't need to be rotated during storage, a less complex lifting fixture may be used to move them. This simplified lifting fixture may also alleviate some of the constraints imposed by the 5 meter hook height of the storage building. The barrel wedges will be stacked on the floor outside diameter side down and two wedges high. This is an acceptable working height for loading the scintillator packages into the wedge's slots. The storage capacity in the building's current layout fits one HCAL barrel half comfortably. Depending on the space requirements of the HE, HF, and HO groups, enough space to accommodate both halves of the HCAL barrel may exist. Currently there is a 9 month interval from the completion of HB+1 and the need of the first wedge of HB-1 at the surface hall SX5. *(See Fig. 2.42 through 2.45 for HCAL Wedge Storage and Tile Insertion Steps 2 through 5.)*

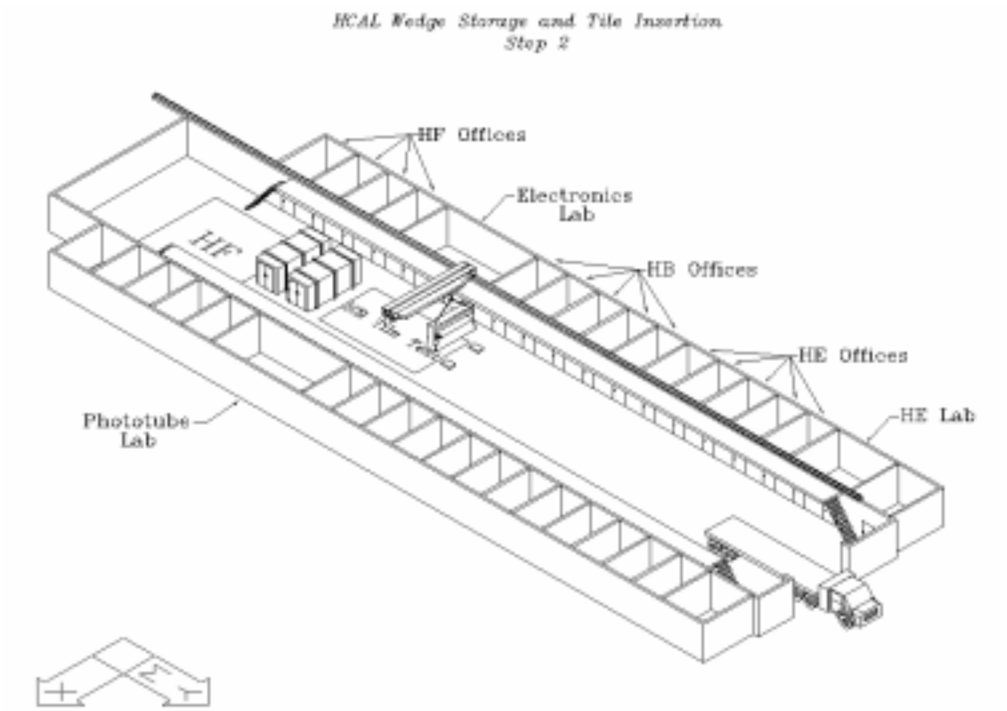

Fig. 2.42: HCAL wedge storage and tile insertion step 2.

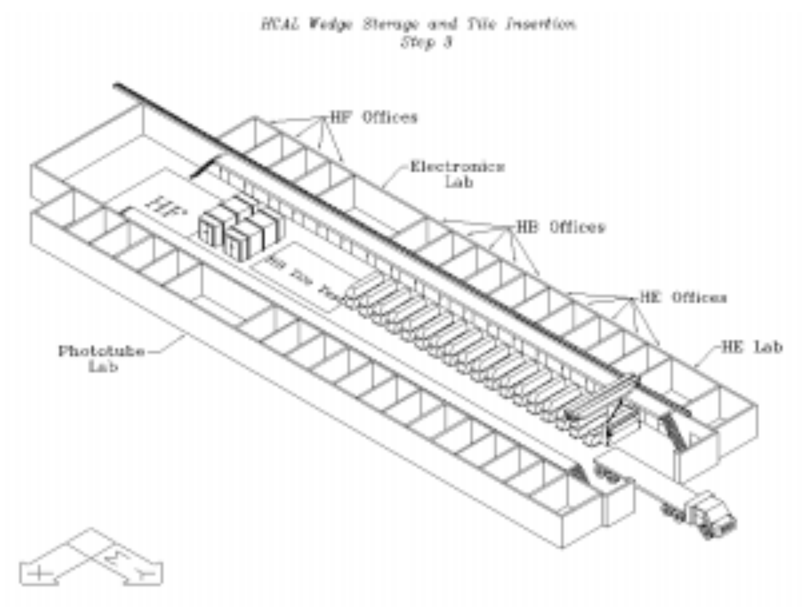

Fig. 2.43: HCAL wedge storage and tile insertion step 3.

The scintillator tiles will arrive stored in two sea containers, each holding one complete half-barrel worth of scintillator. A special lift table will be used to unload the tiles from the sea container and insert them into the stored wedges

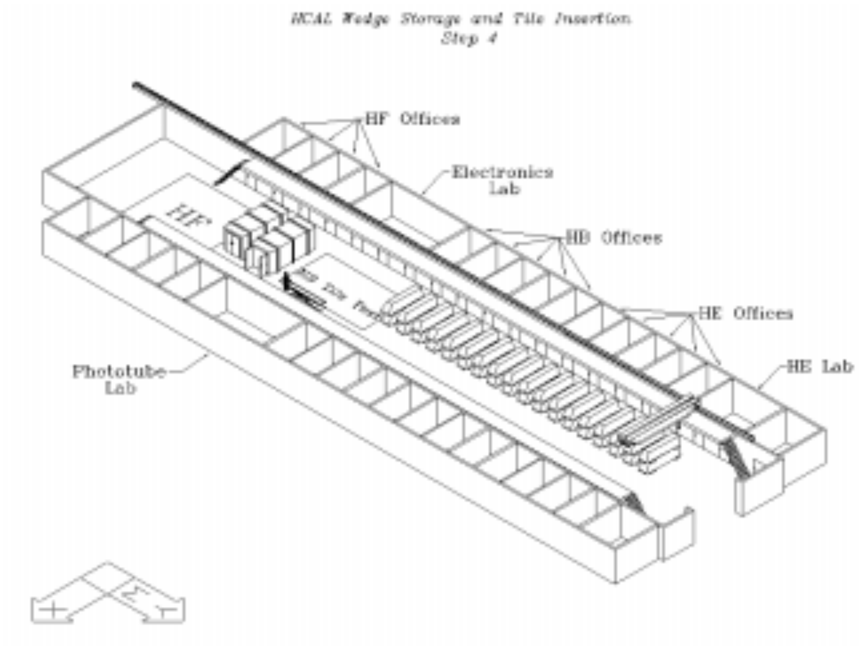

Fig. 2.44: HCAL wedge storage and tile insertion step 4.

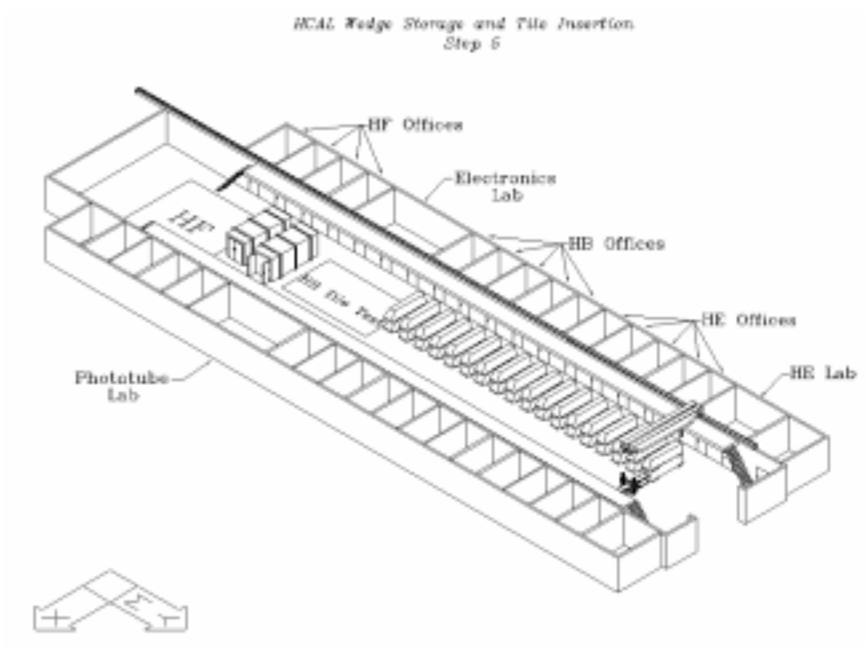

Fig. 2.45: HCAL wedge storage and tile insertion step 5.

Testing and laboratory facilities, set up in Building 168, will be required to test the scintillator tiles upon their arrival and later after they are inserted into the wedges.

Surface hall assembly

The HCAL Barrel Wedges will arrive individually at the Surface Assembly Building by truck from storage in Building 168. Attached to the wedges while in transit will be the HCAL wedge handling fixture. This fixture may be the ALEPH wedge handling device. The eleven steps for HCAL assembly in the above ground assembly hall (SX5) are shown in Fig. 2.46 through Fig. 2.56 respectively.

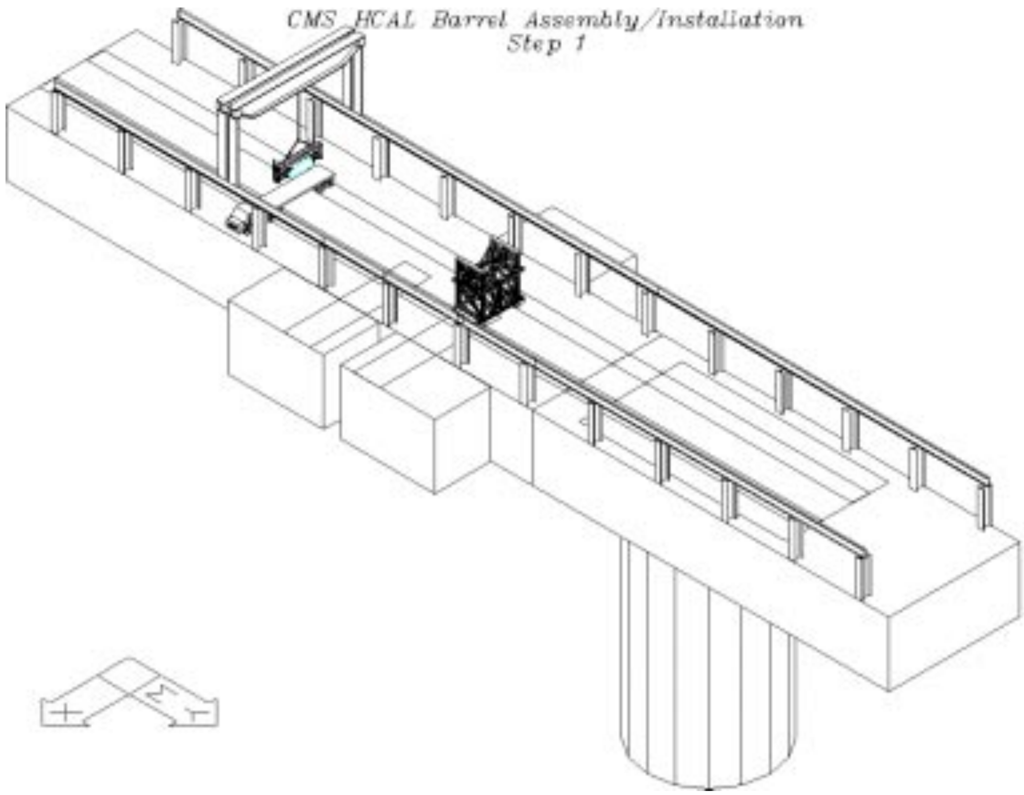

Fig. 2.46: CMS HCAL barrel assembly/ installation step 1.

The first HCAL barrel half, HB+1, has been allotted approximately 8 months of assembly time in the surface hall SX5. The construction time may be shorter depending on the learning curve which was established at the factory trial assembly stage. The HCAL HB+1 barrel cradle will be positioned to proper height before the arrival of the first HB+1 wedge. Currently both halves of the barrel, HB+1 and HB-1, will be assembled at beam height (approximately 8.5 meters). This is due to the fact that the trial insertion of the HB+1 and HB-1 barrels into the vacuum tank precedes the availability of the 2500 tonne gantry crane. Scaffolding will be erected to allow access to the wedge to wedge bolt connections. The position of first wedge is predetermined on the cradle by a set of pins. After lowering the first wedge into position, it will be fixed to the cradle. The first wedge will be surveyed into place and recorded as a fiducial. All subsequent wedges will be assembled with respect to the first wedge. The pins which locate the first wedge will be removed so that they will not interfere with the installation of subsequent wedges. (See Fig. 2.47)

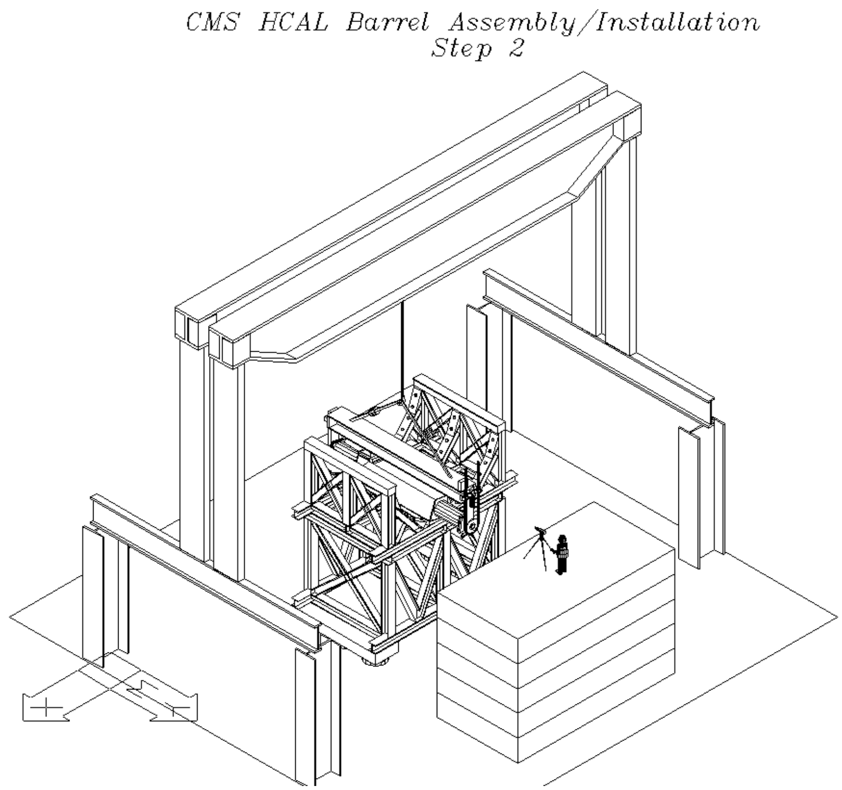

Fig. 2.47: MS HCAL barrel assembly / installation step 2.

Wedges will be assembled in the same sequence as predetermined during the factory trial assembly procedure. The second wedge will be positioned, shimmed if necessary, and then bolted to the neighboring wedge. All inner radius connection bolts and all but a few outer radius connection bolts may be installed and a final survey check performed. Bolts are tightened but with no pre-load at this stage. The outer radius bolt slots that may not be accessed due to cradle interference, will be addressed later. (See Fig. 2.48)

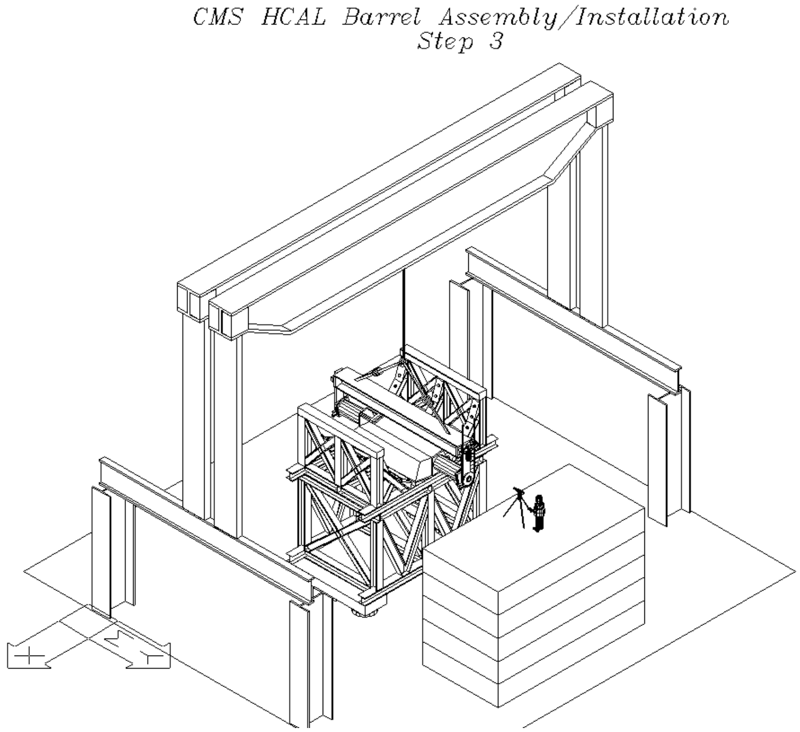

Fig. 2.48: CMS HCAL barrel assembly / installation step 3.

This procedure will continue, alternating sides with respect to first wedge until both support or "rail" wedges are in place. Surveying the rail wedges to verify acceptable dimensions is important before continuing construction. (See Fig. 2.49)

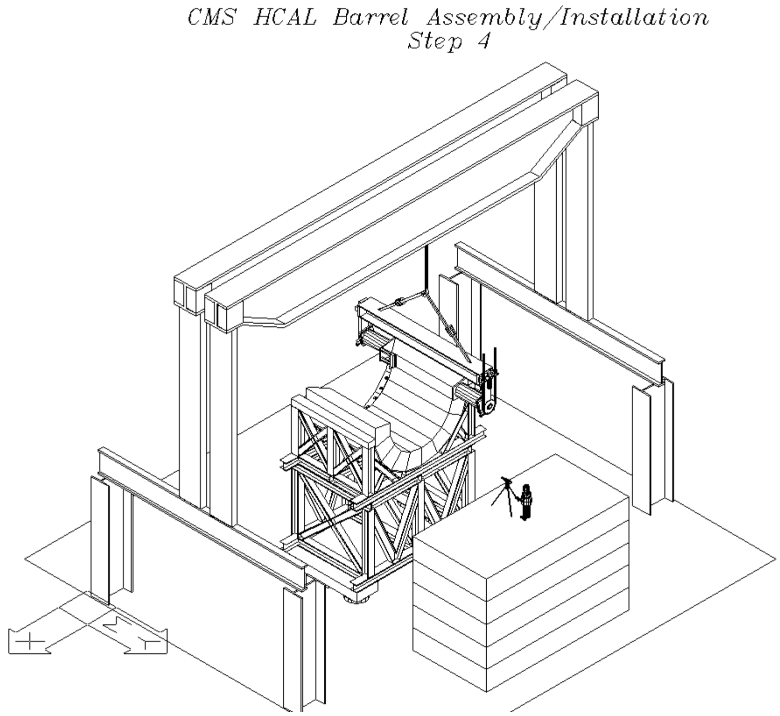

Fig. 2.49: CMS HCAL barrel assembly / installation step 4.

Once the rail wedges are surveyed in place, the assembly spiders are inserted before construction resumes. The two assembly spiders are placed at each end of the barrel and surveyed into the proper location. (See Fig. 2.50)

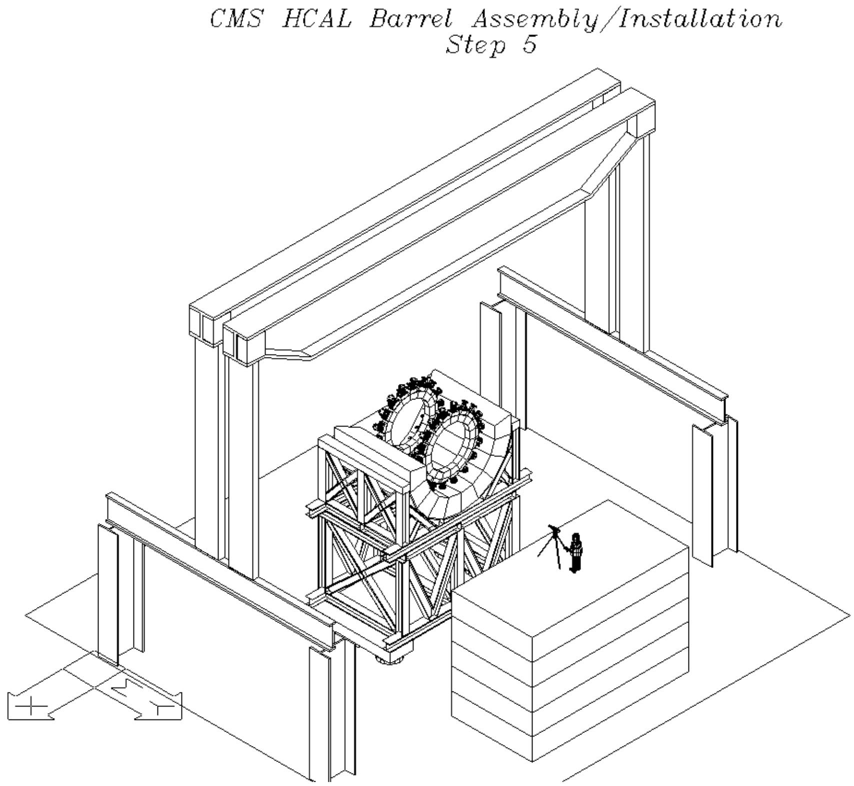

Fig. 2.50: CMS HCAL barrel assembly / installation step 5.

The spider's mechanical actuators are adjusted through the use of an air impact hammer. The position of these actuators with respect to the inner radius dimensional target will be verified by surveying. The spiders will be tied together with connecting rods to ensure lateral stability. Wedge assembly continues alternating from side to side using the spiders to maintain proper inner geometry and counteract the gravity load. (See Fig. 2.51)

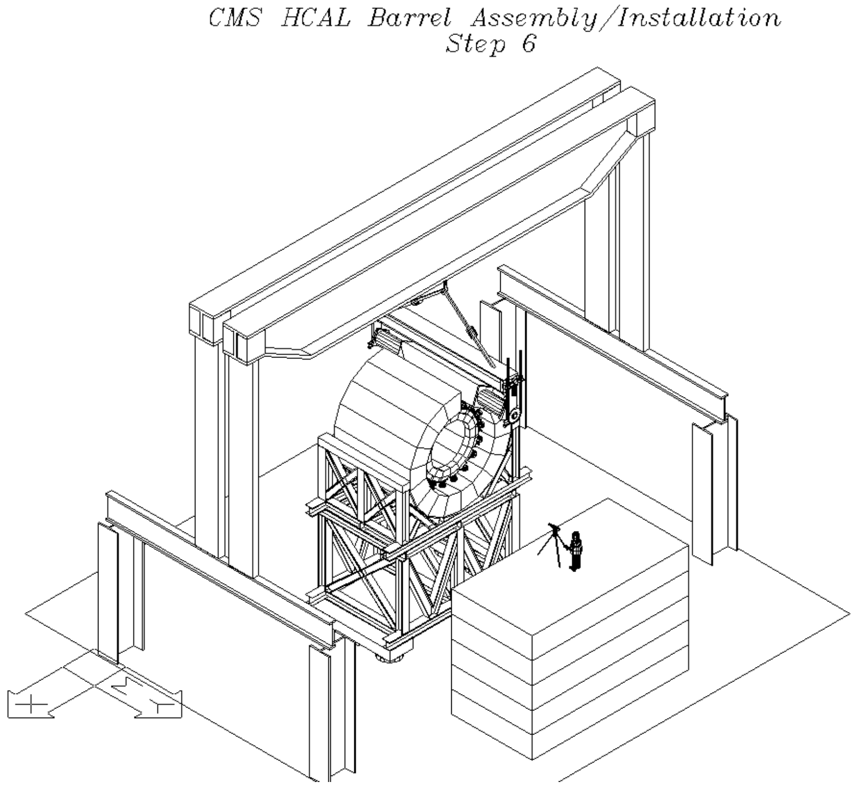

Fig. 2.51: CMS HCAL barrel assembly / installation step 6.

Insertion of the last wedge in a half barrel may require a different approach than that of the others. If needed the spiders may be used to jack open the barrel to force the gap for the last wedge to enlarge. The necessity of this procedure will already have been determined in the factory trial assembly. As an alternative, allowing the spiders to remain at a fixed inner radius may be desirable. In this case, auxiliary spreader bars may be introduced. The spreader bars will force the remaining wedge gap to enlarge to facilitate the insertion of the last wedge. This gap could give as much as 2.2 millimeters of lateral clearance. Once the last wedge is positioned at the correct inner radius by the spider and bolted to its neighboring wedge, the spreader bar can be relaxed to allow the final gap to close. Once the final gap has closed and the wedge to wedge connection is made, the half barrel assembly will be ready for its remaining connections to be bolted. (See Fig. 2.52 through Fig. 2.54, CMS HCAL Barrel Assembly / Installation Steps 7-9).

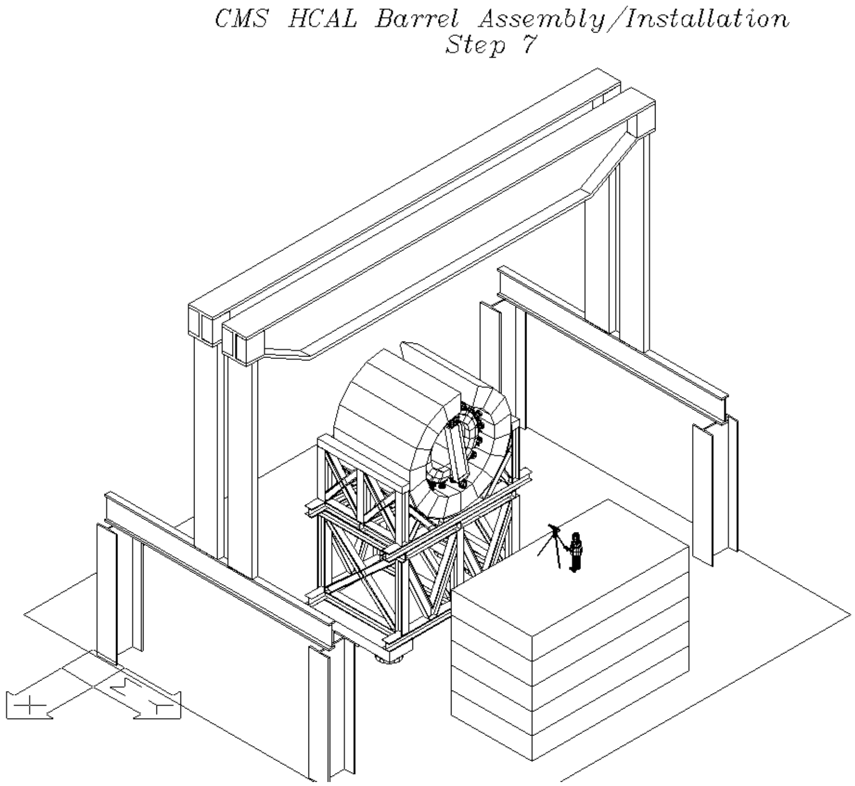

Fig. 2.52: CMS HCAL barrel assembly / installation step 7.

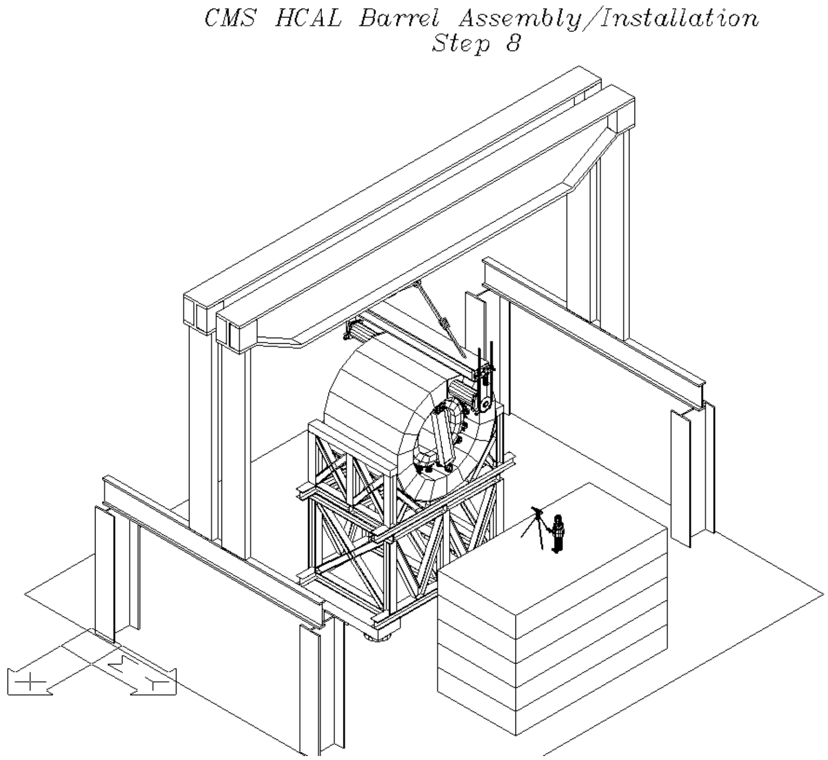

Fig. 2.53: CMS HCAL barrel assembly / installation step 8.

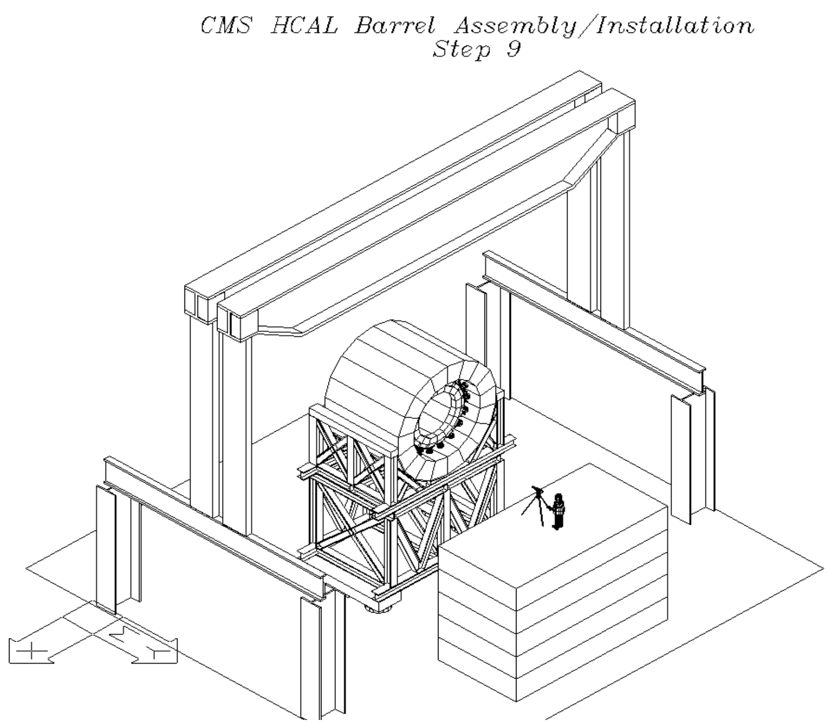

Fig. 2.54: CMS HCAL barrel assembly / installation step 9.

The lower barrel wedge supports will be retracted on the cradle so that barrel will rest on the rail system. The barrel will then be translated on the rails far enough to allow access to the remaining outer radius bolt slots and insert bolts that were inaccessible due to the cradle. Once all bolts are in place a final tightening sequence will be applied to achieve the desired pre-load. If necessary the barrel will then be translated back to its original position to tighten the last bolts. The barrel will be lowered onto the lower cradle wedge supports and stored in this position.

The completed HB+1 half barrel will be moved into its storage alcove in the surface hall SX5. The HB storage alcoves are 17 meters long, 10 meters wide, and 12 meters high. HB+1 and HB-1 will fit into their alcoves with the aid of removable sections of Surface Hall crane rail. The length of the storage alcoves allows for the possibility of scintillator insertion and removal. This is important in the event that the decision is made to insert the scintillator tiles after the absorber structure has been assembled. The alcoves need to be set up for scintillator testing to verify that the tiles survived the assembly process.

The same assembly sequence applies to HB-1 which will take place approximately 9 months later. The five weeks of time allotted for HB-1 assembly is significantly less than for HB+1. Regardless of the prior experience with HB+1, it is felt that this assembly schedule will require additional shift work to complete. (See Fig. 2.55 CMS HCAL Barrel Assembly / Installation Step 10).

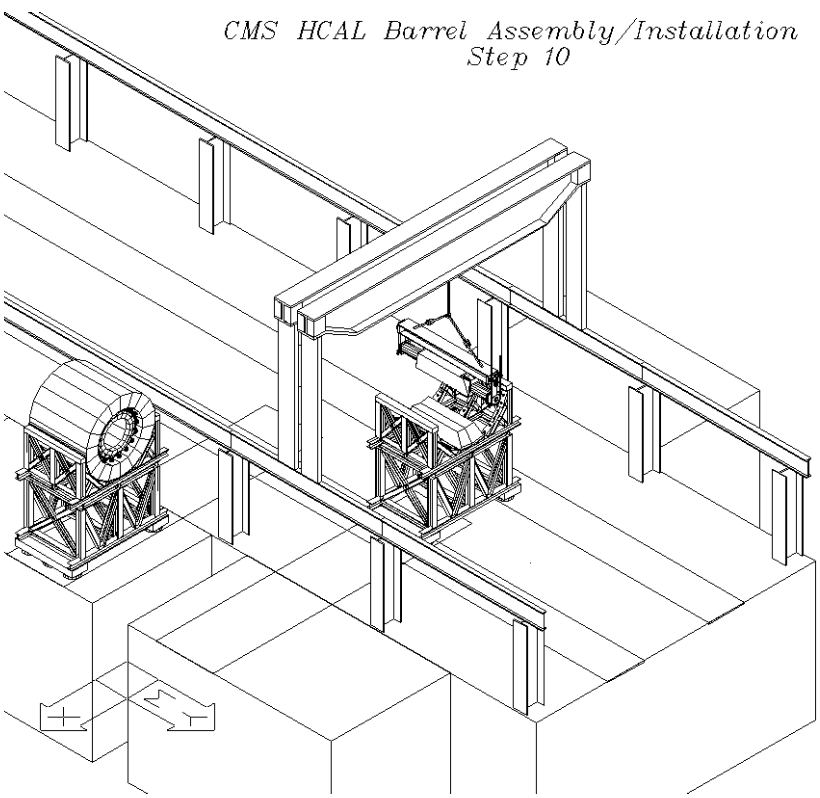

Fig. 2.55: CMS HCAL barrel assembly / installation step 10.

Before lowering the HCAL barrel halves into the Underground Hall, a trial insertion of HB+1 and HB-1 into the vacuum tank will take place. HB+1 and HB-1 will be moved from their storage alcoves and positioned on either side of the central iron barrel ring and the vacuum tank. Each set of HB cradle rails will be lined up with the corresponding rails in the vacuum tank. Once the rails have been aligned, the cantilevered ends of the vacuum tank will be supported to minimize deflection during HCAL Barrel insertion. Each barrel half will be pulled into the vacuum tank via a cable system operating at the level of the rails.

Insertion of the two HB barrels inside the vacuum tank will strain the vacuum tank to its final shape, allowing the adjustment of the position of the coil with respect to the iron yoke during the surface magnetic test (see chapter 18 of the Magnet TDR). In addition, after the trial insertion is complete the deflection of vacuum tank and HB's will be measured. This is to allow for the shimming of the HB supports upon removal so that upon insertion in the Underground Hall will yield a more concentric HCAL barrel shape. (See Fig. 2.56 CMS HCAL Barrel Assembly / Installation Step 11)

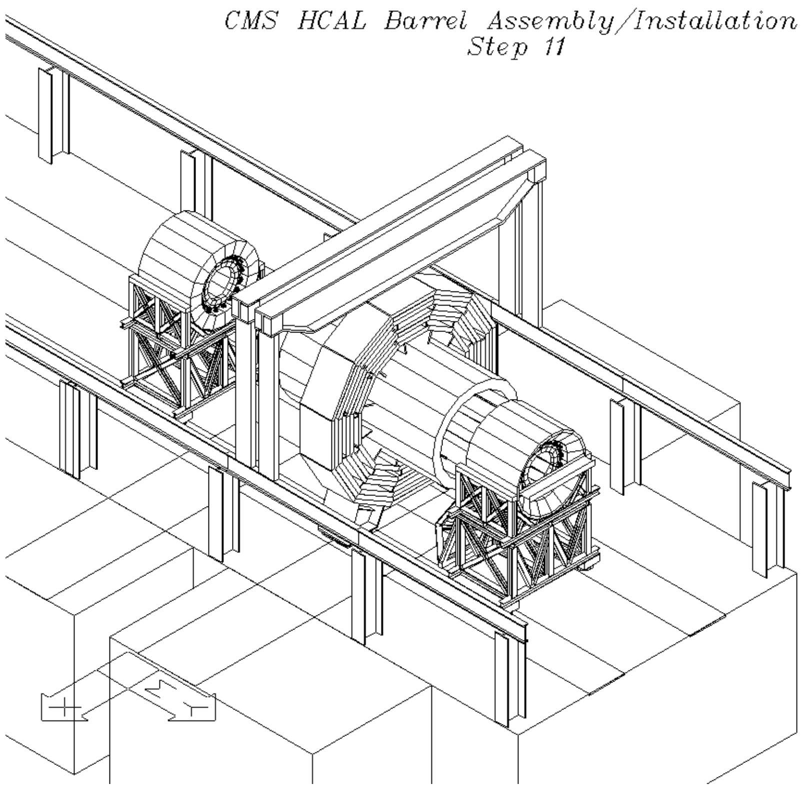

Fig. 2.56: CMS HCAL barrel assembly / installation step 11.

2.12.3 Tooling design

HCAL Barrel Installation Fixture

During the HCAL barrel installation, the cradle in which each half-barrel sits will be securely anchored to the central iron ring and vacuum tank. This will prevent any tipping of the cradle due to the moments experienced during barrel insertion. A stiffback, similar to a large I-beam will be fastened to the opposite end of the vacuum tank at the level of the barrel rails. Two come-alongs will be attached to the stiffback and will be used to pull the barrel into the vacuum tank. A total of 60 tonnes will be required to insert the barrel into the vacuum tank. This value assumes a friction coefficient of 0.1 between the barrel support pads and the rail and also take into account the 1.23% incline of the hall into consideration. Although it would be desirable to pull each come-along will equal force, this is unlikely to occur in reality. Therefore this implies that both come-alongs will each be rated for at least 60 tonnes, so that each is capable of initiating movement of the barrel mass. The stiffback will transfer this load into the edge of the vacuum tank.

Cryostat Support Post

The vacuum tank support post's role is to limit the deflection caused by the cantilever load of the HCAL half barrels during insertion. A set of triangulated I-beams will support the vacuum tank at both ends, under the end flanges.

OPAL Wedge Rotating Fixture

The OPAL wedge rotating fixture or similar device will be used to orient the HCAL barrel wedges for half barrel assembly. The OPAL wedge rotating fixture is designed in such a manner as to be wedge length independent. It has two independent stands to which the ends of the wedge connect via an attachment fixture. Each stand has a bearing and bearing housing providing the rotational adjustment. The wedge attachment fixture is a plate which is temporarily bolted and pinned to the face of the wedge in the region of the inner and outer radius stainless steel support plates. A special fixture will be designed for the 53 degree chamfered end of the wedge so that the attachment fixture plates will be parallel to each other.

A rod with a flange protrudes from this plate at the calculated center of gravity of the wedge. Once the end flange fixtures are secured to the wedge, the crane will lift the wedge to the height of the two stands where the rod end flange will be bolted to the stand's bearing flange. The wedge is now set up for rotation. The wedge may be rotated manually or with a bit of mechanical assistance to the desired angular orientation. Predetermined stops at the desired angles will have been drilled into the stands back plate and been fitted with removable pins. The wedge is then lifted vertically by four support points, two at each end connected by a spreader bar. The wedge is now in the "rough" angular position required for assembly. One support point on each end will be held by a remotely adjustable length link. These two support links or straps will have small degree of vertical adjustment capability in order to provide fine angular adjustment during assembly.

HCAL Barrel Cradle

The two HCAL barrel cradles will serve as the assembly and storage platforms for HB+1 and HB-1. Additionally, they will serve as the insertion interface for the vacuum tank and the barrel halves. (See Fig. 2.57 HCAL Barrel Cradle.)

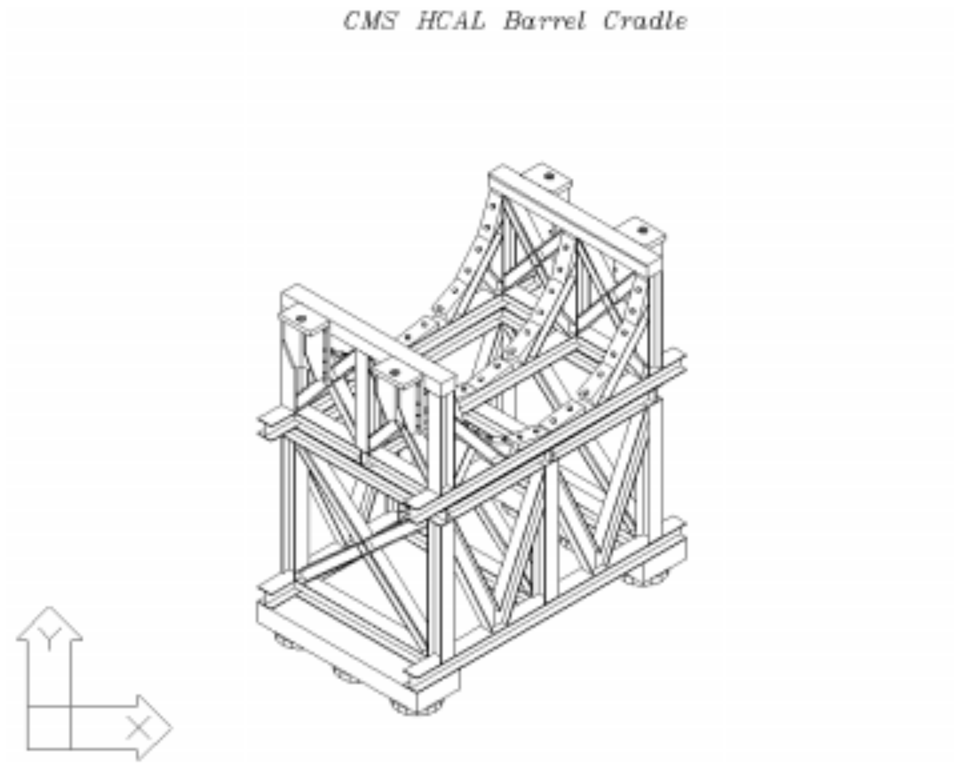

Fig. 2.57: HCAL barrel cradle.

The HCAL barrel cradle will be designed to support each of the wedges below the rail wedges individually during barrel assembly. Each of these wedges will be supported by four independent mechanical actuators which will be surveyed into position before the wedges are attached to them. Mechanical spiders will be use to complete the rest of the barrel above the rail wedge. Once the barrel is completed, the cradle rails on which the support wedges rest will be raised sufficiently so as to support the entire weight of the HCAL barrel half. The cradle rails will have vertical and lateral translation capabilities. In addition, pitch along the beam axis will be incorporated to allow for any angular misalignment with the vacuum tank rails in this plane. This angular misalignment may pre-exist or be a result of the load transfer during insertion of the barrel halves into the vacuum tank.

Four 136 tonne (150 English ton) mechanical actuators, two for each rail, will provide the vertical adjustment of the cradle rails. The actuators have a 36:1 worm gear ratio so will be self-locking when under load. Each rail will be driven by a stepper motor which will control the two actuators associated with that rail. The actuators and the motor are connected via a coupling system that allows synchronous movement of the actuators. In the event that a pitch correction is required, the transmission shaft to one actuator contains a removable flexible disc coupling. Once this coupling is removed, it allows independent adjustment of the other actuator. This actuator will be connected to the cradle by a pivot, and has a constant velocity joint incorporated in its transmission shaft to allow for the angular displacement of the shaft during the pitch adjustment of the rail. The conceptual design for the rail adjustement is given in Fig. 2.58.

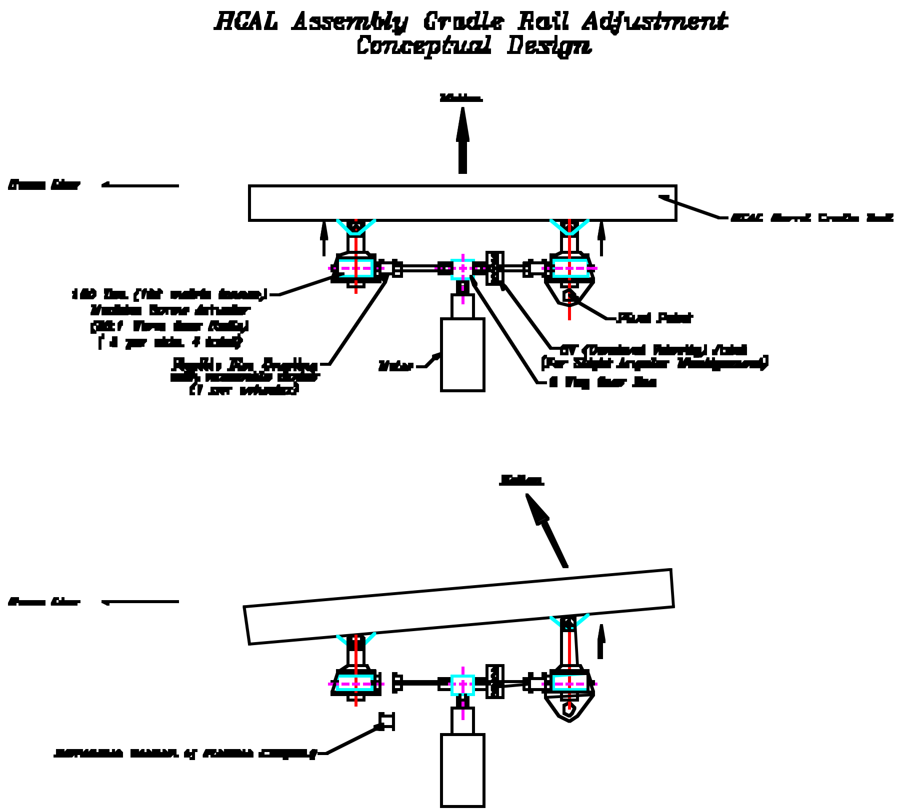

Fig. 2.58: HCAL assembly cradle rail adjustment conceptual design.

The lateral adjustment of the rail is required to accommodate the tolerances of the vacuum tank construction and the ultimate position of the rail welded to it. The entire vertical adjustment system and rail will be resting on an adjustable skidpad with respect to the cradle. The lateral adjustment will be performed by a manual screw mechanism and locked in a similar fashion.

The end of the cradle rails will be tapered and match correspondingly tapered rails in the vacuum tank as shown in Fig. 2.59. The taper is designed to facilitate the smooth transition of the load by the barrel rail support pads from the cradle rails to the vacuum tank rails. At least one full barrel support pad will be in contact will both rails over the transition region at all times. This feature will aid in maintaining rail to rail alignment. The edges of the rail will be chamfered in the transition region to further improve the forgiveness of the rail mating and to aid in the longevity of the Teflon coated barrel support pads.

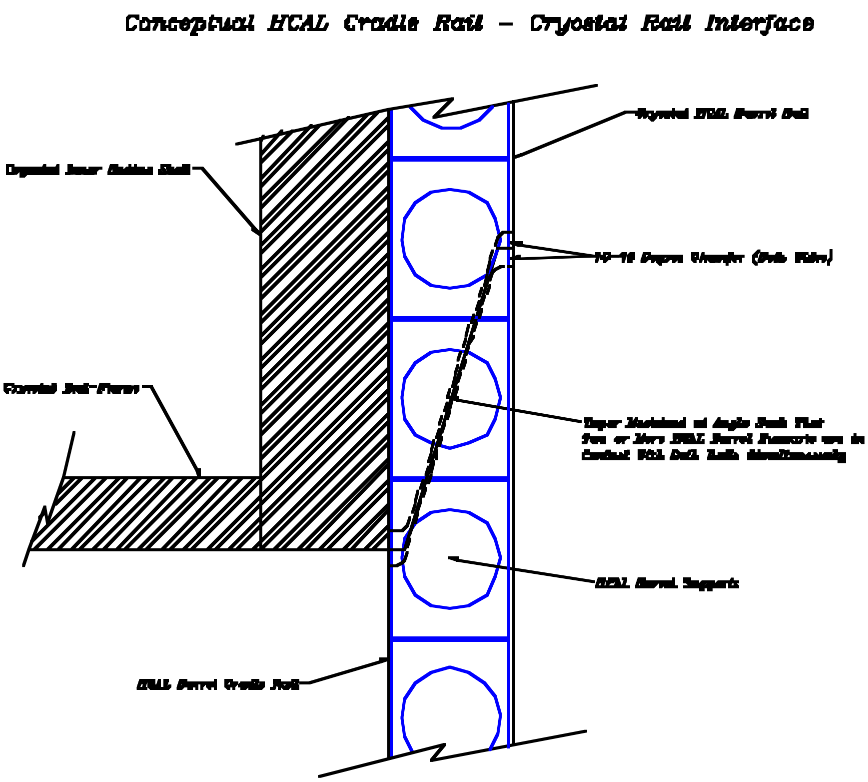

Fig. 2.59: Cradle Rail End Detail.

The entire HCAL barrel cradle moves on a series of airpads which are connected to the bottom of the support stand. These airpads allow the cradle to translate in any direction and move over non- smooth surfaces such as rough concrete (See Chapter 10 of Magnet TDR).

The HB+1 cradle must be constructed in such a fashion as to allow it to be dismantled into sections not exceeding 3.5 meters wide by 6.0 meters long by 7.0 meters high. This requirement is dictated by the size of the transfer tunnel through which the sections must pass in order to be removed from the Experimental Hall to the surface. Once the central iron barrel ring and vacuum tank are installed in the Experimental Hall, they effectively block passage to the main access shaft PX56 leading to the surface hall SX5. The transfer tunnel will help alleviate this restriction by providing passage to the auxiliary access shaft PM54. The HB+1 cradle will be fabricated of several sections which are bolted together each section having a size which does not exceed the transfer tunnel limits. It is not clear at this point if the HB-1 cradle will be constructed in the same manner. The HB-1 cradle does not have the same restrictions imposed on it as it will be accessible by the surface hall SX5 cranes without having to go through the transfer tunnel. Due to the increased cost of a sectional and bolted design, the HB-1 cradle may simply be a monolithic welded structure but still retain the adjustment capabilities for barrel assembly.

HCAL Barrel Assembly Spiders

Assembly spiders are fabricated from a double collar of steel box beam to which is attached 18 screw actuators, as illustrated in Fig. 2.60.

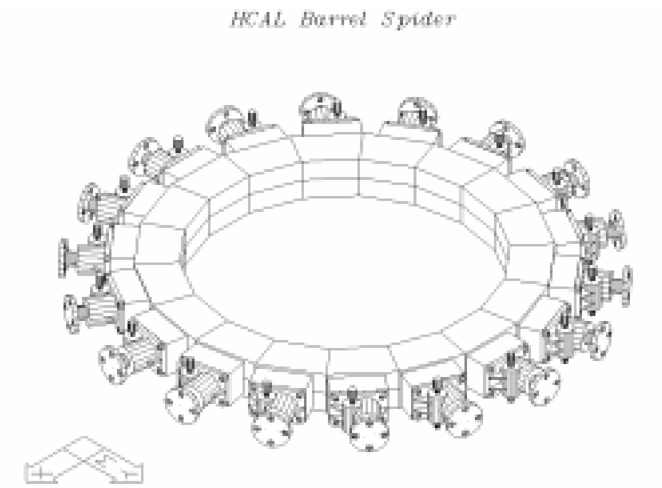

Fig. 2.60: HCAL Barrel Spider

The box beams are American standard 12" x 6" x 0.5" (305mm x 153mm x 13mm) rectangular structural tubing. The double collar will be continuously welded along its seam. The actuators are adjusted with an air impact tool. It takes 48 revolutions of the actuator's input shaft for a 25mm raise. Each actuator is rated at 32 tonnes (35 English tons) The ratio of the actuators was selected such that they allow for fine adjustment and are self-locking under load. Since a pair of spiders will be used for the barrel assembly, the combination will have 2.5 times the rated load capacity for handling a wedge.

HCAL Barrel Assembly Spreader Bar

The HCAL barrel spreader bar consists of one 45.5 tonne (50 English tons) capacity screw actuator and one manually adjustable screw with pad placed at opposite ends of a W610 x 155 I-beam (W24 x 104 US standard). The spreader bar is shown in Fig. 2.61.

Fig. 2.61: HCAL barrel spreader bar.

A preliminary finite element analysis was done to determine the performance of the spreader bar. Under full load (45.5 tonnes), an overall displacement of 2.5 mm (0.98 inches) was realized. The main component of translation we are interested in for assembly is the one in the lateral or "x" direction according to the model.

This component resolved to be about 2.2 mm which will be used as extra clearance for installing the last wedge. The clearance allows for an additional 6 mm of vertical travel for the last wedge.

The barrel is modeled such that the lower half (below the rail) is supported by the cradle and the upper half (above the rail) is free. The localized stress induced by the spreader bar in the wedge where the force is applied is reasonable. The stress here peaks at 106 MPa (15.37 ksi) which is artificially high due to the localized application of the load. In reality one can expect lower stress values.

The reaction force due to the spreader bar load is greatest at the rail support point with a maximum value of about 78 kN (17500 lbs). Again this value is artificially high because of its localized nature. Nevertheless, it is still an acceptable value for the rail.

2.13 BARREL INSTALLATION

2.13.1 Overview, constraints, specifications

The greatest constraint for HCAL barrel installation is the project schedule and timeline. It requires that HB+1 is complete and lowered into the Underground Hall before the central iron barrel ring and the vacuum tank are lowered.

2.13.2 Installation scenario

Once the HCAL barrel halves are ready to be lowered into the Underground Hall, special lifting fixtures will be attached to the sides of the cradles. Since the HCAL barrel weighs around 465 tonnes (510 English tons) and the capacity of the gantry crane is 2500 tonnes, only half of the gantry's cables will be used to lower the HCAL barrels. (See Fig. 2.62 and Fig. 2.63 CMS HCAL Barrel Assembly / Installation Steps 12-13).

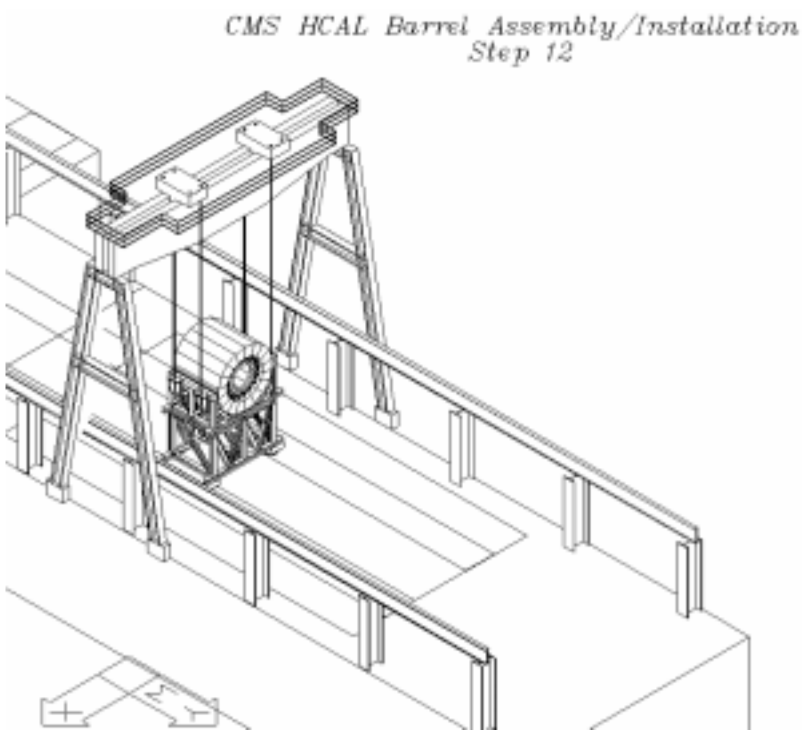

Fig. 2.62: CMS HCAL barrel assembly / installation step 12.

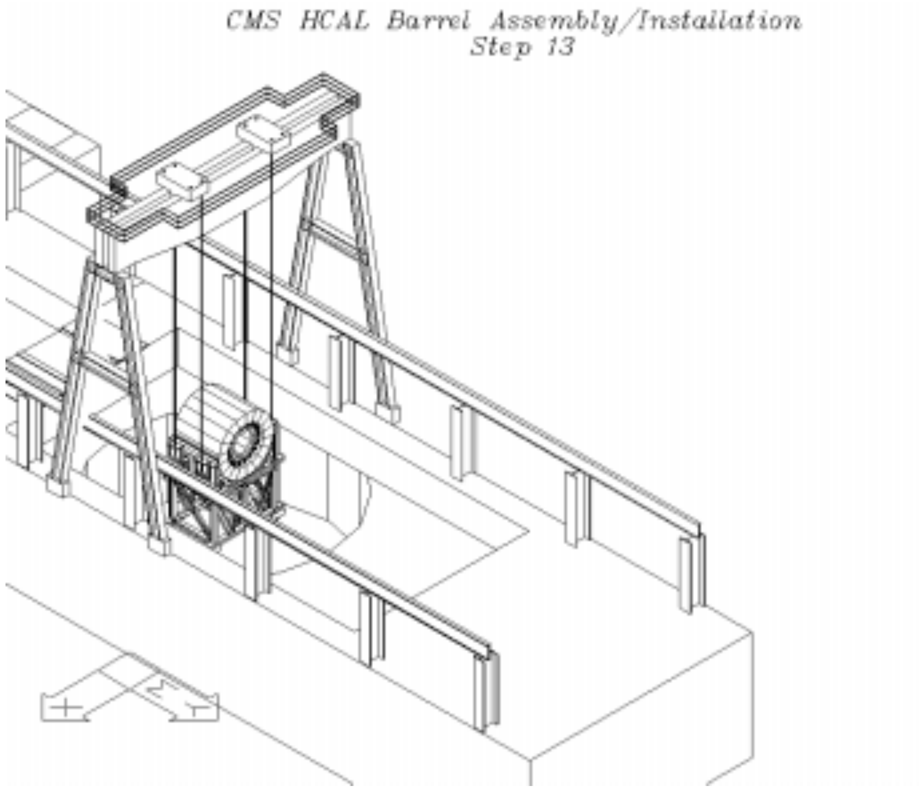

Fig. 2.63: CMS HCAL barrel assembly / installation step 13.

The HCAL barrel will be lowered into the Underground Hall with its lower half supported by the cradle. This will be done to provide an additional margin of stability during the gantry crane rigging procedure. The assembly spiders will remain in the barrels during the lowering process as well. Once HB+1 has been lowered into the Underground Hall, the barrel half must be raised in its cradle and supported on its rail system. The remainder of the outer layer of barrel scintillator will be installed at this stage before insertion into the vacuum tank. Because this procedure is on the critical path for assembly, it is an important step to be included in the Underground Hall activity timeline. The shimmed and fully instrumented barrel will then be inserted into the vacuum tank via the cable come-along device that was used in the surface hall SX5.

The assembly spider will remain in the half barrels during their insertion into the vacuum tank and will be removed upon proper placement of the half barrel. The removal of the spiders will be accomplished by selectively retracting the mechanical actuators and placing a roller bearing surface on the pads. The bearing pads will then be extended back to the inner diameter of the half barrel to provide a rolling surface to facilitate removal.

Once HB+1 has been installed in the vacuum tank, dismantling of the HB+1 cradle may begin. The pieces must be less than 3.5 meters wide, 7 meters high, and 6 meters long so that they will fit through the transfer tunnel. The pieces will be transported through the transfer tunnel to a location under crane coverage from the surface hall SX5 through the auxiliary access shaft PM54. The pieces of the HB+1 cradle will then be lifted from the Underground Hall to be disposed of in the surface hall SX5. The pieces of the cradle should not exceed 80 tonnes.

HB-1 will be lowered into the Underground Hall during the time that HB+1 is being inserted into the vacuum tank. HB-1 will be installed in the vacuum tank in similar fashion to HB+1. The HB-1 cradle will be able to be removed through the main access shaft PX56 in its entirety. If the HB-1 cradle weighs more than 80 tonnes, the 2500 tonne gantry crane may be used to bring it up to the surface hall SX5.

2.14 ECAL SUPPORTS AND ECAL SAMPLING TILES

The ECAL consists of 36 "supermodules", one for each HCAL wedge. The supermodule will be supported by the front plate of the HCAL wedge. The ECAL has a 2 cm thick stainless steel back plate. Anti-friction pads attached to the stainless steel plate provide a “4-point” suspension for the ECAL. This suspension minimizes the distortion on ECAL due to its attachment to HCAL.

It is anticipated that the HCAL half-barrels will be installed into the cryostat in the surface assembly building where they will be surveyed. The survey will be used to make correction machining on the spacers of the supermodules to insure that they are in the right locations after installation onto HCAL.

Analysis of test beam data has shown that the combined ECAL + HCAL has a large e/h which degrades the combined calorimeter linearity and energy resolution. It has been found that making a separate readout immediately behind the ECAL (labeled H1), and using the ratio of H1/Htotal (Htotal is defined to be the sum of H1 plus the remaining layers in the HCAL tower, labeled H2) can largely correct for this problem. Therefore a scintillator readout immediately behind ECAL is required. Fig. 2.64 shows the placement of this scintillator layer. It is anticipated that the ECAL supermodule will be attached to HCAL, and then the scintillator will be installed.

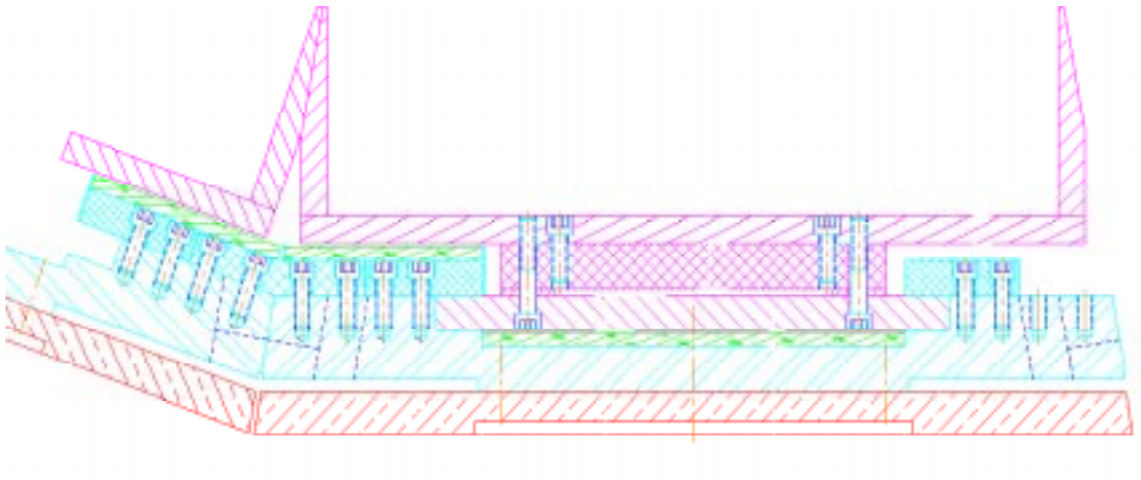

Fig. 2.64: Detail of ECAL attachment to HCAL. Also shown are the scintillators between HCAL and ECAL. Dimensions in mm.

2.15 TRACKING SUPPORTS

The tracker is connected to the HCAL barrel through the cradle, Fig. 2.65. The cradle is connected to the inner stainless steel plates of the barrel by four brackets shown on each end of the cradle. The brackets sit in z beyond the extent of ECAL. If the ECAL supermodule trapped by the bracket needs to be removed, temporary tracker supports will be installed, and the permanent bracket will be removed. Thus all ECAL modules can be accessed without removing the tracker.

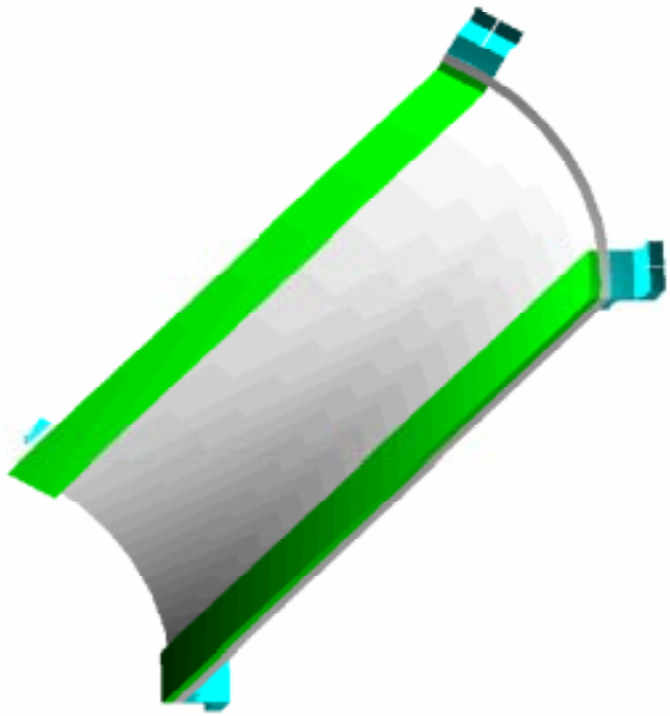

Fig. 2.65: Tracker support cradle.

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