FACILITING MU2E INTEGRATION VIA THE 3D CAD MODEL

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CONTENTS

ABSTRACT

The purpose of my Fermilab Summer Student has been the verification and improvement of aspects of the 3D CAD model of Mu2e. The principal tasks done have been the following:

- Add new components in the 3D CAD model existing to facilitate integration.
- Verify locations and dimensions of various elements.
- Control and refine the 3D CAD model of the Mu2e installation.
- Investigate/explore and where possible resolve interferences.
- Arrangement of the 3D CAD model of the Detector Support and Installation System.
- Contributions to the concept design of Calorimeter services.

Furthermore, I cooperated with my supervisor in the co-ordination of the 3D CAD files management of groups working on Mu2e experiment. I also

addressed shortcumings of the model as presented in the Lifecycle Viewer, a tool in which provides overview of the model.

1 INTRODUCTION

The purpose of the Mu2e experiment at Fermi National Accelerator Laboratory (Fermilab) is the search of the neutrino-less coherent conversion of muons into electrons in the electric field of an aluminium nucleus. The discovery of this physics process would demonstrate the existence of physics beyond the Standard Model. The experiment core consists in three Superconducting Solenoids Fig. 1:

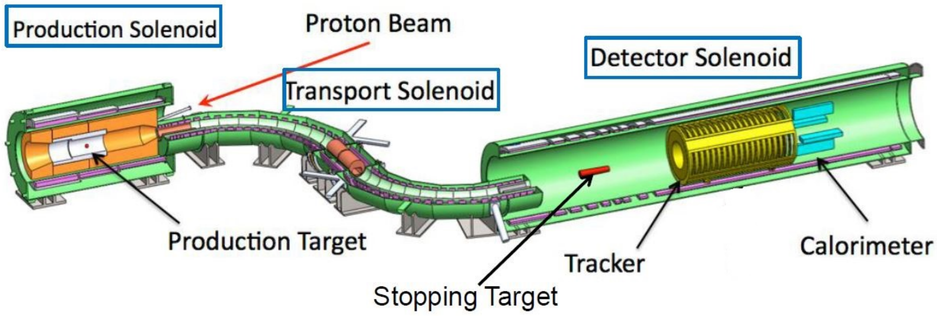

Figure 1: The Mu2e superconducting solenoids.

- **Production Solenoid (PS)** - 4m long x 1.5m diameter.
- **Transport Solenoid (TS)** - 13m long x 50cm diameter; S-shape to move the detector solenoid out of the line of sight from the production solenoid (suppresses neutrons and gammas produced at the production target entering the detector solenoid).
- **Detector Solenoid (DS)** - 11m long x 2m diameter

Inner bore evacuated to:

- 10^{-5} **Torr** in the Production Solenoid, and upstream half of Transport Solenoid.
- 10^{-4} **Torr** in the Detector Solenoid, and downstream half part of Transport Solenoid.

Below there is a brief description of the experiment operation:

- A pulsed proton beam hits the production target to produce pions which decay into muons.
- The muons get transported via the transport solenoid to the detector solenoid where some stop in the aluminium stopping target.

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- If conversion electrons are produced in the stopping target, they will move through the tracker to the calorimeter (measure momentum in tracker and energy in calorimeter)

2 ARRANGEMENT OF MUON BEAMLINE

The fundamental goals of the muon beamline are to deliver a stopped muon rate of approximately 10^{10} per second to the muon stopping target, located in the Detector Solenoid (DS), and to reduce the background in the tracker, calorimeter and cosmic ray veto detectors to a level sufficient to achieve the desired experimental sensitivity.

The changes made primarily relate to two submodels of the Muon Beamline 3D CAD model shown in Fig. 2

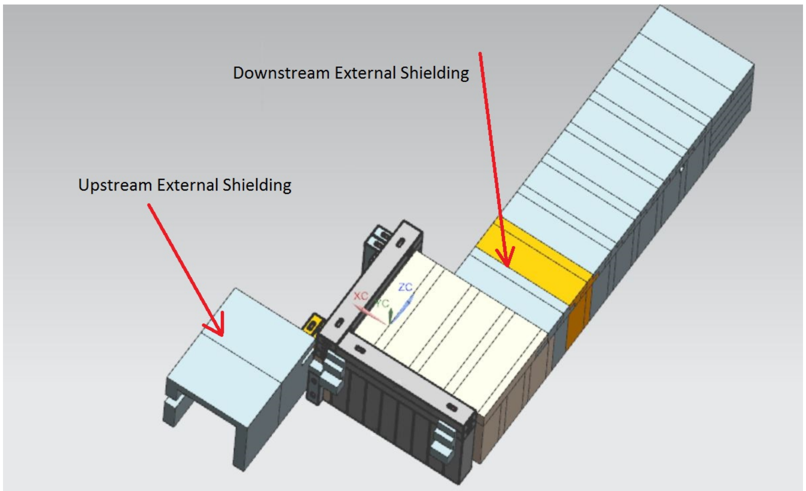

Figure 2: Downstream and Upstream External Shielding

- Downstream External Shielding.
- Upstream External Shielding.

2.1 Downstream External Shielding

Shielding needs to be placed around the downstream Transport Solenoid and the Detector Solenoid. The main requirements for the shielding are as follow:

- Reduce the neutron and gamma background generated by muon stops incident upon the Cosmic Ray Veto (CRV) Counters.
- Provide a base for support CRV modules.

Material requirements depend upon a number of factors:

- Shielding performance
- Mass of the components

- Forces induced by effects of the solenoid magnetic field on the steel renforcement bars
- Capacity to support CRV modules

To suppress backgrounds generated by cosmic ray muons incident through TS aperture, additional blocks have been added and a few blocks have been repositioned.

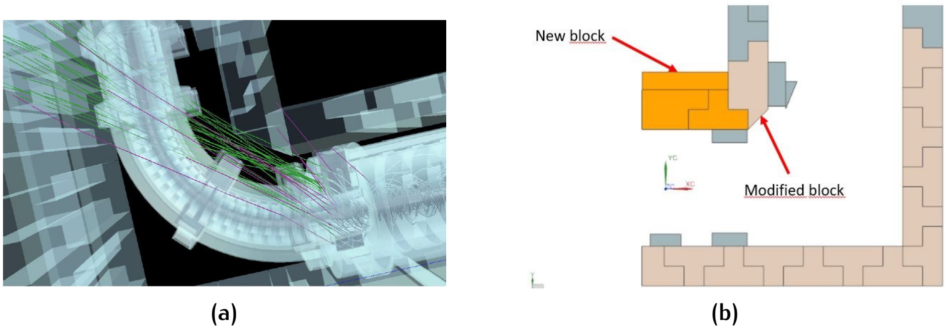

Figure 3: a) Cosmic Background in the TS gap b) Modified done to suppress backgruond

Furthermore, the labyrinth in the DS external shielding has been modified to allow the installation of the transfer line because the dimensions of that transfer line had been increased since the time the shielding was originally modeled.

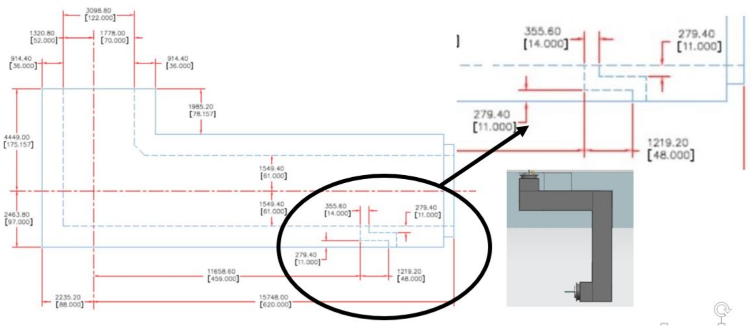

Figure 4: Current cavity dimensions

The downstream External Shielding wall is made by T-shape concrete blocks, since the transfer line will be installed before the wall, an important thing to consider is the installation process of the T-blocks to build the wall. In the Fig. 5 below is shown our idea for the blocks installation sequence:

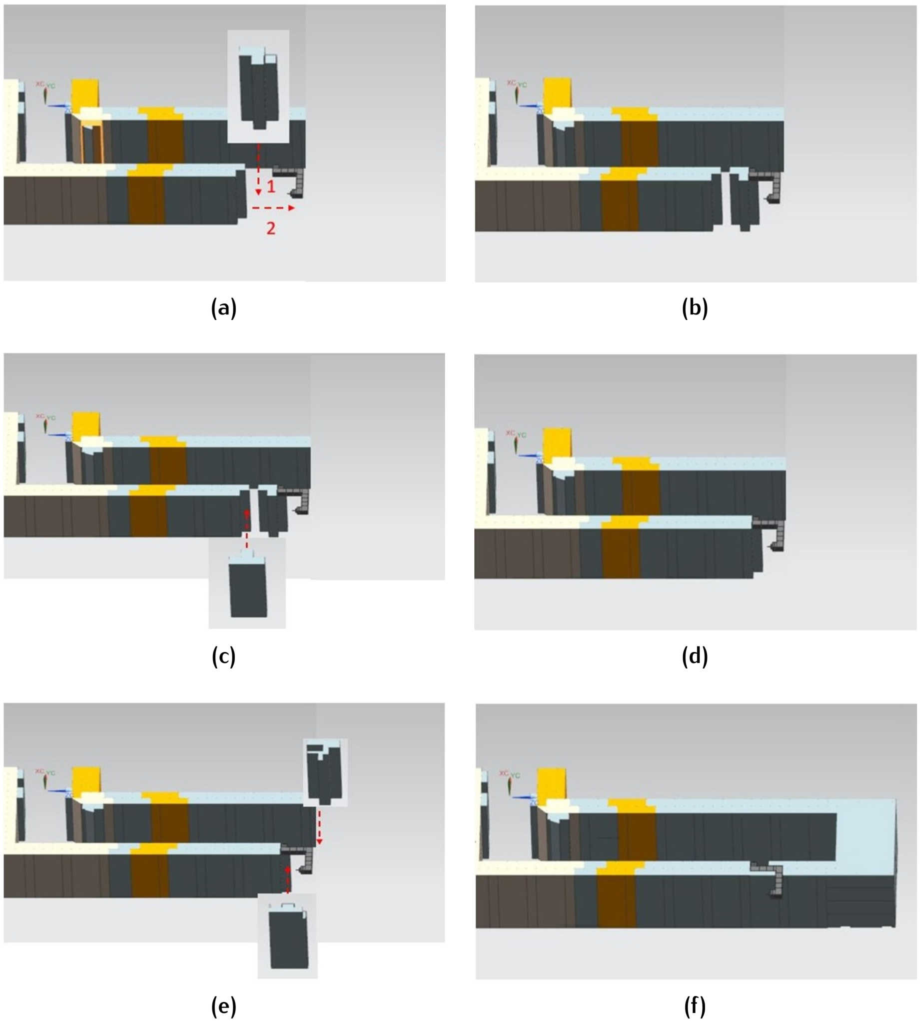

Figure 5: Cronological sequence of T-blocks installation

2.2 Upstream External Shielding

The upstream external shielding of the Muon Beamline surrounds the Production Solenoid and isolates the primary proton beamline from the Detector Solenoid hall while shielding the Cosmic Ray Veto (CRV) from radiation generated at the production target located in the Product Solenoid and resulting from the secondary beam transported by the upstream Transport Solenoid. The primary purposes of the Upstream External Shielding are:

- Shield the Mu2e detector.
- Reducing the rate of neutron and gamma impinging on the CRV to an acceptable level.
- Isolate the primary proton beamline from the downstream muon beamline, dividing the lower level of the Mu2e Experiment Hall into two independent zones.

On this submodel I ressigned the material of the various blocks and modified the shape of the PS External Shielding to reflect the current plan and eliminate interferences. As shown in Fig.6 there are three different types of concrete used in this version:

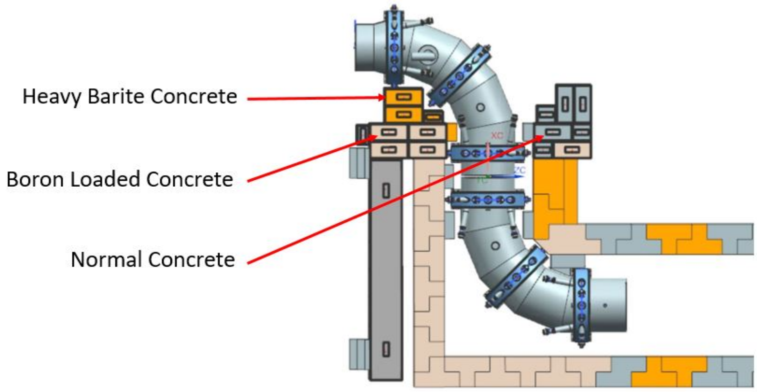

Figure 6: Downstream and Upstream External Shielding with indicated the various type of concrete used. It's also shown the Transport Solenoid

- Normal Concrete
- Boron Concrete
- Heavy Barite Concrete

The choice of material is developing yet, but the main concept beyond this choice is to shield the CRV to facilitate the efficient operation of those detectors.

3 DETECTOR SUPPORT AND INSTALLATION SYSTEM

The detector support and installation system is required to transport and align components within the Detector Solenoid warm bore, and facilitate access to these components for servicing. The muon stopping target, proton absorbers, tracker, calorimeter, and muon beam stop form the detector "train" and must be transported accurately and safely into position and aligned with respect to the standard Mu2e coordinate system. These components will be supported by the inside wall of the Detector Solenoid cryostat. In this part I worked on the arrangement of all the detector train 3D CAD model.

3.1 Detector Train components

3.1.1 *Muon Stopping Target*

The muon stopping target is a central component of the Mu2e experiment. Interactions in the stopping target cause energy loss and the capture of the beamline muons after they enter the DS. The stopped muons form muonic atoms in the stopping target, where they can potentially undergo neutrinoless conversion of muons to electrons. The stopping target design goal is to maximize the number of stopped muons while minimizing the amount of material traversed by conversion electrons that enter the acceptance of the downstream detector. The stopping target is shown in Fig.7, the muon stopping target support structure will be mounted on custom adjustment mechanisms mounted to four blocks riding on the detector rail system, this support adjustment mechanism is explained in a section below 3.2.5

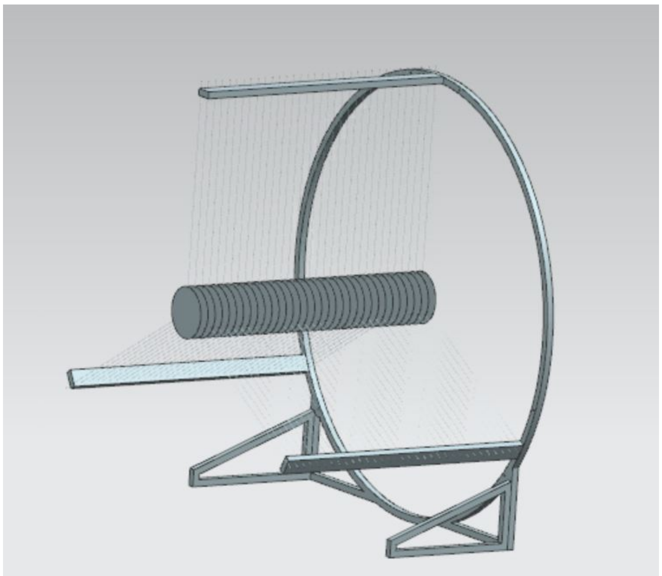

Figure 7: Muon Stopping Target with support structure

3.1.2 *Proton Absorbers*

A collection of absorbing materials is placed inside the DS warm bore to suppress the rates of protons and neutrons. Excessive amounts of these particles will result in undesirable backgrounds in the tracker. Both proton absorbers consist of HDPE (high-density polyethylene) surfaces of revolution aligned along the axis of the DS bore. The OPA is conical, smaller at the upstream end and larger at the downstream end. The IPA is cylindrical. The OPA surrounds both the IPA and the muon stopping target Fig.8

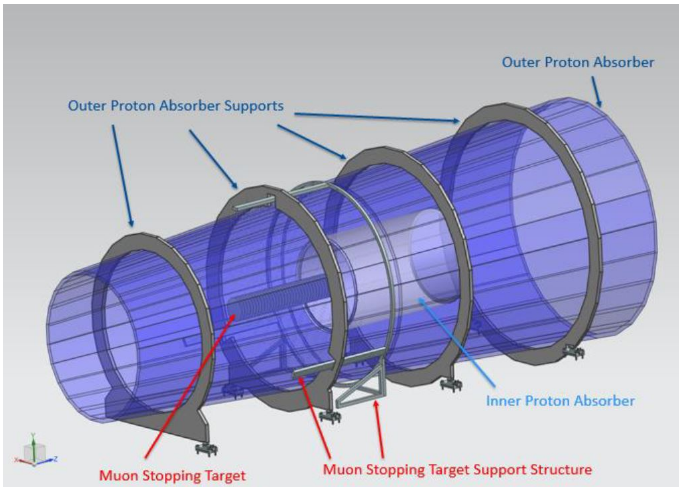

Figure 8: Illustration of the Muon Stopping Target and the Inner and Outer Proton Absorbers with the adjustment mechanisms

The proton absorber support structure will be mounted on custom adjustment mechanisms on eight bearings blocks riding on the detector rail system 3.2.5. Laterally, only the four bearing blocks on one side will be adjustable during alignment (and then locked), while the other side will float freely. The bearing blocks will include features to facilitate longitudinal connections to the surrounding Muon Stopping Target and tracker support structures.

3.1.3 *Tracker*

The Mu2e tracker provides the primary momentum measurement for conversion electrons. The tracker must accurately and efficiently identify and measure 105 MeV/c electrons while rejecting backgrounds. The Tracker detector support structure will be mounted on custom adjustment mechanisms on four bearings blocks riding on the rail system 3.2.5. Laterally, both bearing blocks on one side will be adjustable (in X) during alignment (and then locked), while the other side will float freely. The bearing blocks supporting the Tracker will provide features to facilitate longitudinal connections with the Proton Absorber and with the Calorimeter.

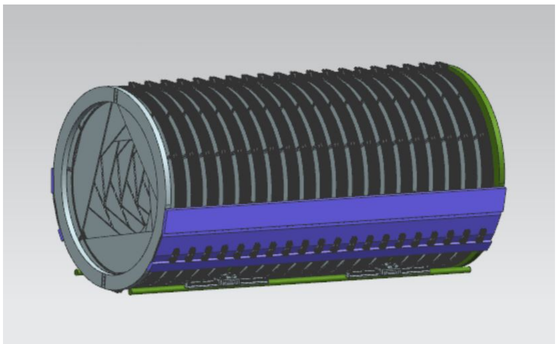

Figure 9: Tracker

3.1.4 *Calorimeter*

The design of the Mu2e detector is driven by the need to reject backgrounds to a level consistent with a single event sensitivity for $\mu \to e$ conversion of the order of 3×10^{-17} . The calorimeter system is a vital link in the chain of background defenses. Thus a primary purpose of the Mu2e calorimeter is to provide a second set of measurements that complement the information from the tracker and enable us to reject background due to reconstruction errors. The calorimeter consists of two disks, each disk is housed in a support structure. As are the other detector train components, the calorimeter support structure will be mounted on four bearings blocks fitted with custom adjustment mechanisms to accommodate adjustment in elevation and side to side. Laterally, only the two bearing blocks on one side will be adjustable, while the other side will float freely. The bearing blocks provide features to allow longitudinal connections with the Tracker and with the Muon Beam Stop.

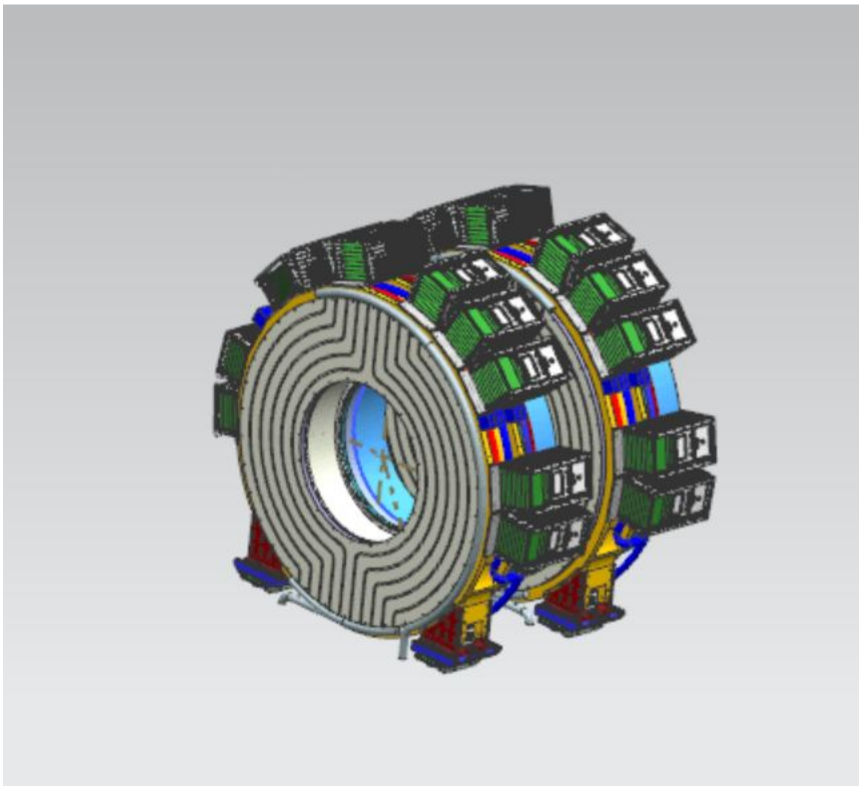

Figure 10: Calorimeter

3.1.5 *Muon Beam Stop*

The muon beam stop (MBS) will be located within the bore of the DS, and is designed to absorb beam particles that reach the downstream end of the solenoid while minimizing the background to the upstream detectors resulting from muon decays and captures in the beam stop. The upstream (spherical) support for the muon beam stop will be mounted on bearings blocks riding the detector rail system. The bearing blocks provide features to accommodate longitudinal connections to the Calorimeter. During initial installation, the downstream end of the Muon Beam Stop will be mounted on a temporary support using four additional bearing blocks. Once the initial assembly of the detector train is complete, the support of the downstream end of the Muon Beam Stop will be transferred to trunnions which are integrated into the Instrumentation Feedthrough Bulkhead and are captured by the pockets on the downstream end of the Muon Beam Stop.

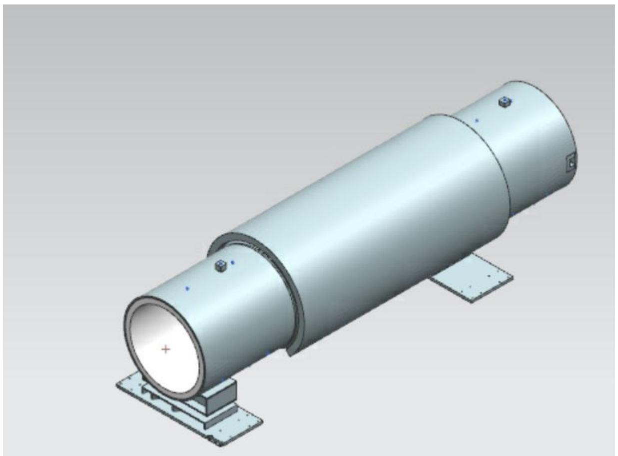

Figure 11: Muon Beam Stop

3.2 Detector Train Installation

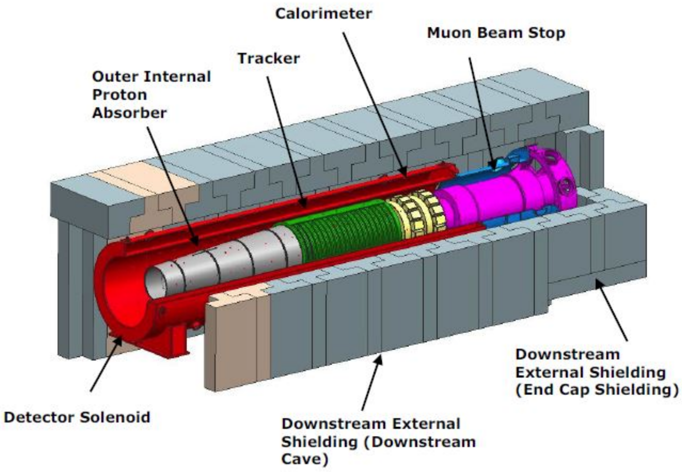

Figure 12: Location of the various elements inside the DS bore

The components are supported by two rails and transported on linear ball bearings. Two separate rail systems will be implemented, the "internal" and "external" systems. Once installed, the alignment of all components will be maintained by the internal rail system. Fig.12 shows the components inside the Detector Solenoid bore supported by the internal rail system, while Fig.13 shows the components on the external system (or staging area) before insertion into the Detector Solenoid.

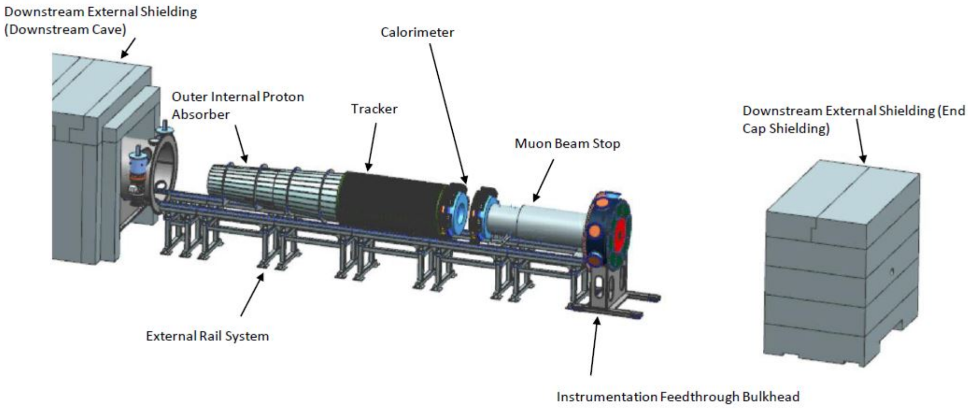

Figure 13: Detector components positioned on the external rail system.

3.2.1 *Internal Rail System*

Each component is enclosed within an individual support structure. The support structure for each component will be mounted onto the rail system and aligned to the Detector Solenoid cryostat inner wall independently in the vertical (Y) and lateral (X) directions. Vertical and lateral adjustment of components will be done using the adjustment mechanisms illustrated below. The rails will be shimmed/aligned via the 2nd tier bars and attached to stainless steel support platforms that are welded onto the inside wall of the DS cryostat. The rails and the cryostat wall will support the weight of each component, allowing all alignment criteria to be achieved. The rails and bearings are made exclusively of non-magnetic components.

3.2.2 *External Rail System and IFB*

The external rail system is positioned outside of the Detector Solenoid as the detector train is extracted and is used to support the detector train during servicing, and to move components into position inside the DS warm bore for operation. The external rail system consists of six stands. The external stands are made of aluminum, each with sections of rails mounted to the top surface that can be connected and disconnected accurately. The rails will be identical in cross section to those used for the internal system, and the last stand, closest to the cryostat, will be attached to the internal system during installation. Cables, fibers, cooling tubes and source tubes from the tracker and calorimeter will be installed and attached to the Instrumentation Feed-Through Bulkhead (IFB) before moving the entire assembly, including the detector components, into position. Once the services have been connected and routed, the detector train will be rolled into position in the DS bore. The externals stands will be removed sequentially to allow the train to be inserted. Both the IFB and the End Cap Shielding are supported and rolled on Hilman rollers Fig.14

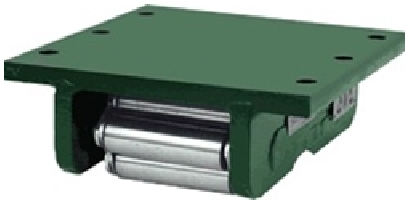

Figure 14: Exemple of Hilman rollers used

3.2.3 *Space allocated to support and installation system*

The total volume that is allocated to the various detector elements, to avoid interference between any of the components, in the longitudinal direction and in cross section, are shown in Fig.15 and Fig.16, respectively. In Fig.15 is also shown the locations of bearing blocks that reduce strength and deflection in static condition to meet the accurancy required.

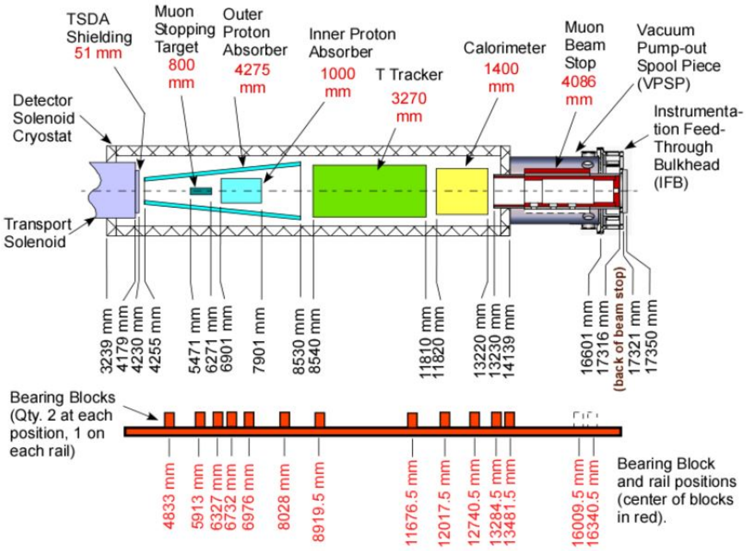

Figure 15: Lenghts and longitudinal positions of components and locations of bearing blocks

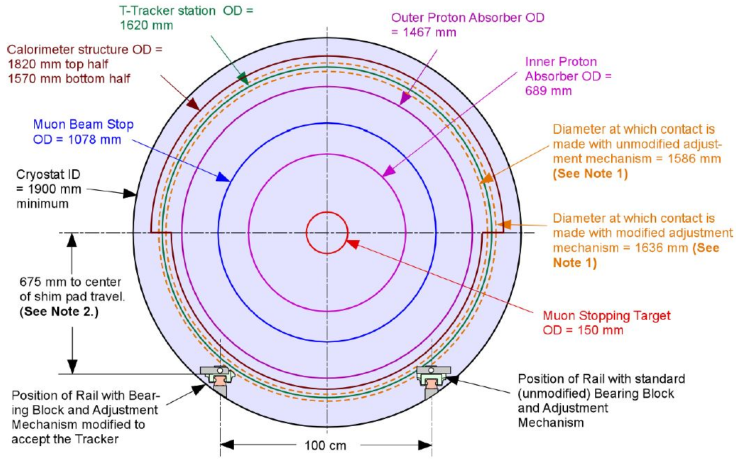

Figure 16: Cross section of the volume devoted to the various components and devoted to the detector support system

3.2.4 *Spacing and positioning of structural support*

Supports for the rail mechanism must be designed such that the DS bore can support the loads without unacceptable deflection or risk to the cryostat structural integrity. Fig.17 shows an illustration of one of the supports, with rails and linear bearings included. Although the stainless steel rail platform will be welded to the cryostat wall, the linear rail can be shimmed or adjusted as needed (using the 2nd tier bar) and bolted to this base to achieve the appropriate alignment.

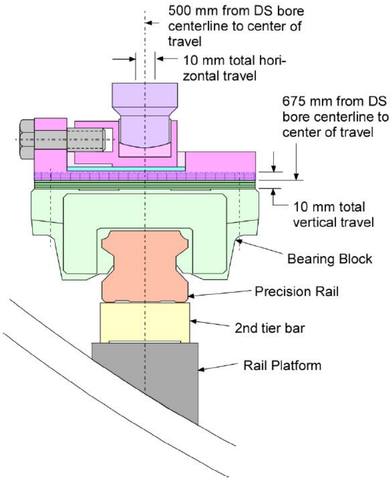

Figure 17: Cross section view of the internal rail system assembly

3.2.5 *Adjustement mechanisms*

Vertical (Y) and lateral (X) adjustment of detector support structures will be accomplished with the custom adjustment mechanisms. Lateral adjustment is accomplished with a screw mechanism, which is locked once the adjustment is complete. Vertical adjustment is achieved by shimming between the bearing block and the adjustment mechanism. The full range of adjustment is 10 mm in both the horizontal and vertical directions. Mechanisms like that shown in Fig.18 will be used for all components except the Muon Beam Stop and the Calorimeter. All bearing blocks under a component will adjust vertically (in Y) by shimming. Only the bearing blocks riding on one rail will be adjustable laterally (and then fixed), while the bearings on the other rail will float freely, using a low-friction "DU bearing material" as the slip plane.

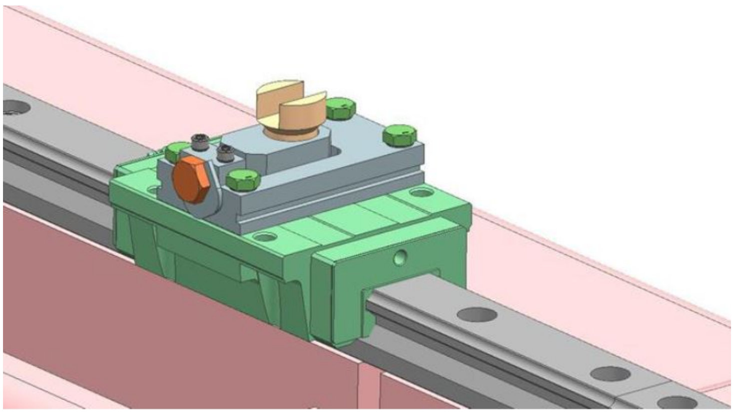

Figure 18: Custom adjustment mechanism mounted on a bearing block on the rail system.

3.2.6 *Axial attachment of components*

Each detector component within the DS bore will be coupled axially to the adjacent components. Although each component will be aligned separately in X and Y, all detector support structures will be connected in Z on one side of the rail system by mechanisms as shown in Fig 19. After initial alignment studies, all components will be inserted and removed from the DS internal bore as a single integrated unit (the detector train).

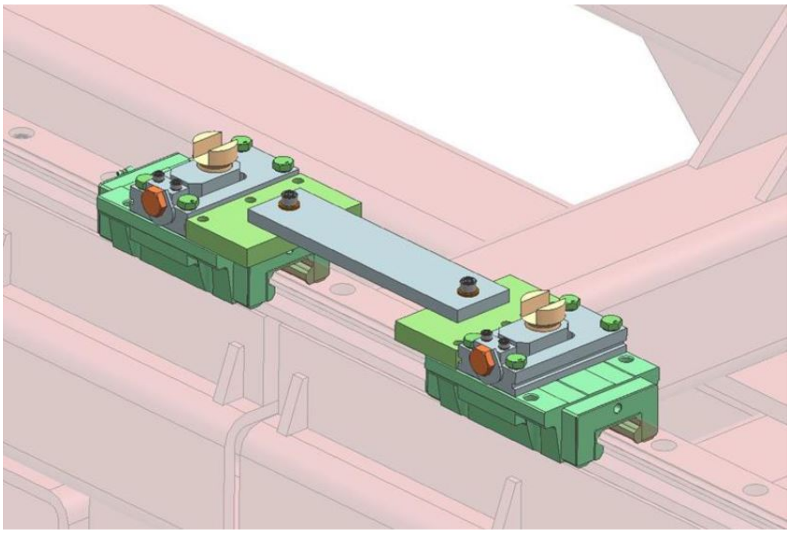

Figure 19: Two outfitted bearing blocks with an axial coupler

3.2.7 *Installation*

The Detector Solenoid, will initially be measured with respect to fiducials placed within the detector hall. The internal rails will be installed accurately with respect to the DS bore by use of specially machined 2nd tier bars bolted to the rail platforms. Each detector component will then be placed on the rails and aligned. During the initial installation, each component will be lowered onto the external rail system, rolled into the DS bore and placed into its approximate final axial position. The components will be measured in X and Y with respect to the geometric bore of the detector solenoid, comparing targets placed on the component structures to the initial bore measurements. Several iterations may be required to achieve the alignment criteria. After the initial installation has been completed, the detector train can be rolled out of and back into that position on the set of rails provided by the detector support and installation system. The rail system is designed to maintain the appropriate level of reproducibility every time the components are extracted and re-inserted into the DS bore.

3.3 Summary

At the end of my work

- I have learnt a new CAD software “NX”.
- The net result is that the 3-D model now more accurately reflects the currently Mu2e plans, and the organization of the model more accurately reflects the project WBS structure, and these modifications will facilitate Mu2e integration activities.

- I have participated in various Mu2e meetings and discussions aimed at facilitating integration of aspects of the Mu2e subsystems, and learned techniques adopted by the project to support integration activities