Mu2e System Integration

Jacopo Aurigi
Supervisor: George Ginther

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Abstract

The report present the work accomplished during the nine weeks of Internship at Fermilab. The student has been involved in the system Integration of the Mu2e project, carried out at Fermilab from many years. The purpose of the project is to measure the ratio of the nutrinoless muon to electron conversion with respect to the ordinary conversion.
The work has been accomplished mainly via software, using both the project database Teamcenter and the online database as well as the 3D CAD software NX. Another learning path of the Intern has been provided from the atteindance to the Muon Integration Beamline meeting, the Mechanical Integration Muon Beamline meeting and the Mechanical Toolbox Muon Beamline meeting. Different problems have been faced during the period of the internship. The topics are not presented in a cronological order but are presented in a more coherent way, mating similar topic together even if not accomplished consequently.
After a first period of a few days, necessary to get confident with the experiment and the tools, the first weeks have been spent detailing concrete blocks used in the Downstream External Shielding. Lifting features, as well as chamfers and corner reinforcements have been added to many concrete blocks.
The following step was to look for interferences, between those blocks and other part of the experiment, that could have caused serious problem during the assembly phase.
The following step was to check clearances between concrete blocks and other subassembly of the experiment highliting the different region of interferences.
Another task related to concrete blocks was to make up an alternative cheaper configuration of the West Wall Shielding in the Upstream External Shielding subassembly.
Finally, the blocks of the End Cap Shielding have been properly modified to host the adaptor plate placed at proper elevation and offset.
Another task accomplished was to implement in the 3D model an existing plate placed at the corner between the West-East trench and the North-South trench. Cover plates have been consequently added to make other people aware of the gap left for wire and cables.
Finally, the IFB Cable Placeholder has been implemented making a new version which mainly consist of an up-to-date of the previous design that better reflects how the tracker and calorimeter cables coming out from the downstream face of the Instrumentation Feedthrough Bulkhead are expected to be in the final configuration.

Introduction

This chapter is thought to provide a very brief introduction to the Mu2e project, focusing on the goal of the experiment and on the way used to achieve it. All the phisycal details of the experiment will be skipped or just cited not being directly related to the topic presented in the report. More details will be introduced when needed, in the following of the report.

Mu2e Project

Mu2e proposes to measure the ratio of the rate of the neutrinoless, coherent conversion of muons into electrons in the field of a nucleus, relative to the rate of ordinary muon capture on the nucleus. The conversion process has never been observed experimentally and is an example of charged lepton flavour violation. The total project costs for the entire project is $271M at the date of October 2014.
Just a preliminary explanation of the project will be given in this section. In a very semplicistic description we can identify three major parts of the experiment. The Production Solenoid (PS), the Trasport Solenoid, split into two halves named Upstream and Downstream Transport Solenoid (respectivly TSu and TSd) and finally a Detector Solenoid (DS). A proton beam arrives into the PS from NW (see following section for NW definition) and hit a tungsten target producing many types of particles. Between them pions, one are interested in pions, which decay into muons, later on muon get accelerated by mean of TSu, go across an Antiproton Stopping Window placed in between the Upstream and Downstream Transport Solenoids (aiming to remove different types of particles, mainly Antiproton) and finally arrive at the DS. Here Muons are supposed to hit a target made of a series of 12 Aluminum foils suspended within the bore of the DS, downstream the target there is a Tracker, made of several aluminum panels and a lot of straws filled with Inert gas, encharged to measure the momentum of the impinging particles. Downstream the tracker, a Calorimeter is placed in order to provide a second set of measurement that complements the information coming from the Tracker. Downstream the DS there is a Muon Beam Stop, which is a stainless steel and high density polyetylene tube designed to absorb beam particles that reach the downstream end of the solenoids while minimazing the background. Surrounding the PS, TSd and the DS a concrete shielding limit the number of nuetrons and gamma particles coming out from the solenoids and clogs up the passage of cosmic rays. An active shielding, Cosmic Ray Veto is placed over the concrete shielding all around the TSd and the DS. Downstream the Muon Beam Stop, an Instrumentation Feedtrough Bulkhead gathers all the fibers and electronic wires coming out from the Tracker and the Calorimeter and enclose them all in a trench in the floor.

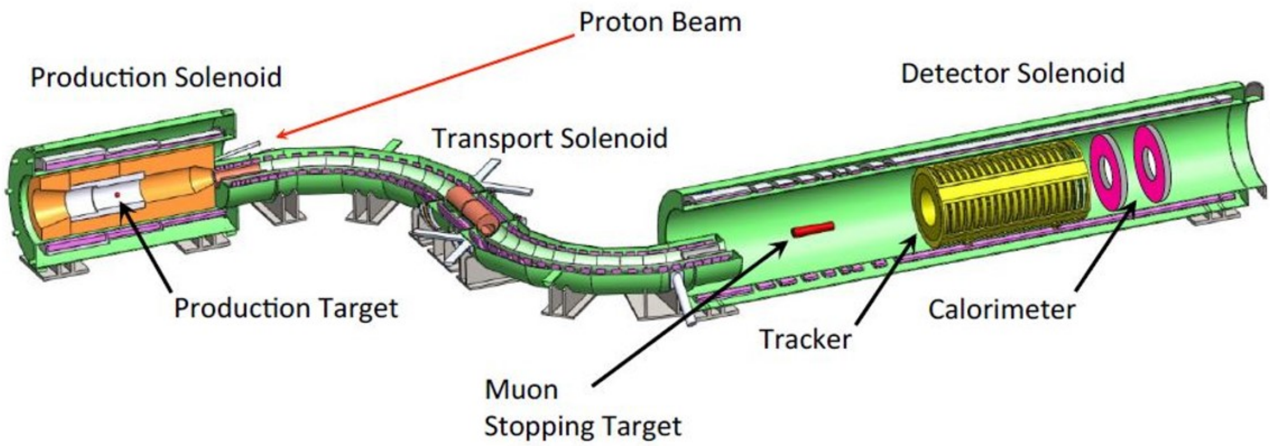


Figure 1: Overview of Mu2e Project

Mu2e Coordinate System

Different coordinate System are adopted in the Project.
One refer to Mu2e Coordinate System as a coordinate system having the origin coincident with the point where the transfer solenoid changes curvature, at an elevation with respect to the floor of 2312.4658 mm. The x axis pointing the project North, the z axis pointing the project East and the y-axis coming out of the page, for definition of Project North etc., the reference figure is Fig 2. It's worth noting that the the project North doesn't coincide with the geographycal North: there is instead an angular offset that obviously reflects also on the other cardinal points.

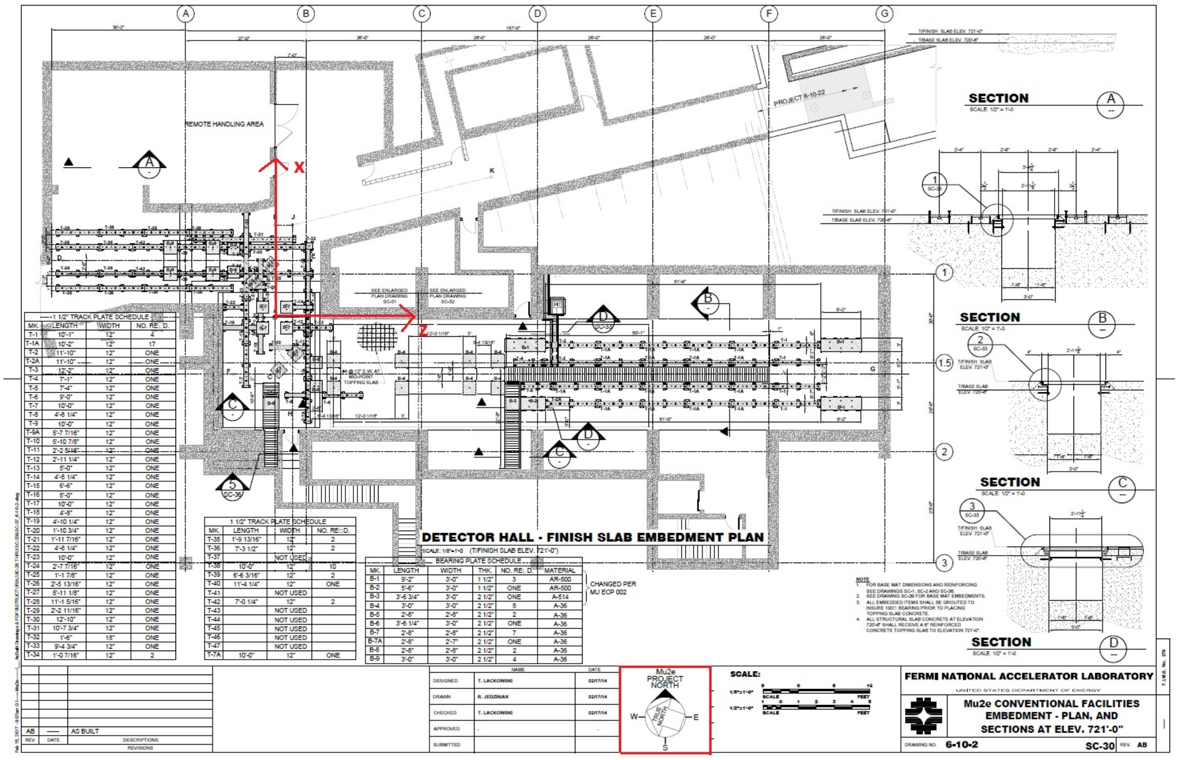


Figure 2: Mu2e Coordinate System

The 3D Integration Model shows up instead a slightly different coordinate system, in which the origin is in the same position and at the same elevation as for the Mu2e Coordinate System but the axys orientation is different. The x axis points the project South, the y axis the project East and the z axis is coming out of the page as resulting from the right hand rule.
Finally there is a reference system for every part designed, those are normally randomly oriented and will be no more taken into consideration in the report. On the other hand, when not specified the Mu2e Coordinate System will be used, otherwise the particular coordinate system adopted will be denoted case by case.

Downstream External Shielding and Blocks detailing

This section presents the work done on the concrete blocks of the Downstream External Shielding. This subassembly has the main goals to reduce the neutron and gamma background incident upon the CRV and to allow the line of sight to the muon stopping target monitor. Other requirements it has to satisfy are:

- provide a support for the CRV
- Facilitate access to the IFB and the Detector train inside the DS
- Facilitate access to antiproton stopping window assembly
- accomadate passagges of power, cryo and vacuum services to the DS while reducing rates of particles escaping through this penetration
- reduce rates of particles escaping through the TSd and DS trenches
- satisfy the costraints imposed by the building geometry

This shielding is essentially split into two parts, the Downstream Cave and the End Cap Shielding. The downstream cave sourrounds the TSd and the DS, while the End Cap Shielding encloses the IFB and is supposed to be pulled out and pushed back in the East-West direction.

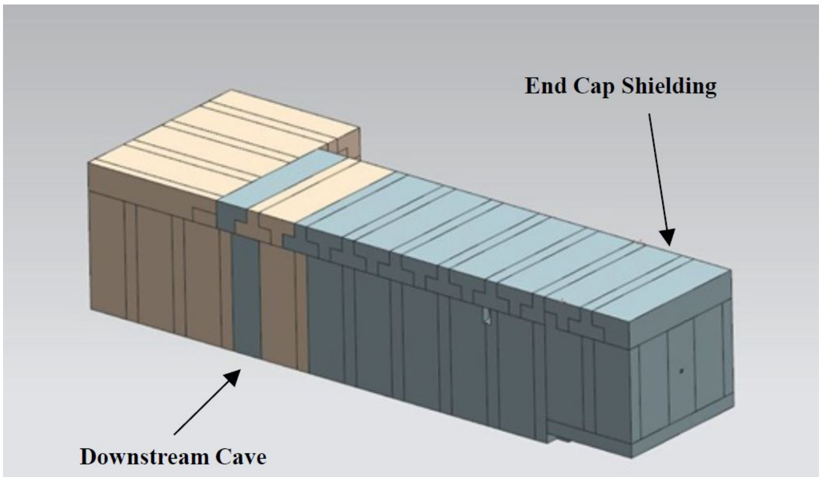
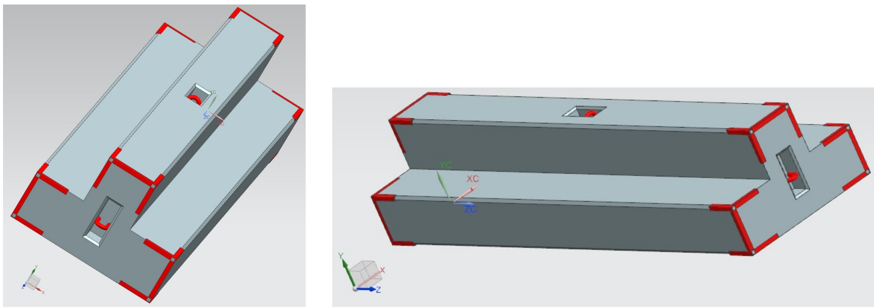


Figure 3: Downstream External Shielding, baseline configuration

At the same time, the shielding is made of several concrete blocks of different shapes and dimension but closely mated one to eachother so as to constitute an unique rigid structure. The blocks are divided into three subgroups according to the different concrete density: the blocks represented in grey are normal density concrete, the brown blocks are borate concrete blocks, obtained mixing boron atoms within concrete while curing, finally there are also high density concrete blocks, not represented in Fig 3, placed in those points where high shielding is required. As a matter of fact, shielding capability increases if density increases but the price gets higher and higher as well so that a borate concrete block costs three times more than an identical normal density concrete block while in case of a high density concrete the price can arise up to five times as much. In the following of the report I will talk about North and South face of the shielding referring respectivly to the walls of the assembly looking project-North and South, and to downstream and Upstream sides in accordance with the direction of the Muon Beamline.
The first task accomplished was to measure and document the overall dimension of the shielding, great attention has been given to the hole in the downstream face of the End Cap Shielding by the moment that this hole has to be perfectly aligned with the line of sight of the Muon Beamline.
Later on the detailing of many blocks has been done: more in depth, to those blocks that are possible to be actually used, that is normal density concrete blocks and borate concrete blocks, handling and lifting features have been added. Corner reinforcement have been added to every corner to protect blocks from possible formation of cracks while moving them during assembly phase, by the moment that they could eventually hit one eachother. For the same reason, chamfers have been addeed to the long edges of every blocks. Finally lifting features, necessary to be grabbed and moved by cranes, have been added in a proper number and position, based on centre of mass consideration, also to take into account possible reutilisation of those blocks in the future for other Fermilab experiments.



(a) *Lifting features and corner reinforcement* (b) *Chamfers*

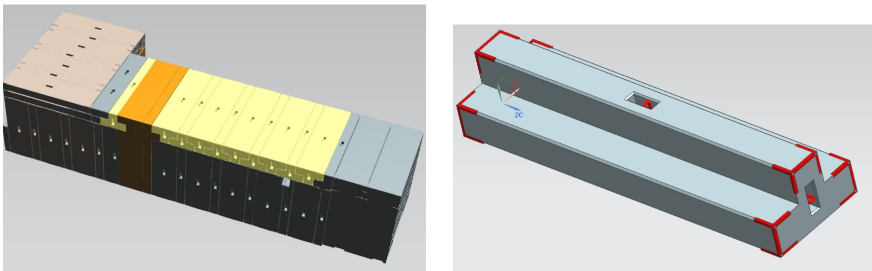
Figure 4: Blocks lifting and handling features

Block detailing

This part presents the same structure for all the blocks detailed. The picture on the left represents the position of the block in the shielding assembly while the picture on the right shows up the block after having been detailed. The names of the blocks have been assigned according to the material used to form the block (first letter), the cross sectional shape (second letter) and the longitudinal dimension expressed in inches.

CT-194

Normal density concrete block, roof of the Downstream Cave

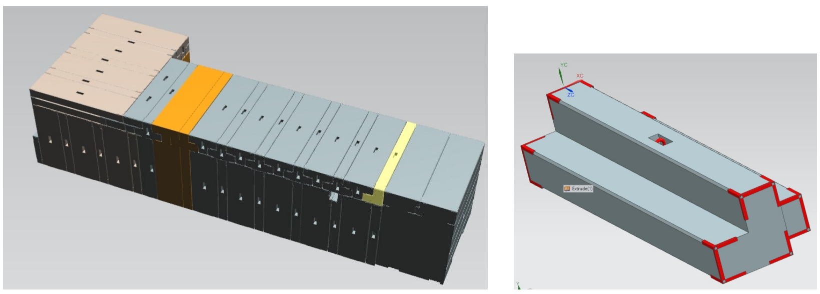


(a) *CT-194 position* (b) *CT-194 details*

Figure 5: CT-194

CT1-194

Normal density concrete block, intersection between Downstream Cave and End Cap Shielding

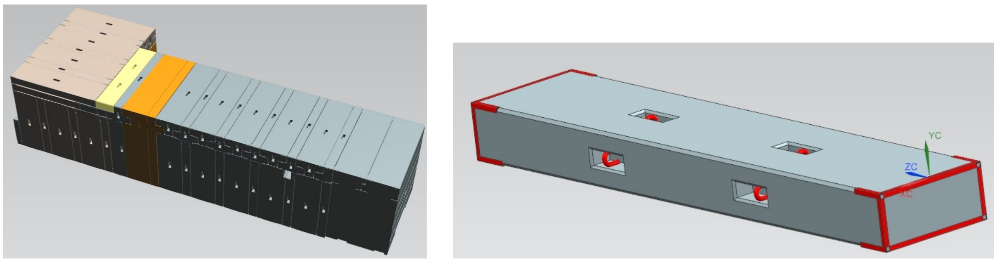


(a) *CT1-194 position* (b) *CT1-194 details*

Figure 6: CT1-194

CRH-194

Normal density concrete block, Downstream Cave roof

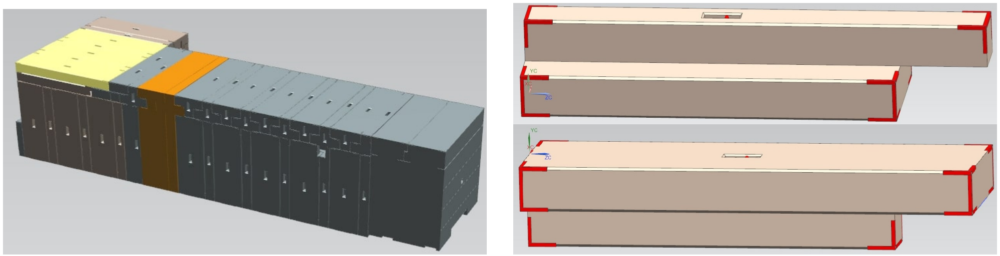


(a) *CRH-194 position* (b) *CRH-194 details*

Figure 7: CRH-194

BT1 and BT2

Borate concrete blocks, roof of Downstream cave sourrounding TDs

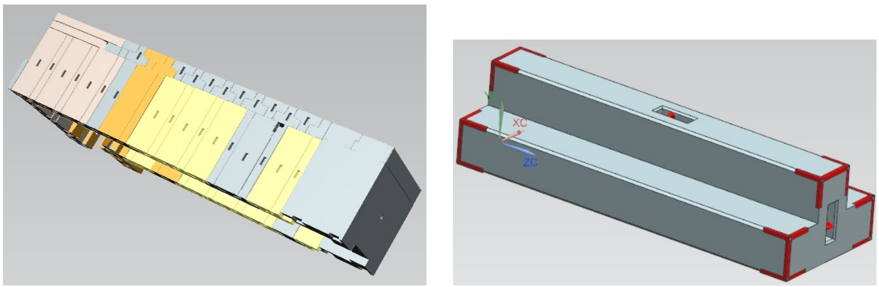


(a) *BT1 and BT2 position in the assembly* (b) *BT1 (up) and BT2 (down)top sirface up*

Figure 8: BT1 and BT2

CT-152

Normal density concrete blocks of both the North and South walls of the shielding



(a) *CT-152 position* (b) *CT-152 details*

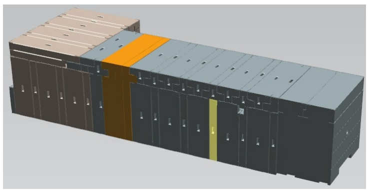
Figure 9: CT-152

CT4-152, CT5-152 and CT6-152

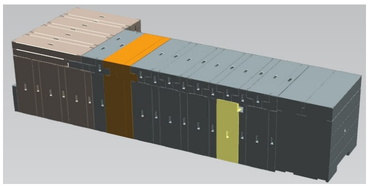
These three normal density concrete blocks host a passage in the thickness off the block to accomodate vacuum line directed through the DS. The reason why the duct within the wall is not straight but S-shaped is that as a primary goal it has to guarantee radiation shielding and by the moment that radiation propagaate along straight lines, if it would not have had this shape it would have lost shielding capability.

CZN-152 and CZS-152

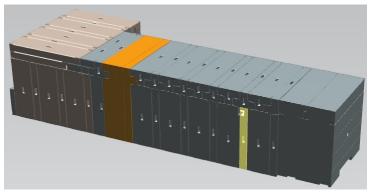
Normal density concrete blocks, placed in the North and South wall of the Downstram Cave, Z cross sectional shape.



(a) *CT4-152 position*

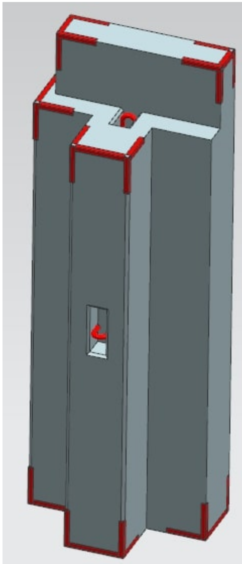


(b) *CT5-152 position*

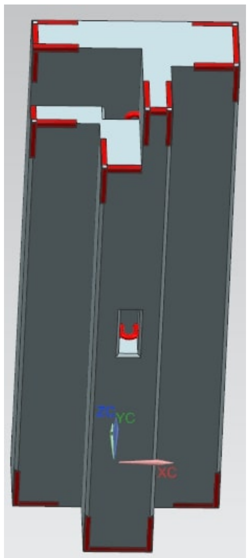


(c) *CT6-152 position*

(d) *CT4-152 details*

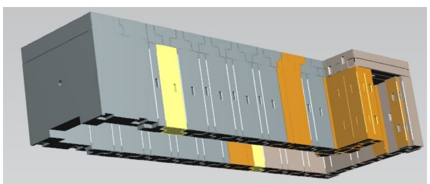


(e) *CT5-152 details*

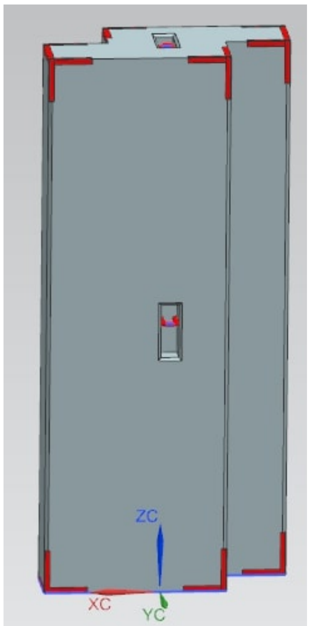


(f) *CT6-152 details*

Figure 10: South face blocks CT4-152, CT5-152 and CT6-152



(a) *CZN-152 and CZS-152 position*



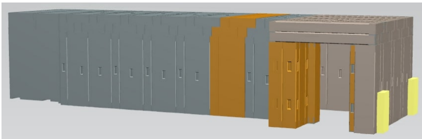
(b) *CZN-152 details*

(c) *CZN-152 details*

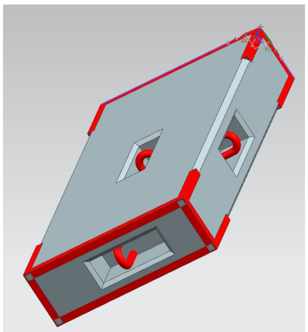
Figure 11: Z Cross section blocks

CRV-70

These small normal density concrete blocks are not used for shielding purposes but as a support for the west wall of the Cosmir Ray Veto that has to lay down on this two blocks.



(a) *CRV-70 position*

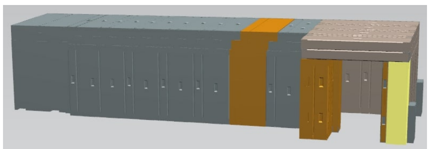


(b) *CRV-70 details*

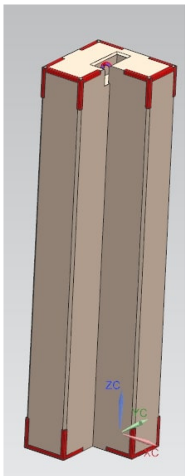
Figure 12: CRV-70

BLW-152

This is the only high density concrete block modeled during the Intern. The reason why the others high density concrete blocks have not been modeled yet is due to the fact that is still uncertain if they will be used or not because of high price with respect to normal density concrete blocks. BLW-152 is instead an important block because it has to clogs up the passage of cosmic rays that could eventually penetrate through the upstream gap through which the TSd enters the shielding, and could eventually hit the target affecting the sensitivity of the experiment and giving fake results.



(a) *BLW-152 position*



(b) *BLW-152 details*

Figure 13: BLW-152

Model Interferences

In this chapter is presented an analysis of clearances and interferences between some of the part of the experiment. The work has been accomplished using the Lifecycle viewer on Teamcenter, analyzing in detail every part of the experiment, looking for part in contact that, if not corrected, could have been resulted in serious assembly issues. Unfortunately some components are affected by rendering mistakes or are hidden because of permission issues. These particular cases will be addressed case by case.

Interferences between blocks

Zoomming in in the vicinity of two adiacent blocks is clear that a smal gap is present between two consecutive blocks in the direction of the Muon Beamline. This clearance is essential because of both building constraints and concrete tolerances. The problem actually arises because of the fact that the Downstream External Shielding is made of several different blocks but the overall dimension of the assembly is costrained by the geometry of the building and the Cosmic Ray Veto. On the other hand, is mandatory to take into account concrete tolerances due to the fact that when a concrete block stiffens, it could possibly acquire slightly different dimension with respect to what expected. Although more easily concrete blocks will be smaller than nominal dimension is mandatory to take into account the possibility that each blocks could be bigger than expected so that the overall dimension of the shielding exceed the building constraints. To take into account this situation has been decided to leave a gap of 0.5” between to adiacent blocks in the direction of the Muon beamline.

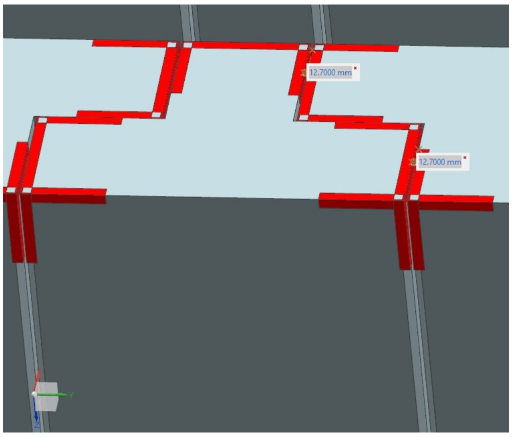


Figure 14: 0.5” gap between adiacent concrete blocks

Exception are made for those blocks of the Entrance Cosmic Suppression Shielding, that is the region close to the junction betweeen the TSu and TSd, where in order to guarantee shielding capability of Cosmis Rays the blocks are close one to each other so that no gap is present between them, Fig 15.

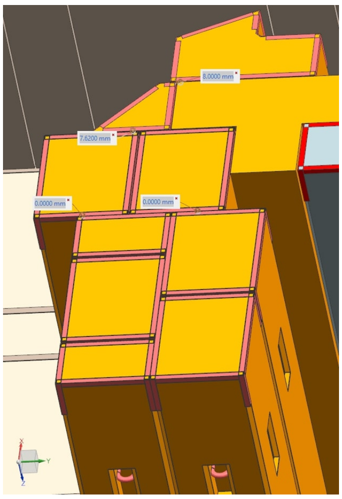


Figure 15: Blocks of the Entrance Cosmic Suppression Shielding

Another exception is present at the intersection of the Downstream Cave and the End Cap Shielding, where a bigger gap is left between consecutive blocks Fig 16.

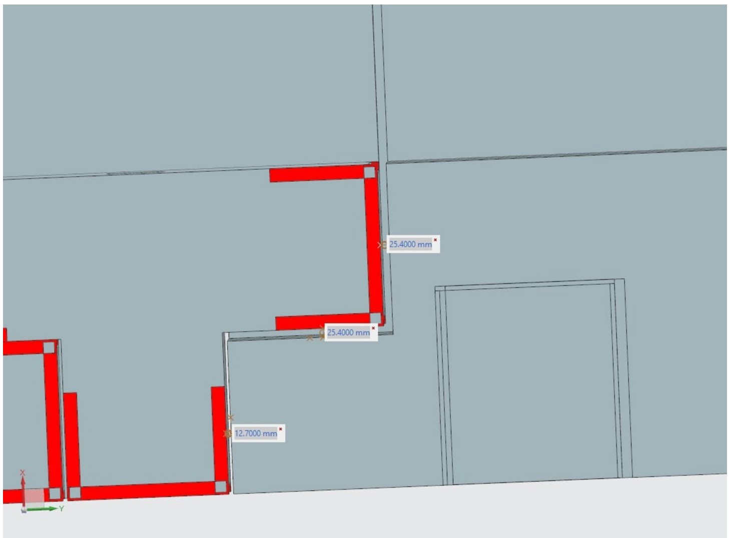
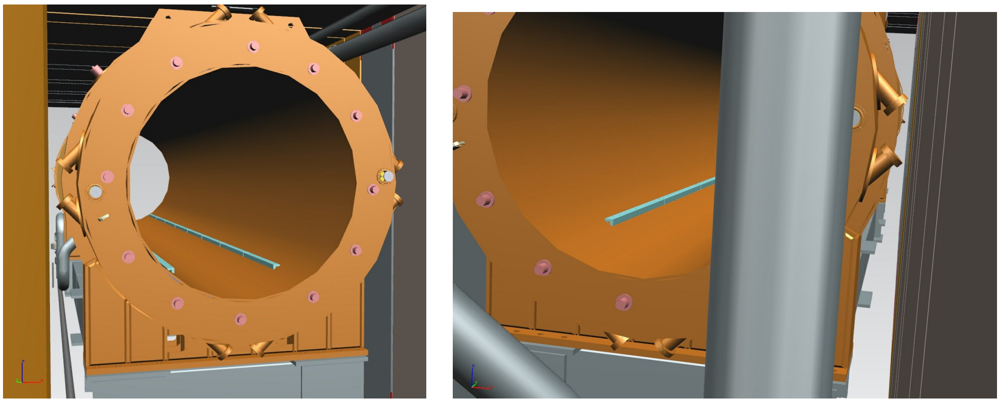


Figure 16: Gap between blocks at the interference between Downstream Cave and End Cap Shielding

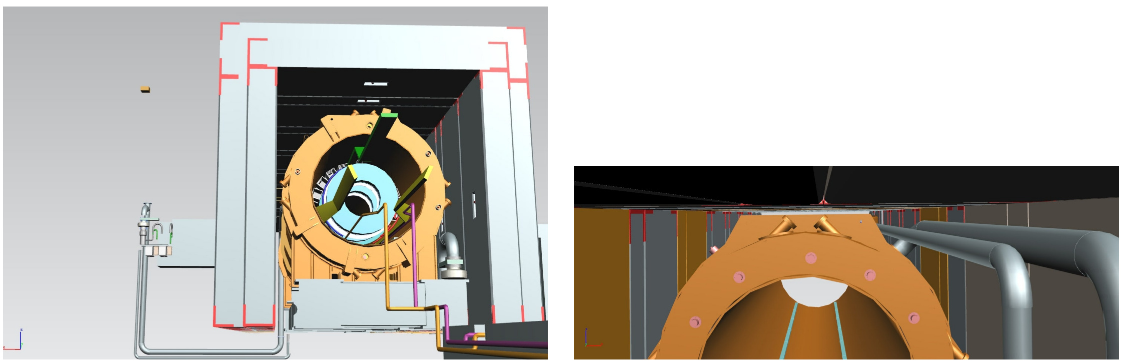
Interferences between concrete blocks and DS

Any interference has been found between concrete blocks of the Dowstream Cave and the DS.



(a) *North side* (b) *South side*

Figure 17: Interference North and South side



(a) *Bottom face* (b) *Top face*

Figure 18: Interference top and bottom face

Interferences between concrete blocks and PS

A similar check has been done also in the vicinity of the PS. Altough the Downstream External Shielding does not surround the PS, there is another subassembly, namely the Upstream External Shielding, composed of several blocks mated toghether as for the Downstream External shielding, that surrounds the PS and some part of the TSu. A top view of the Upstream External Shielding is presented in Fig 19

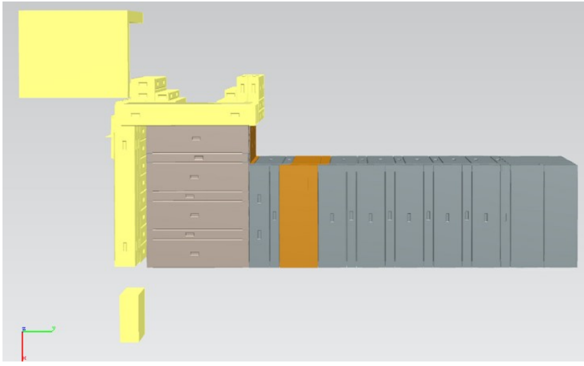
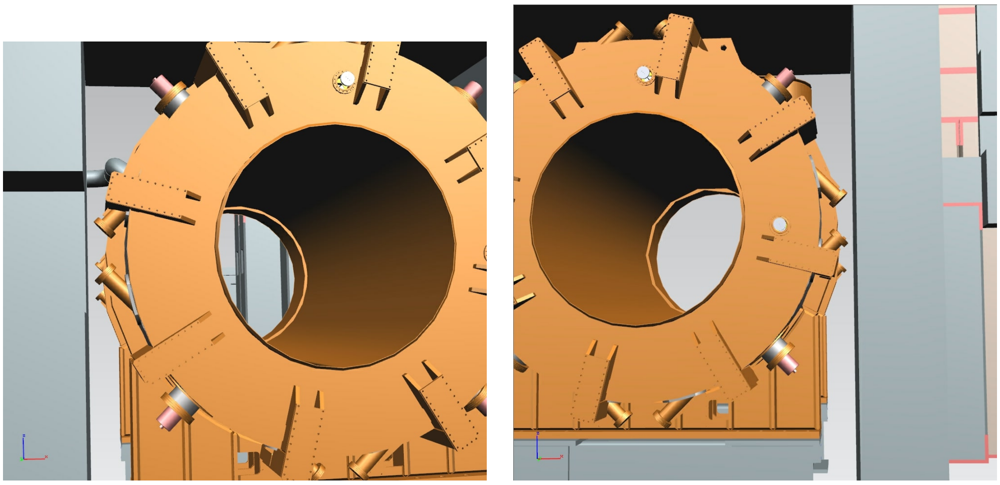


Figure 19: Upstream External Shielding highlighted in yellow

Also in this case any interference has been found between the PS assembly and the concrete blocks.



(a) *North face* (b) *South face*

Figure 20: Clearance North and South sides

In this case there is no warry about the bottom surface because the PS does not have any trench nearby and the concrete blocks lay on the floor.

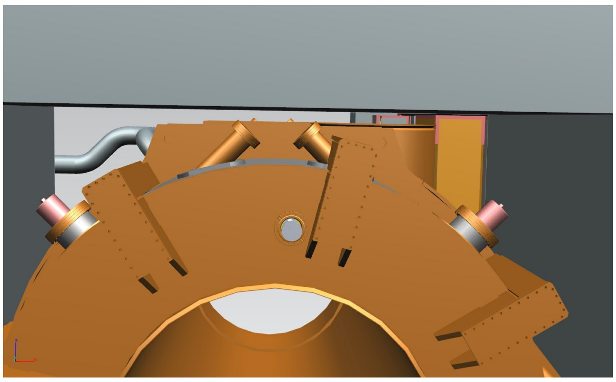
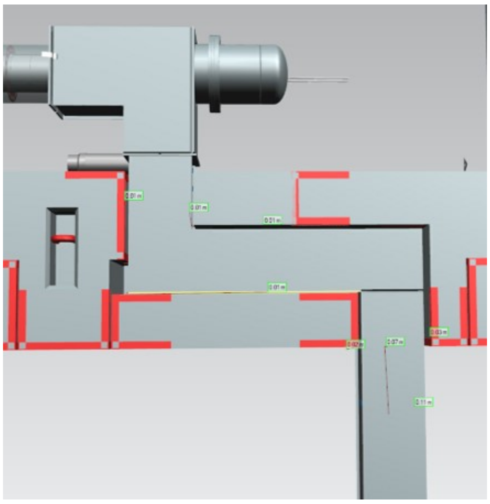


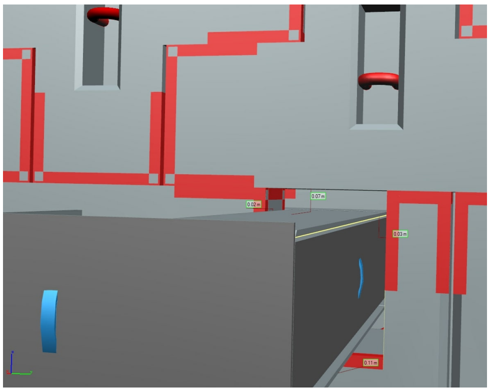
Figure 21: Clearance between the North face of the PS assembly and concrete blocks

Interferences between concrete blocks and Cryogenic System

Another possible source of interference with the concrete blocks is the Cryogenic System, with all the pipes and ducts necessary to deliver cryo fluid to the PS and the DS. The analysis af clearances and interferences has been accomplished following the same approach as for the PS and for the DS, just paying more attention in the most critycal regions. For istance deep investigation has been dedicated to the feed line passing through the thickness of the South wall of the Downstream Cave, through the CT-4, CT-5 and CT-6 blocks, directed to the DS assembly.



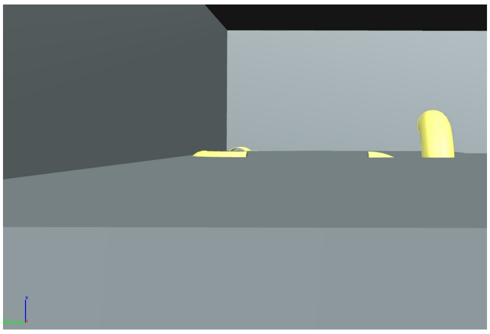
(a) *Top view*



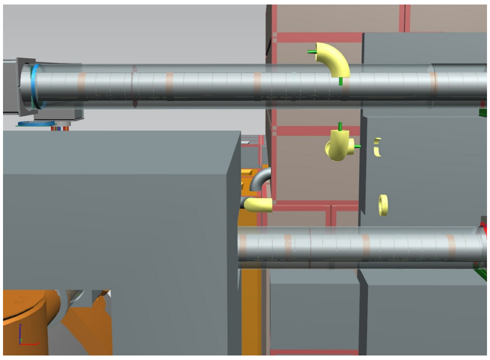
(b) *South view*

Figure 22: Clearance between concrete blocks and feed line

Similar investigation has been adopted in the vicinity of the PS where strange situations have been found. Fortunatly enough, any apparent interference resulted in a rendering mistake, as can be seen in Fig **??**



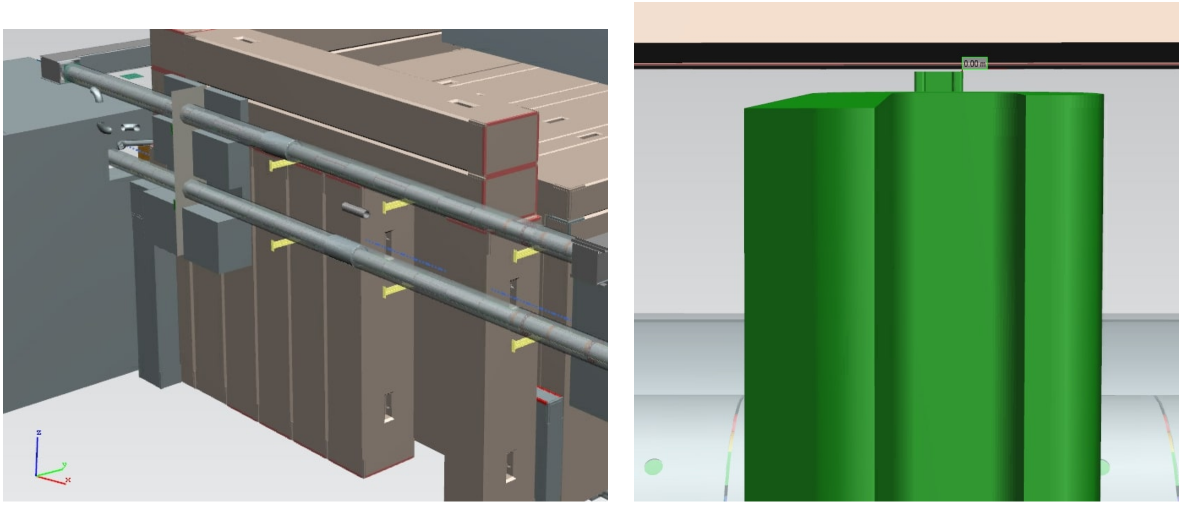
(a) *Rendering mistake*



(b) *South view*

Figure 23: Rendering mistakes in the vicinity of PS

More time have been spent to investigate the bracket needed in order to support pipes directed to the PS. Afetr a first investigation they looked like entering within the West Wall Shielding of the Upstream External Shielding. With a more detailed analyis a small gap have been found in between. Fig 24 represents the position of the brackets in the assembly (left) and the clearance with respect to the Shiedling blocks.



(a) *Position of support brackets in the assembly* (b) *Clearance*

Figure 24: Clearance between the bracket and the West Wall Shielding

The only situation that's worth noting is a hook of the Cryogenic System that looks like interfering with the bottom face of the roof's concrete block, that is the yellow hook within the blue circle in Fig 25

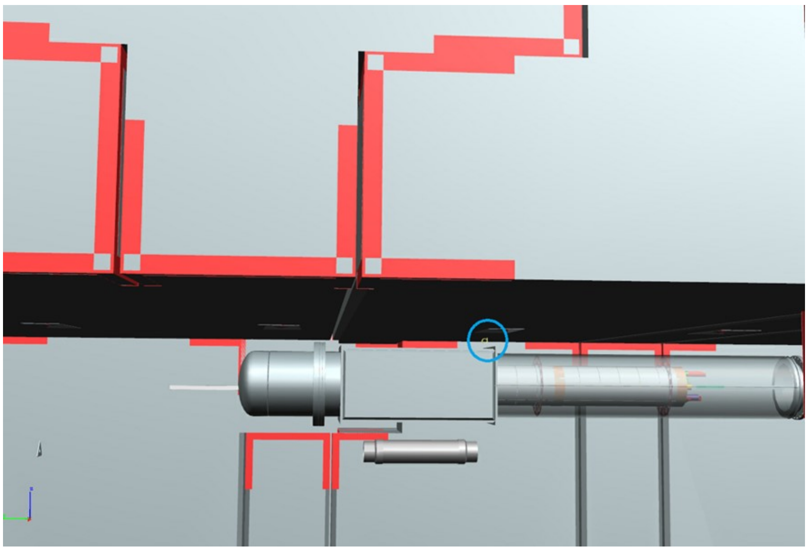


Figure 25: Interference between Cryogenic System's hook and concrete blocks

Implementation of the West Wall shielding of the Upstream External Shielding

The West Wall Shielding in question is the Westernmost wall of the Upstream External shielding placed between the West side of the Cosmic Ray Veto and the wall of the building. The request was to make up an alternative cheaper configuration made of old already existing Fermilab Concrete blocks. The baseline configuration is composed of 10 borate blocks, and so highly expensive to be manufactured, the new configuration on the other hand is made of two stacks of 12 J blocks and two rows of 6 L blocks. Although the new configuration is slightly more bulky, every blocks can be achieved for free and without the risk of delivery delay. Even if a trade of study has still to be done about which configuration is better, the advantage of saving money sounds attractive for the money budget of the experiment.

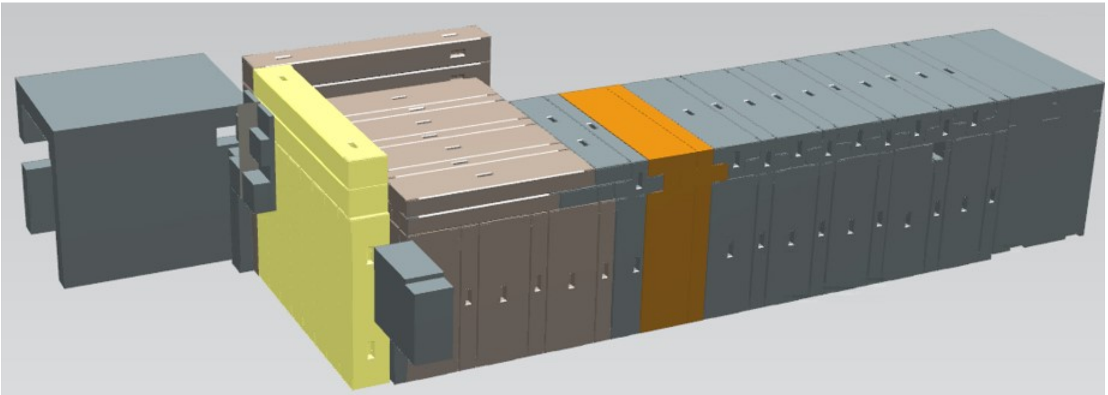


Figure 26: Position of the West Wall Shielding in the Upstream External Shielding subassembly

Baseline configuration

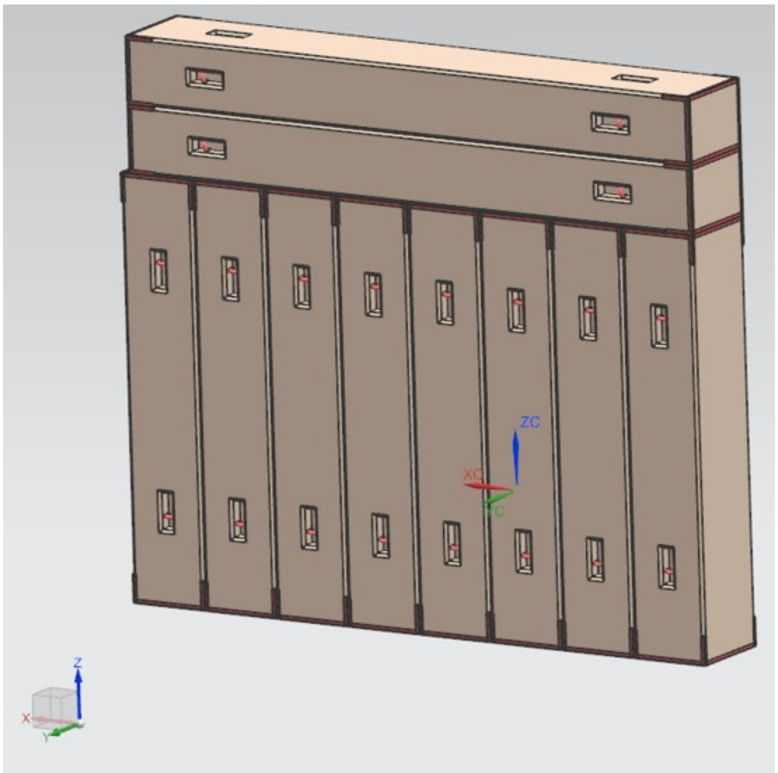


Figure 27: Baseline configuration

Alternative configuration

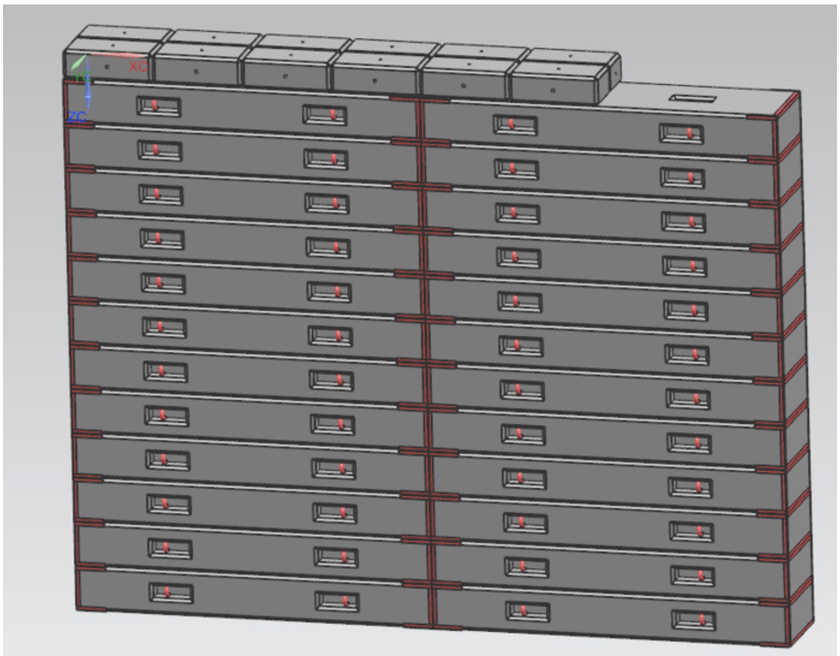


Figure 28: Alternative configuration

Pushing-Pulling mechanism for the End Cap Shielding

Another task accomplished during the Intern was to place in proper position and orientation, the adaptor plate for the Pushing-Pulling Mechanism necessary for moving the End Cap Shielding. The system is Hydraulically actuated and is supposed to move the End Cap Shielding back and forth. The mechanism is designed in such a way that the line of force is 4.75" height with respect to the floor. Unfortunately, the elevation of the bottom surface of the last concrete block of the End Cap Shielding (namely CU2-194) is heigher (152.4 mm=6") than the line of force of the actuation system (4.75"). The consequence of the lack of the matching between the two make impossible for the End Cap Shielding to move and it is not accettable.

Figure 29: Gap between the line of force of the pushing pulling mechanism and the bottom surface of CU2-194

Further modification of the height of the blocks are therefore necessary. The choice taken was to modify the height of each of the four normal density concrete blocks composing the walls of the End Cap Shielding (namely CU-194, CU1-194 and CU2-194) so as to use the same form for all the four blocks obtaining holes and pockets by means of plastic or wooden forms embedded case by case within the primary form. This procedure would save the cost of manufacturing four different forms but is therefore necessary that all the blocks have the same external dimension. In accordance with that, the height of the four blocks has been modified taking into considerations two parameter:

- the clearance between the bottom surface of CU2-194 and the floor
- the relative position of the hole

Has been decided to leave a clearance of 2.5" between the blocks and the floor: this gap is necessary to take into account the series of tolerances due to concrete stiffening. Also in this case the overall dimension of the wall of the End Cap Shielding are fixed and would be unacceptable to have a wall bigger than the maximum available dimensions. The other parameter to take into consideration is the relative position of the hole: it must be exactly centered with the line of sight of the Muon Beamline. It's worth noting that also in this case, taking into account tolerances consideration, it has been decided to manufacture a hole bigger than the nominal dimension and finally to adjust the dimension using a plastic insert that guarantee the centering of the hole.

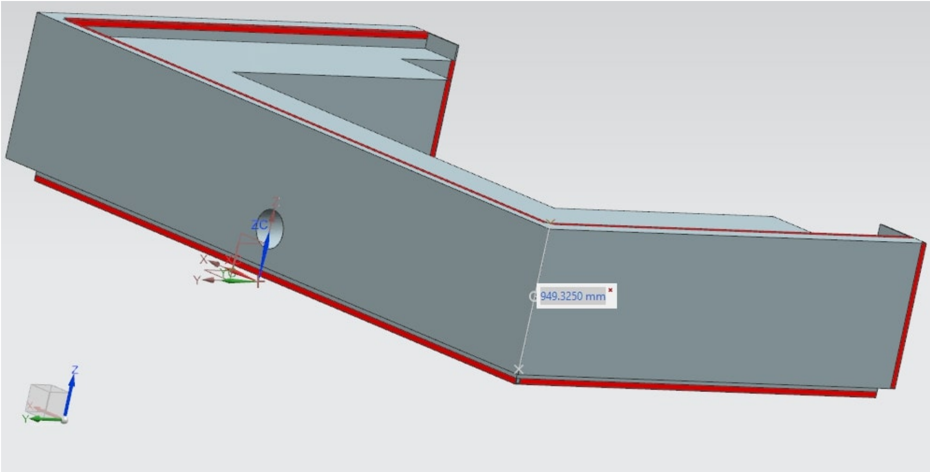


Figure 30: New dimension of CU1-194 with hole centered with the line of sight

The Pushing-Pulling Mechanism is connected with the CU2-194 by mean of a klevis bracket, which is bolted to a steel adaptor plate embedded within the concrete structure. The dimension and geometry of the adaptor plate have been decided by the designer of the mechanism.

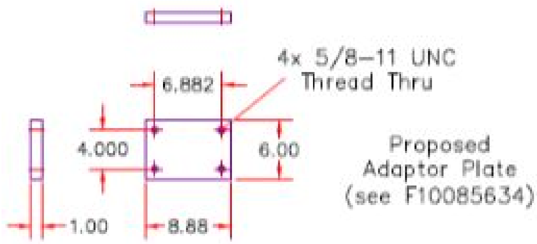
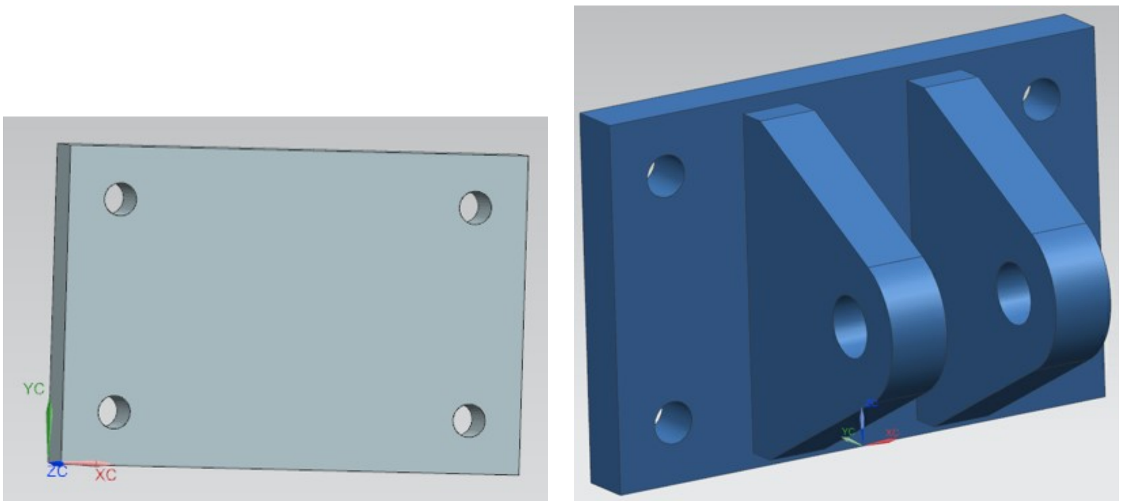


Figure 31: Dimension and geometry of the adaptor plate

The centering of the adaptor plate in the proper position in necessary for the mechanism operation, since the force should be transmitted through the klevis and the adaptor plate itself,connected by mean of 4 bolts, to the concrete blocks.



(a) *Adaptor plate*

(b) *Klevis bracket*

Figure 32: Force transfer mechanism, adaptor plate and klevis bracket

DS Trench Grating Corner Plate

This task involved adding into the 3D CAD model a component that was already manufactuerd and put into position within the building but that was not yet inserted into the 3D CAD model. This component is essentially a steel plate, placed at the crossover between the North-South DS trench and the West-East DS trench. The goal of this component is to provide a support for the cover plates, that is a series of rectangular plates (following figure) whose longitudinal dimension is a couple of millimiters less than the width of the trench. Those plates are necessary to cover the trench so as it's possible not only to walk but also to assembly the experiment and to move staff as if the trench would not exist. Each plate lays on stell support that are specifically obtained and cured into the concrete floor. A problem arises at the crossover between the two DS trenches, where the plates miss a support on the South face, fig 33, part. 9. That's why the DS Trench Grating Corner Plate has been introduced, so that also the plates at the crossover have a support.

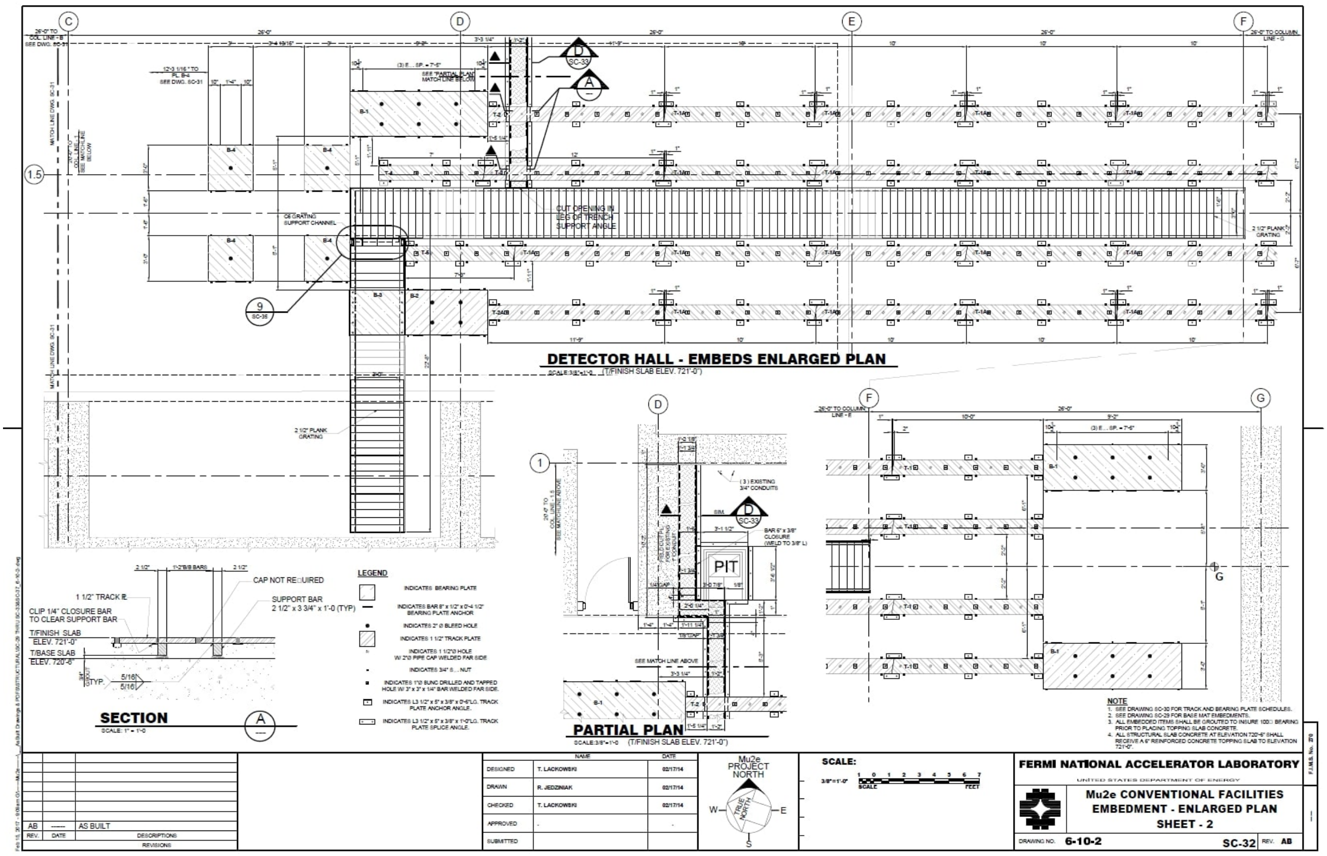


Figure 33: Position of the DS Trench Grating Corner Plate, docdb 11669, SC-32

The DS Trench Grating plate is made of three parts joined together in a rigid way. The main structure is a C-channel, with the web facing the bottom surface of the trench. A steel cover plate is welded on top and three small stiffening panels are welded between the C-channel and the cover plate. Finally, four bolts, two on each side, get rid of the last degree of freedom with respect to the floor keeping the plate rigidly anchored to the floor.

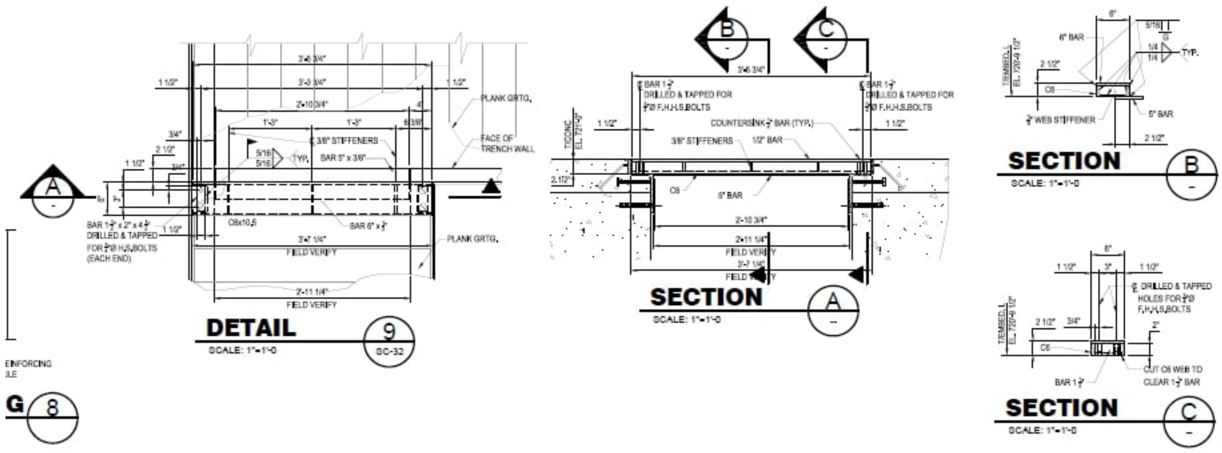
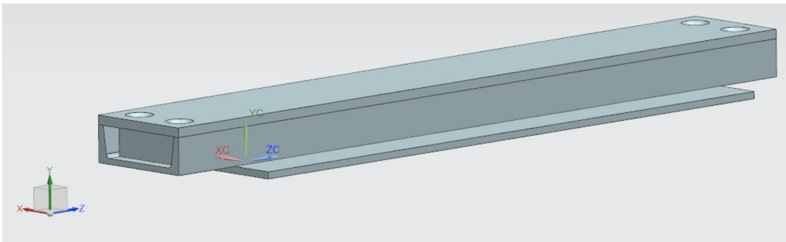
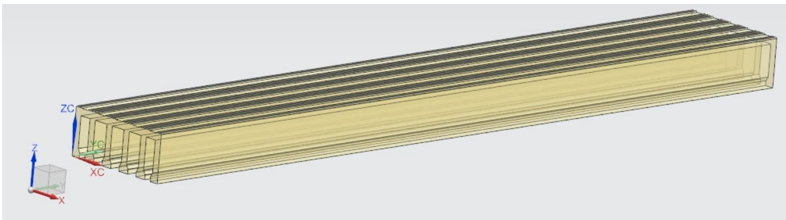


Figure 34: Particular drawings of DS Trench Grating Corner Plate, docdb 11669, SC-35, details



(a) *3D Model of the DS Trench Grating Corner Plate*

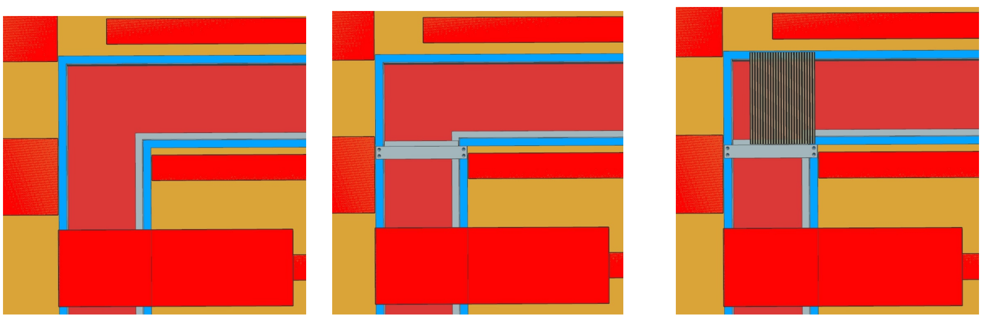


(b) *Cover plate*

Figure 35: 3D Model of the DS Trench Grating Corner Plate and cover plate

This part has been implemented not only to have the 3D model fully defined but also to let other teams know how big is the gap between the standfoot of th IFB and the upstream cover panel of the trench trough which all the cables, that is wires and fibers, have to pass.

As can be seen in Fig 37 just from a first rough investigation some unaccaptable interferences come to light.



(a) *Trench crossover* (b) *Trench crossover and DS trench grating* (c) *Trench crossover and cover plates*

Figure 36: Trench Grating Corner Plate

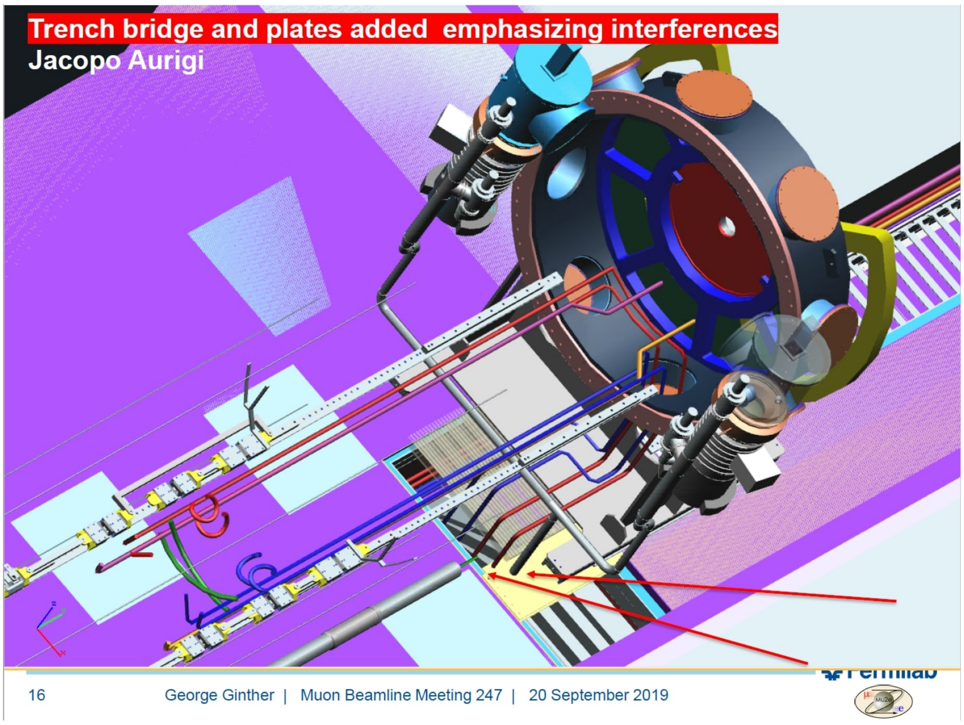


Figure 37: Some interferences come to light after inserting the cover plates and the DS Trench Grating Corner Plate into the model

IFB Cable Placeholder

Another work done during the Intern was about designing a new more realistic version of the IFB Cable Placeholder, that is a new envelope of all the cables coming out from the Instrumentation Feedthrough Bulkhead. The previous cable placeholder, as seen from a downstream view, is shown in Fig 38

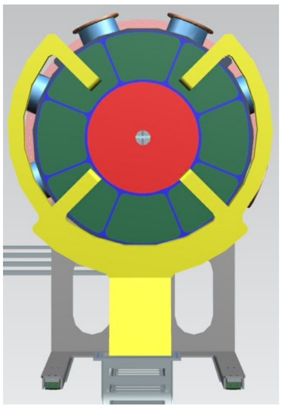
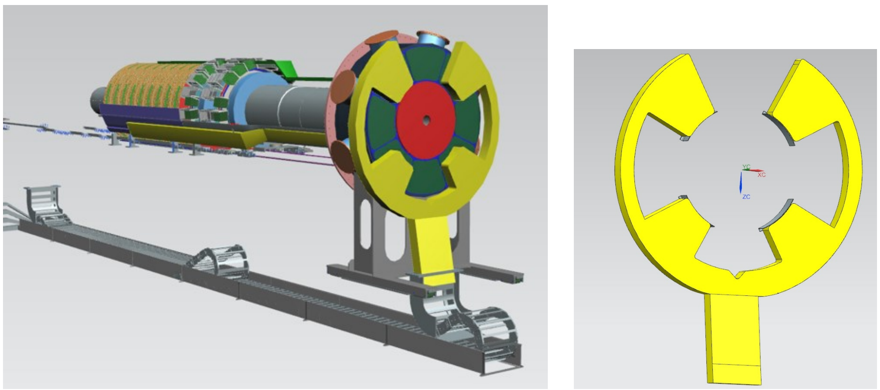


Figure 38: Downstream view of the old version of the IFB Cable Placeholder and of the downstream face of the IFB

The yellow part is the envelope of all the cables coming out from the rear face of the IFB. It was required to design a more realistic configuration showing how actually the cables, that is wires and fibers, coming from the tracker and the calorimeter, get collected once came out of the IFB. All the wires come out from the four green panels placed, with respect to normal geographic convenction, at NE, NW, SE and SW while the other four green panels and the red central panel are not designed for cables gathering. On the other way it's important that the envelope of the cables does not intersect the normal direction of the panels cited above, by the moment that they are willing to be pulled out. The four green panels have to be pulled out for guarantee a perfetc alignement of the instrumentation within the DS bore,the red panel instead has to be temporarily removed because it covers two trunnions embedded in the structure of the IFB, necessary for the assembly of the Muon Beam Stop. So the new configuration had to cater to the above requirements, and moreover to show a more realistic shape of the cables.
In order to prevent cables unplugging during pulling out the panels, it has been decided to add some double curvature steel brackets as a protection for the cables, one for each panel. Each bracket will be bolted to the structure of the IFB. There is no need to make hole in the structure of the IFB that already present some bolts in the required position. The idea is therefore to use the same bolts to joint also the above protection brackets. In Fig **??** is shown the position of protection bracket with respect to the cables.



(a) *South-East view*

(b) *Relative position of protection brackets with respect to the cables envelope*

Figure 39: Up-to-date version of the IFB Cable Placeholder and Protection bracket

Conclusion

During the 9 weeks spent at Fermilab I accomplished many task all of them involved with the Mu2e System Integration. I finally realized that my training Programm was deeply different from the training programs of the other guys of the project. Many of them had what I would define an ”Academic training program”, that is listening to their presentation it sounds like they had a problem and two months of time to solve it, like a project at University. On the other hand I found my training program more challenging because I was involved in team and I not only had to solve problems and carry-on the project, but I also experimented what team-working really is.
My learning process passed through a CAD software NX and the database of the project Teamcenter, through which I acuatually did all my work. Anyway another great part of the learning process went through all the meeting atteinded, that is Muon Beamline meeting, Mechanical Integration meeting and Mu2e Tool Box meeting, as well as consultation with senior engineers and experts.
I am sure the hard and soft skills acquired in direct and indirect manner during the Internship will turn very useful in my future experiences.
Last but not least, I took advantage of my staying at Fermilab for travelling around the USA during week-ends, so as to get in contact with the many and different American cultures and enlarge my cultural backgrounds.