ENGINEERING STUDY

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RUTHERFORD APPLETON LABORATORY
PROJECT ENGINEERING DIVISION

CMS ECAL END CAP PROJECT

Maintainability and Upgrade of CMS ECAL End Cap Detector

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CONTENT

1. DETECTOR HISTORY AND INSTALLATION

The CMS ECAL End Caps (EE) was designed and engineered at Rutherford Appleton Laboratory with assistance from its UK collaborating members in the period between 2003 and 2007. This followed Engineering Design Reviews presented at CERN in November 2000 (EDR-04) and September 2002 (EDR-06). An internal final design review was also conducted at RAL in May 2007.

An End Cap is made up of two 'Dee' shaped assemblies that are mechanically (internal and external) identical; one is rotated 180 degrees to the opposite side to complete an End Cap. There are several internal differences to the electronic and fibre optic layout per Dee depending on it's location on CMS. The Dee's were numbered 1 to 4 and are screw and dowel mounted to the Hadron Calorimeter (HE) on both +ve and –ve ends of the CMS detector.

The Main Support Rings and Backplates were manufactured in the UK by TM engineers between December 2003 and January 2006. These major components were successfully trial fitted to HE calorimeter at Point 5 (CERN) in September 2004 and February 2005.

Final attachment of the Dee assemblies to HE was by using an expandable dowel design similar to that fitted throughout the HE construction. Five such units would be used per Dee, their final position would be marked on an intermediate piece prior to the load transfer procedure to ensure correct fitting. This temporary attachment was to be made by fixing 24 M20 bolts to the HE; these remain after the dowels are finally placed. All expandable dowels are uniquely marked for each location.

Some major engineering items were manufactured in Russia through our CMS collaborators. From our existing RAL design and layouts the Environmental Shield Assemblies and Moderator Shielding system were produced by Energia in Moscow. These items were delivered to CERN in March 2006 and July 2007 respectively.

Existing assembly and installation frames were used from a previous CERN experiment. The OPAL detector was of a similar design and size and a number of rework programs was undertaken to the existing frames and rotation beams that brought them up to EE specification. This included the addition of assembly and installation feet, a strengthening beam required for additional Backplate stiffness during Dee manipulation and a new set of frame-to-Dee support brackets.

The End Cap Dee's were assembled and completed in the ECAL Assembly area in Building 867 (Prevessin) from June 2007 till July 2008. This included the construction of a test assembly (on Dee 4) for beam tests during the summer of 2007. Following this prototype build a number of modifications were undertaken namely on the electronics cooling system. The majority of the internal structures were procured and manufactured in the UK and delivered to CERN.

2. REMOVAL AND MAINTANANCE OF DETECTOR

Any internal maintenance or replacement of End Cap internal components will require the removal of a Dee from CMS/HE Detector.

Despite a number of delicate operations during the installation the removal process should technically be straight forward if undertaken in a correct manner. Some complications may arise during a number of load transfer stages of a Dee assembly and some on-line solutions may be necessary. Certainly the most complex of these load transfers is the removal of a Dee from the HE and off the five expandable dowels and consideration for alignment of assembly frames to the Dee prior to the load transfer should be taken. Full details of this process has been written in a separate paper but below is a summary of the expected removal process.

- Set-up Installation platform. This may require some further modification to the existing alignment brackets for the platform as these were designed to connect to HE bolt holes.
- Undertake the necessary removal of ES Pre-shower, services and covers for both ES and EE detectors.
- Remove Environmental Shield linking strips top and bottom. Clear any seals, tape and any linking connections that may have been fitted between the Dee assemblies.
- Fit the specific Blue Brackets to the Dee Backplate to be removed. Do not fit brackets at 45° positions, check clearance and available space for all bolts and dowels.
- Prepare installation platform ready to accept OPAL frame (including layout of guide plates), hydraulic rams and control system and pre-grease guide plates
- Prepare the correct OPAL frame in proper orientation and with screw jacks plus lifting jig. Lift complete assembly onto installation platform in outer/furthermost position on guide plates. NOTE using the lifting jig on an empty frame means that the correct centre of gravity will not be achieved. Optionally the frame can be raised with correctly mounted slings.
- Once on platform the frame can be moved into position a number of ways but a combination of taking some of the frame load and using the rams maybe the safest. Craning directly into position may lead to collisions.
- Screw jacks are to be used to achieve the correct height although this will be obvious once the frame is closing into the Blue brackets. The interest here is how perpendicular is the OPAL frame with respect to the Dee, some possibility of a survey at this point but this may not provide the necessary information. It is felt that this will be a fit-and-see situation and may require patience (and time) to align the Blue brackets to the holes.
- Fix Blue brackets to OPAL frame. On attachment of Blue brackets to OPAL frame it is recommended that some weight is now taken by the overhead crane (somewhere between 2-3 tonnes) prior to un-tightening the 24 fixing bolts on the Dee.
- Remove the five dowel pins from the Dee (the order of this should be considered). It is at this point that some degree of load transfer may occur; this maybe noted by changes to the load-cell display on the overhead crane and should be noted.
- With some load still being taken by the overhead crane (approximately 3 tonnes) remove the 24 fixing bolts starting from the bottom end of the Dee. At this point where the load has now transferred to the frame there will be a tendency for the Dee to move away from HE; it is possible to keep several loosened bolts in position to act as stops until it is certain that the assembly will not move further.
- Move the new framed assembly away from the Dee using the hydraulic ram system. First movement should be away from the opposing Dee (in X axis). If it is set up correctly there should be enough play in the guide plates/jacks to do this. This is recommended as there are a number of sealing features between the two Dees, separating them at this stage would be advisable as not to cause damage between Dees. As the Dee assembly is withdrawn in the Z axis the gap between the Dee assembly and the Pre-Shower cone should be kept consistent and clear (using Y axis manipulation/screw jacks).
- The Dee Assembly should be moved into its most outer position and the load should then be removed from the crane.

It is at this point that a decision has to be made on where to undertake any repairs or modifications to the Dee. If it is required to lift the Dee Assembly up to the surface it is recommended that the strengthening beam is fitted. However depending on the nature of the updates it may not be possible to access some of the rear electronics area whilst the beam is fitted. If any major movement of the Dee is planned please note that FE analysis has shown possible major distortions (with potential resulting damage) of a Dee assembly. For the strengthening beam to be fully fitted the screw jacks will have to be removed and the original feet fitted to the frame. Once the beam has been re-fitted to the Backplate, the ends of the strengthening beam can be reconnected to the OPAL frame via the original feet.

Once in a position for repairs or updates consideration must be taken in handling the radioactive assembly. There are a number of ways on doing this depending on the levels of radiation present and the operations required. Refer to section 4.

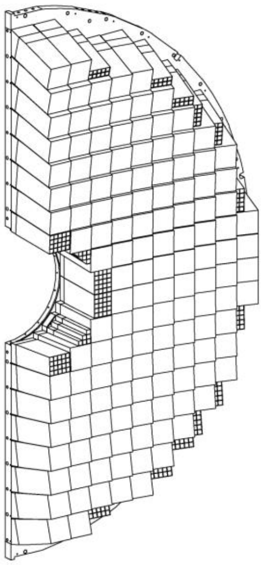
3. REPLACEMENT OF DETECTOR COMPONENTS

Whether it's for detector maintenance or component replacement there are many issues to be taken into account on removing and opening a Dee assembly. In a simplistic form there are two main areas to consider, the first are the Super Crystals at the front of the Main Backplate and second are the related services and support structures to the rear of the Main Backplate. Any removal of Super Crystals will have a major effect on services to the rear of the Dee. For this section I have decided to split the two main areas as they each have certain peculiarities relevant to themselves although they will always remain completely linked to each other.

For detector maintenance or upgrade the Dee would have to be removed from CMS/HE and moved into an appropriate facility. With full protection from radiation exposure already in place (refer to section 4) the first decision should be whether to undertake any changes with the Dee in either an upright position or in a rotated horizontal position. Orientation of the backplate will affect the overall size of the maintenance facility and the services (e.g. overhead crane) required to handle the large components.

i.) End Cap Super Crystals

The main mechanical design work on the ECAL EE Detectors began in earnest during the late 1990's. The decision to construct the 'standard' 5x5 Super Crystal units allowed engineers to fix the size of the major supporting elements including the Backplate. Each Super Crystal would necessitate an individual spacing element to point the unit at the correct angle towards the interaction point. The close proximity of all units required a novel approach of their mounting onto the main supporting Backplate. This was solved by using four mounting holes on each spacer element; two shoulder bolts would provide the accurate positioning of the units whilst the remaining two bolts were added for extra mechanical support. A further 4 holes were added onto one face of the spacer element, this to provide attachment for an assembly jig to position and place the 45 kg Super Crystal onto the Backplate.



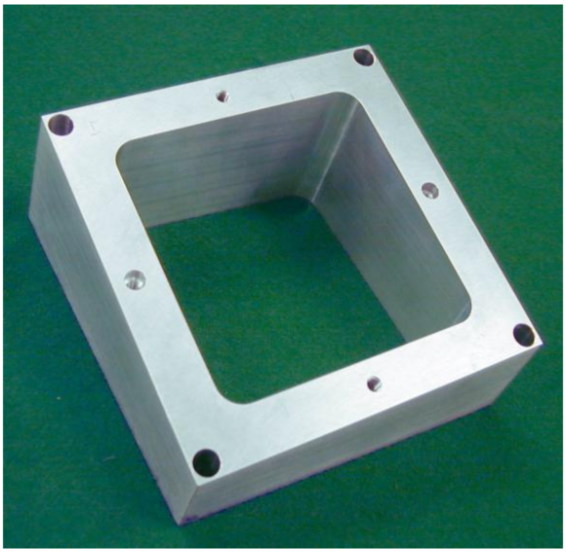


Fig.1 Dee Super Crystal Assembly

Fig.2 Typical Positional Spacer

The assembly jig was further developed with a supplier of pneumatic manipulation systems. They put forward a number of bespoke solutions to allow the full movement of the Super Crystal unit during its assembly procedure.

The initial procedure of mounting a Super Crystal to the Dee (in its horizontal assembly position) necessitated a 90˚ rotation in the head of the manipulator. This was to allow the feed through and connection of the monitoring fibres from the rear of the detector (where they were pre-attached), through a slot and into each individual Crystal. Full manual access for this operation was required for this delicate operation with little physical room available for full vision. Once the fibres were attached the manipulator head was able to rotate to its correct angle allowing shoulder bolts and screws to be attached from the rear.

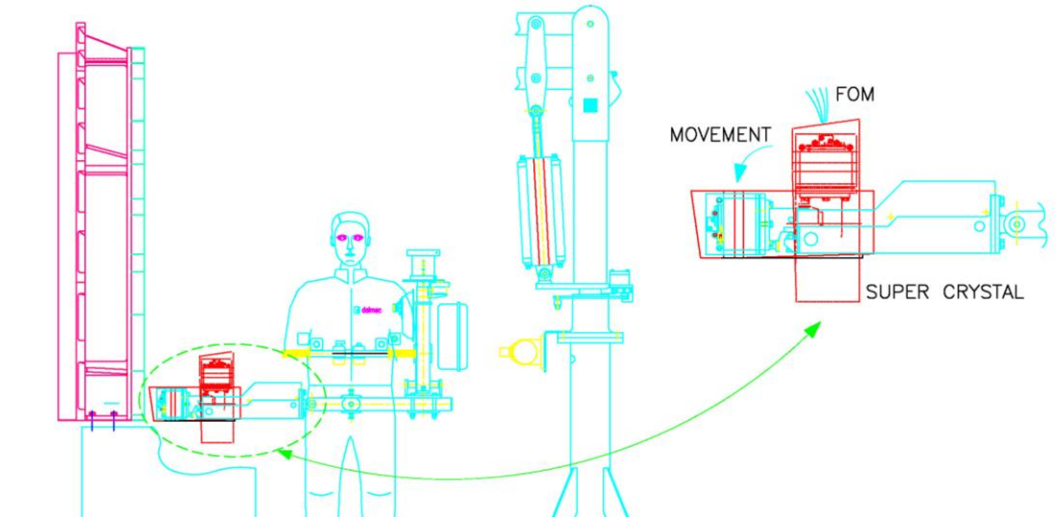


Fig.3 End Cap Super Crystal Assembly process with pneumatic manipulator

Due to the angular pointing of all Super crystals, assembly of the units had to be completed in an orderly manner. These were mounted in columns working from the centreline outwards to the circumference of the Backplate. This was also necessary as the manipulator fixings were only available on the one exposed face of the Super Crystal.

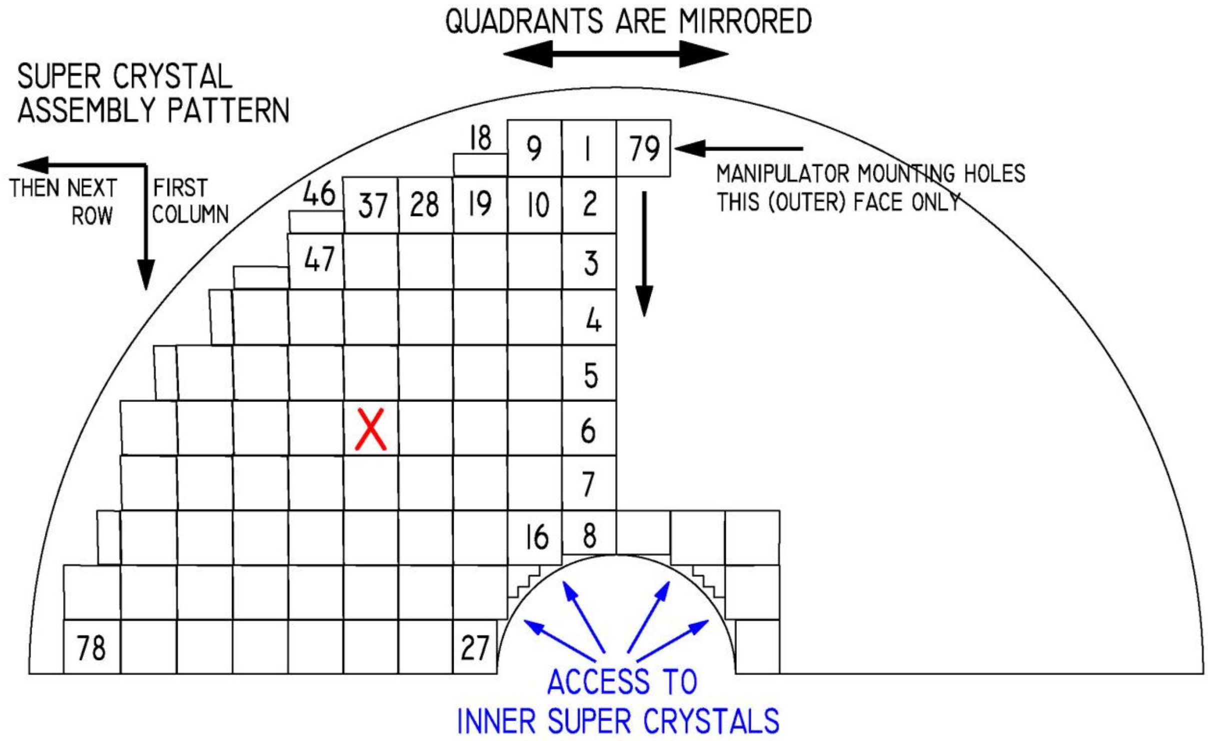


Fig.4 Super Crystal Construction Pattern of typical Dee

Dismounting most of the Super Crystals for replacement however would not be so straightforward. Certainly if one needed to replace a unit located within a group of Crystals (marked as a red X in Fig. 4 above) the only supporting access would be the front face; this for a 45kg unit would not be recommended. Also the compound angles and small gaps of >0.5mm to the surrounding crystal unit's makes removal non-trivial and hazardous as there is no way to grip or support the unit. The safest way to replace the crystal would be to remove all the units preceding its position so that full access for the manipulator holes would become available.

The only Super Crystal Units to have improved access are those on the periphery (whose mounting holes are available) and the inner set of crystals. Although the later does not have the manipulator mounting holes available, there is at least one supporting face where the unit can be held safely in case of removal. Also the compound angles at the inner positions are at their least severe. However removal would still be challenging and require a new approach for supporting the unit. In all of the cases of Super Crystal removal it would be necessary to gain access to the four mounting screws to the rear of the backplate.

Past FE analysis has shown that the Super Crystals have a major dynamic affect on the Backplate and deflections vary depending on orientation. Gaps between Crystals will vary slightly and this must be taken into account during the replacement of any Super Crystal units. Once access to the rear of the Backplate has been achieved and the Super Crystals for removal have been selected and prepared for dismount (umbilical and FOM cut), it is possible that an updated manipulator could be used to remove each inner unit. A simple cradle structure with load sensing cells could be mounted on to the existing manipulator head providing some degree of remote handling thus avoiding any physical contact with the active unit. On removal the active Super Crystal Unit can then be placed into a safe box and sealed prior to transportation.

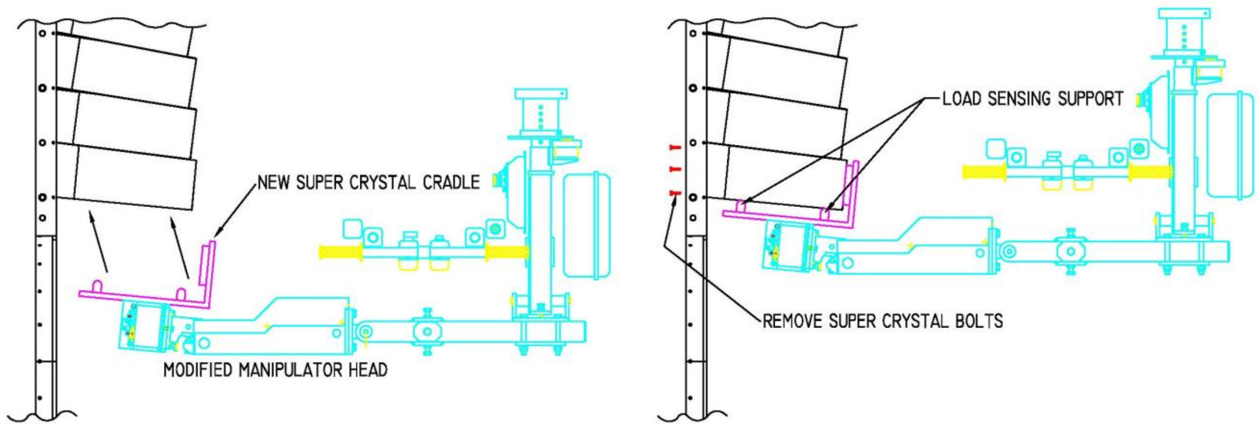


Fig.5 Possible Dismounting Procedure for Inner Super Crystal Units

Mounting new Super Crystal units into the inner region will require a new and more complex approach to the already described original assembly procedure. The main issue is that room for manoeuvre and close physical inspection will be at a premium as the existing main Super Crystals are already in position. The original procedure required the careful attachment of the Fibre Optic Monitoring fibres into the rear of the Crystal, these originally protruding from the rear of the Backplate through a slot. The Super Crystal umbilical and High Voltage also had to be fed through the slot into the electronics region. It is not known what service requirements the ‘new’ crystals will require at this stage but this will have an impact on their mounting. With Dee crystals already in position the new inner region units can only approach their location by ‘sliding’ past existing crystals (in the Y direction) as the pointing and angular aspect of the Dee crystal dismisses the original frontal approach (in the Z direction).

There are several potential solutions, some of which need closer investigation into their validity and much depends on the allowed exposure time for technical staff working on the assembly. If one can assume that the Dee assembly is left in an upright position then a potential fast method (reducing exposure time) to mount the new inner region would be as a pre-assembled block (or blocks) of Super Crystals. This could be achieved replacing individual positional spacers with a common machined plate mounting 3-4 Super Crystal Units however a better understanding of services and their attachment would be required. A heavier duty manipulator would be required to cope with the extra weight and this should have excellent handling properties to allow precision assembly would be necessary.

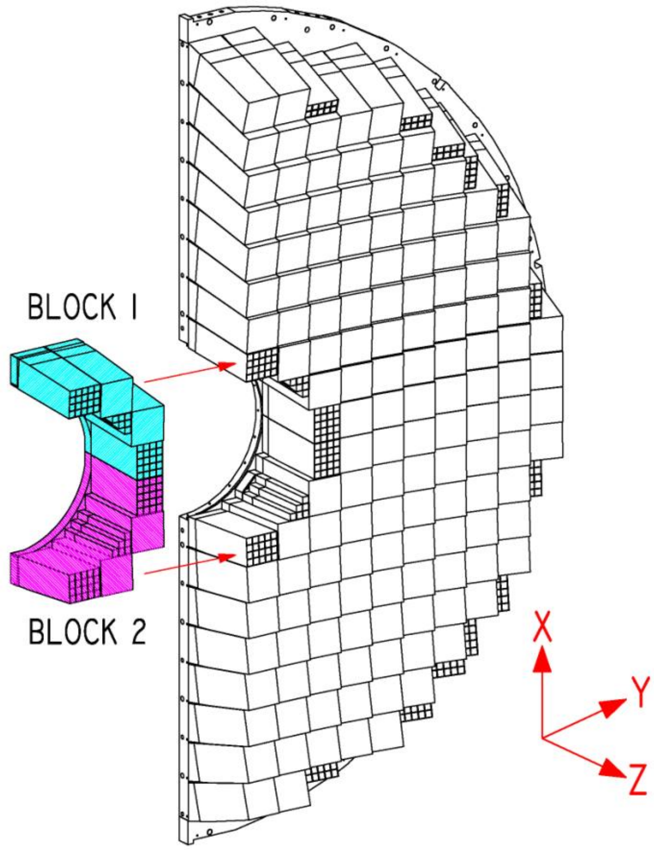


Fig.6 Block mounting Super Crystals on a common spacer plate

The more simplistic solution would be to use the same individual mounting scheme as the original Super Crystal assembly. This individual assembly of crystals could occur with the Backplate in horizontal or vertical positions but it would require a major rework of the current manipulator and the way it supports each crystal. As mentioned earlier in this document each Super Crystal Positional Spacer had a set of holes to provide attachment for an assembly jig (manipulator). One common face of each spacer was selected and this attachment face defined the build procedure for the construction initial End Cap Dee's. This one face was selected because in common with all other spacer faces it had the most material available for the four fixings required. The compound angle on extreme position crystals meant that little material was available for manipulator fixings on at least two of the faces. However if the intention is to upgrade only the inner section of the Dee's an alternative manipulator mounting face could be selected for the new spacers.

However it is clear with this solution that with Super Crystal clearances at a known minimum (typically between 2mm and 0.2mm at the leading edge) the current manipulator does not have the precision movement necessary to undertake such delicate operations. Although suitable for the original assembly procedure there is too much 'float' with the existing pneumatic control and brake system. If the manipulator was to be updated one could expect to use some electric servo motor controlled system that could provide sub-millimetre movement for precision placement, see Fig.7 below.

Above all of these technical details, all updates have to be undertaken on an assembly that is radioactive to some degree. Close proximity work such as component removal, the connection and feed through of umbilical's and fibres in the 'hot' central area of the detector will have to be undertaken with full protection provided for the technical staff.

This will not only be challenging and uncomfortable for the users but basic operations will be non-trivial and take significantly more time to complete. This latter statement must take precedent in the future planning of any Dee detector upgrade as safety is of paramount importance.

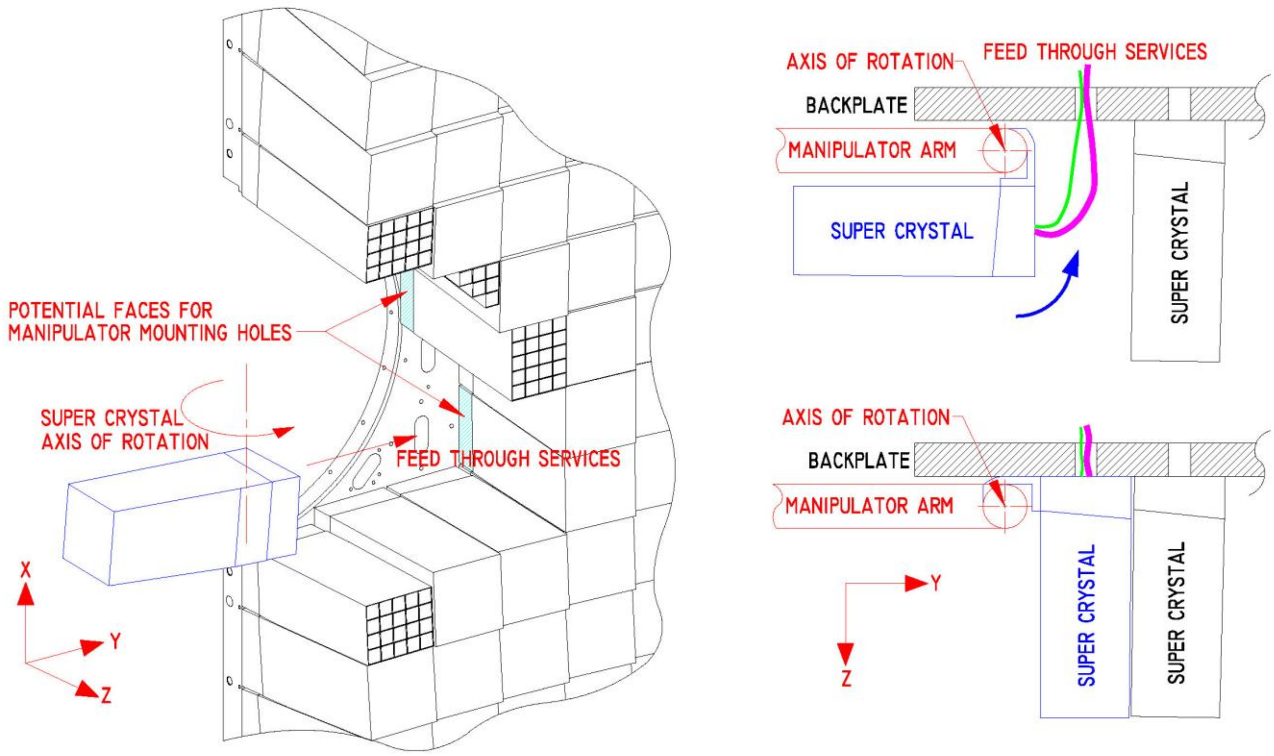


Fig.7 Potential method of Super Crystal attachment (inner region)

ii.) End Cap Services and Support Structures

From an early stage of the End Cap design it was clear that the most logical construction of the main electronics assembly would be in the form of layers towards the rear of the Super Crystal units. Working with RAL and ECAL collaboration teams, areas to the rear of the Backplate were reserved and agreements reached on the space required for the following main systems.

- Super Crystal Fibre Optic Monitoring – in collaboration with SACLAY
- Super Crystal HV system
- End Cap Front and Inner Moderator Structure
- Very Forward Electronics Low Voltage system
- VFE cards and Cooling system
- Data and Trigger Fibre Optic system
- End Cap Rear Moderator

Once this arrangement had been agreed work started towards a final design. The layer system was further segmented when ECAL Project leaders requested that each layer should allow for some modular construction in order to match a planned in-parallel Super Crystal and electronics assembly on the Dee's. In the event this in-parallel construction of Super Crystals and electronics did not occur, Dee's were not worked on until they were fully populated with Super Crystals and had their respective Fibre Optic Monitoring (FOM) fibres mounted. Although each Super Crystal had it own FOM arrangement, routing of the fibres to patch panels and laser splitters were spread across the whole Backplate. Some late development in the design of the VFE electronics cooling allowed this structure to be mounted in sections (four per quadrant, eight per Dee). For final assembly however the cooling systems were mounted in quadrants, this allowed for full testing of cooling and the installation of VFE electronics on one quadrant whilst motherboard soldering and Super Crystal umbilical connection occurred on the other.

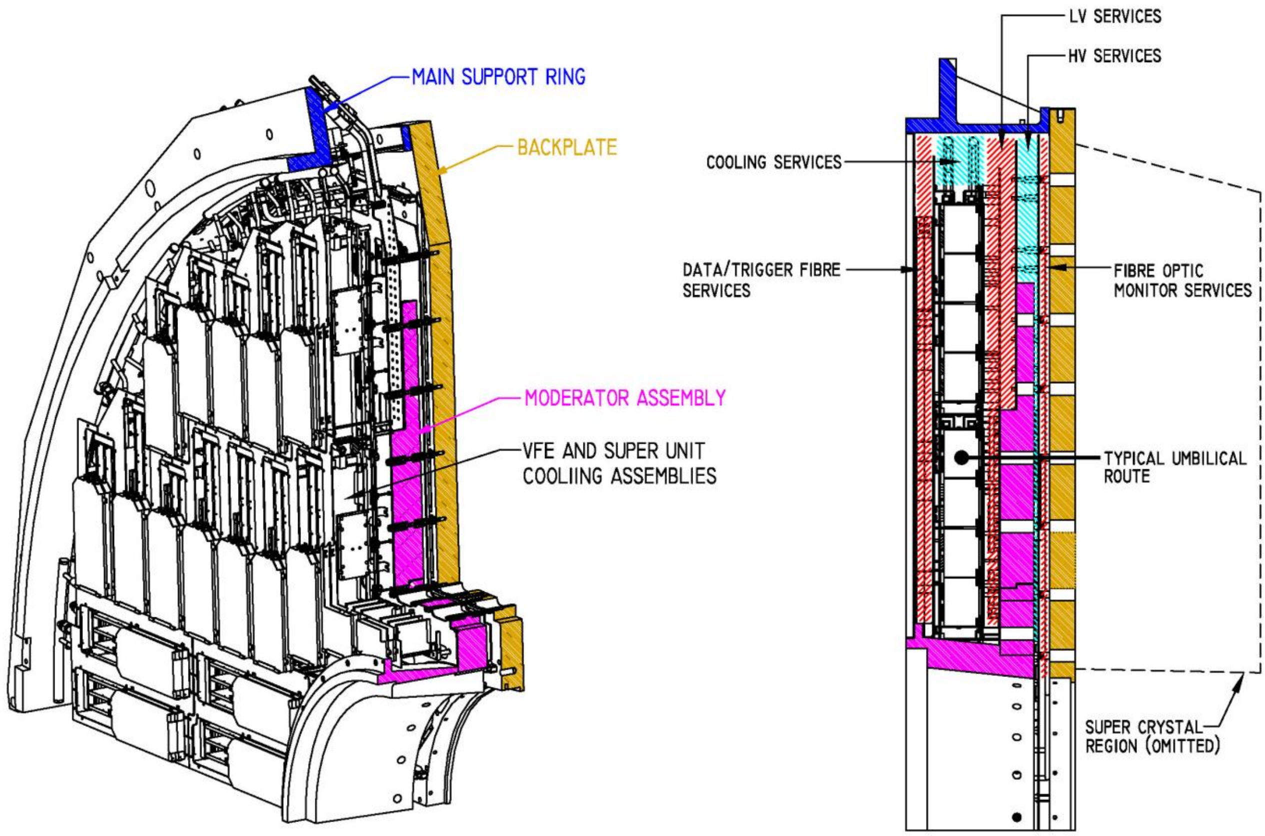


Fig.8 Section views though Dee assembly

Despite best efforts to segment sections of the Dee assembly during the design stage, much overlap of fibre optic, electrical and super crystal services occur between regions. It is without doubt that trying to remove a section of Super Crystals as with the proposed inner area of the EE upgrade will result in a major dismounting exercise of the region behind the Backplate. Depending on the cross knitting of certain services it may be possible to leave some of the outer support plates in position (as shown on Fig.9 in the regions of cooling Super Unit 3 and 7). However it's more than likely that any new inner Super Crystals will require some routing of services to the patch panels of the outer support ring thus the removal of all support plates and moderator shielding will be necessary. Full access to the mounting screws of the to-be-replaced Super Crystals can only be achieved by the removal of the support plates covering the specific Super Unit area.

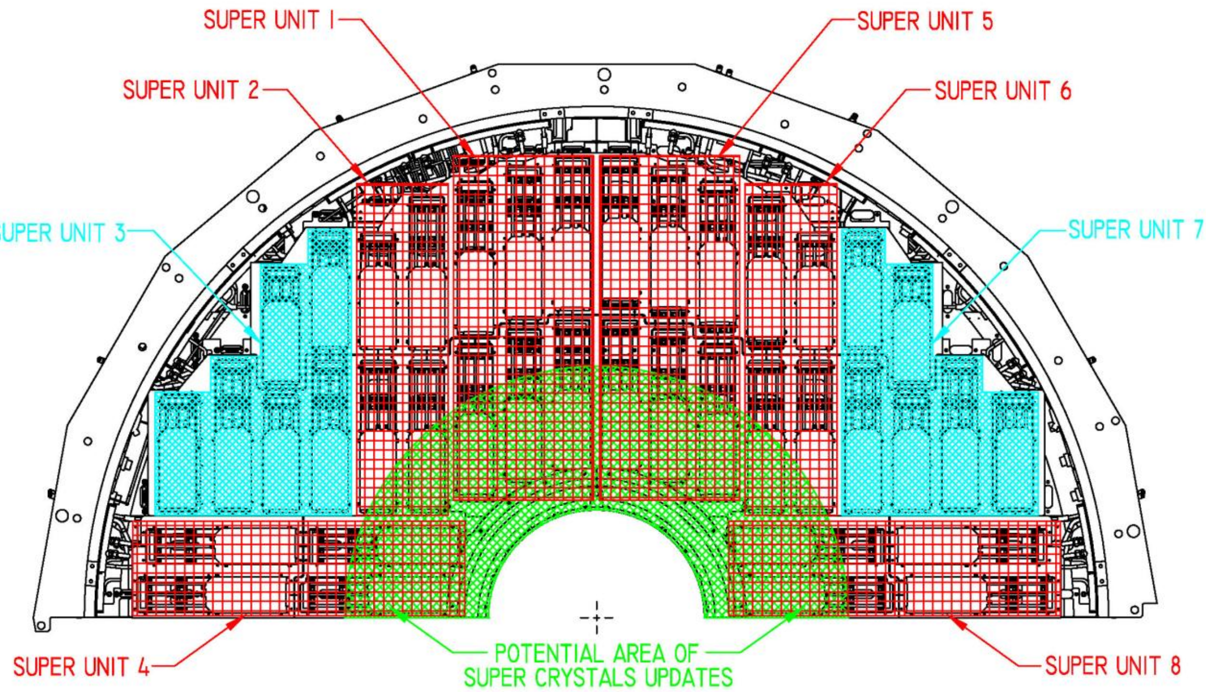


Fig.9 View of region behind the Backplate

Details of all service routings for the individual Dee's are well documented in other papers, a much detailed study on what services can and can't be removed in the rear region would be have to be undertaken and not subject of this document. However to generalise it is felt that nothing short of full disassembly of this region will be required for any detector upgrade. There are no major reasons to why this cannot be done as experience tells us that all layers of the Dee's are dismountable however once again this work will have to be undertaken in an active environment. To reiterate the conclusions of dismounting the Super Crystals this will not only be physically challenging for the users but basic operations will be non-trivial and take significantly more time to complete.

All work will take place close to the Dee and depending on the effects of radioactive exposure some materials may be affected or remain partly active after dismount. As the central area of the detector will be affected by neutrons, the particle reacts weakly with the metallic components assembled and is only moderated by the polyethylene shield assembly (Moderator). Therefore it can be assumed that the majority of existing metal components (e.g. support plates and fixings) could be re-used although closer investigation of actual exposure time and levels reached should be double checked against all material properties. Constant exposure to neutrons however may affect the long-term material properties of the polyethylene moderator. Until the LHC begins its experimental program there will be no technical data to what level this exposure will be. Nonetheless a full study should be undertaken prior to upgrade and calculate what degradation may have occurred, this could result in the complete replacement of the moderator shielding. It is unknown what other radioactive effects the Dee assemblies will undergo during the planned detector run, this should be indicated in advance of any upgrade as to prepare for any necessary replacement of components or cabling. A relatively high number of fixture spares were accumulated during the End Cap Dee assembly program and many of these could be potentially used during any reconstruction.

4. HANDLING COMPONENTS EXPOSED TO RADIATION

There are four main levels of handling for protection and manipulation of radioactive components currently in use, these are:

- Glove Box – this offers a low level of contained protection whilst allowing physical hand manipulation of components.

- Tong – Together with some level of protective shielding this offers mechanical manipulation (through linked hand movement) at a set distance from the components thus avoiding physical contact.

- Manipulator – Together with a high level protection 'Hot Cell' this offers assisted mechanical manipulation, preferably using pneumatic systems, within a contained area avoiding physical contact.

- Robotic - Together with a high level of thick walled protection this offers full powered manipulation from a control desk using electrical motor systems and live video feed avoiding the need for any physical contact or presence.

Naturally the most important issue of any work with radioactive components is the health and safety of the people working in the immediate vicinity. It is of extreme importance that all work is undertaken within the strict guidelines of the CERN Departmental Safety Plan under section 4.6 (http://safety-commission.web.cern.ch/safety-commission/SafetyPlan/ts/e_index.htm).

All users of any facility specifically set up for work carried out on the End Cap Dees should be fully aware of rules laid down in CERN Safety Code F (Radiation Protection Manual). It is also clear that a full understanding of the levels of radiation worked to are known prior to the start of any planned manipulation or major replacement of components. Only when this is fully understood can one make a decision and prepare in advance what level of protection will be necessary to work on the End Cap Dee's. No matter what radiation levels are expected, any work undertaken on the Dee assemblies should be within an enclosure or a fenced-off area with restricted locking systems to the active components and equipment.

The first two levels of handling are systems that are readily available to purchase off the shelf but may need some local modifications to suit the requirements of the End Cap and its location. Protective clothing is also available for the user during these operations. Although the simplest method of manipulation, the Glove Box system can be ruled out for any large scale work that may be required on the Dee's. It may be possible to use some form of protective gloves/clothing but careful calculations for time allowance and expected dose for the user will be required. The Tong system provides a greater level of protection for the user as they are able to work some distance from the active components and also behind a (mobile) screen. Mechanical grip systems are available for basic manipulation tasks however this system does not provide the full dexterity one would expect from using hands and therefore the simplest tasks are expected to take significantly more time to complete.

The third level of handling is a step further in both protection and manipulation techniques. Hot Cell environments are required where components are deemed at a high level of radioactivity and limit the long-term exposure of users. These are suitably constructed enclosures with shielded walls, ceilings and restricted door access. A fully enclosed area large enough to accommodate the Dee assembly and manipulation equipment will either need to be found on CERN site or specifically constructed for purpose. The manipulation equipment should be housed internally but control systems should be handled remotely outside the Hot Cell environment. Manipulation systems should be pneumatic as opposed to hydraulic and should ideally be provided with a live video feed showing handling motion. Like the Tong handling however not having the ability to touch removes physical dexterity of user's hands and again the simplest of tasks are not as straightforward to perform. Building a brand new Hot Cell specifically for the task will be expensive; there are a number of companies that are experienced with on-site construction of such environments. Off the shelf manipulation and air-gun systems can be purchased but appear to be fairly limited in manipulation of high loads (and expensive) however there is no reason why existing pneumatic manipulation systems cannot be used if suitably converted for remote handling. Certainly the ECAL EE group has the Super Crystal manipulator available for such operations and it is expected that some remote station could be incorporated at extra cost.

The fourth the level of handling is a robotic system, similar to that of the Hot Cell this provides the highest level of radioactive protection where ALL manipulation is remotely handled by electro-mechanically systems. This arrangement is typical of the Nuclear Power industry where physical contact with radioactive components is completely avoided. This is a much specialised area and the cost to develop such an arrangement is deemed to high in this case.

5. UPGRADE FACILITIES

There are a number of steps and considerations to be taken into account prior to removal of any ECAL Dee assemblies at Point 5. Advice would be sought from CERN Safety Supervisors on the best way to handle the assemblies during the removal process. Once the decision has been made to what type of upgrades are required, facilities should be prepared much in advance to allow time to develop procedures and operations.

CERN has been a working nuclear science laboratory for many years therefore has already a number of existing facilities for working on or in radioactive environments. Again advice from supervisors and existing users should be sought during the early stage planning of the ECAL EE Dee upgrade. In all cases it is recommended that a specially constructed cell is assembled and being that Point 5 is the most likely place of work this could be based on using standard concrete blocks with an appropriate roof structure to maintain cell integrity. An adjacent storage area (temporary and for transit) must also be considered as when upgrade work is undertaken many components including environmental shield assemblies, Super Crystals and service support structures will require stacking and safe storage. Holding Areas may also be necessary for Dee's awaiting upgrade or when completed and awaiting transportation. With all of these areas taken into consideration it can be seen that the footprint and size of the Upgrade facility will be large, this must be noted during the decision process to indentify its location.

Looking at the various work requirements of a Dee upgrade it can be seen that any of the first three levels of handling and protection could be used. Work on smaller components or sub-assemblies could be undertaken in a suitably sized Glove-Box. It can be envisaged that work carried out in the rear region of the Dee during disassembly can be done manually (with glove/clothing protection) for limited periods or by Tong (behind a shield using grips or air-guns). For heavier duty work (such as removal of Super Crystal units) remotely operated pneumatic manipulator could be used where the operator is located outside the cell or behind some level of shielding thus avoiding long-term exposure.

If working with a high level radioactive component it is recommended that the least time possible is taken to update and reassemble the components. Correct shift and a manpower management structure should be in place before hand to ensure safe user dose levels throughout the operation.

6. CONCLUDING NOTE

Many open questions have been left in this report; most of these rely on the answer to 'what is the expected radioactive exposure of End Caps during LHC program'. Only when this is fully understood can we determine the level of protection required for the facility and its users. This will also determine the equipment specifications for detector manipulation and handling plus what new components are required for the upgrade.

A further decision should be made on the orientation of the Dee's during upgrade. This will have also have an affect on Dee preparation, facility size and the arrangement of the handling equipment. Some of the proposals made in this paper rely on the Dee being a particular orientation for certain operations; this must be taken into account when deciding the final upgrade facility layout.

The technical proposals made here require further studies to fully understand the effects on the End Cap Dee's electrical and fibre optic services. This will determine the level of disassembly required to upgrade certain Super Crystal Units within the region behind the backplate.

An accurate program of work should be assessed prior to the completion of any project schedule, above all this must take into account the working conditions and safety of the facility users.