FERMILAB FINAL REPORT

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HOISTING PROCEDURE OF THE Mu2e CALORIMETER

Sommario

Mu2e EXPERIMENT

Mu2e will search for coherent, neutrino-less conversion of muons into electrons in the field of a nucleus to a few parts in 10^{-17}, a sensitivity improvement of a factor of 10,000 over existing limits.
The Charged Lepton Flavor Violation (CLFV) μ -> *e* can occour in the Coulumb field of a nucleus, through the creation of a muonic atom. The final state consists of a mono-energetic electron recoiling against the intact and unobserved atomic nucleus, without any neutrino. The electron in final state has the energy of the muon rest mass less corrections due to the nuclear recoil and the K-shell binding energy of the muon. In the aluminum nucleus case the electron energy is 104.96 MeV, while 10 the lifetime of the bound state is 864 ns.

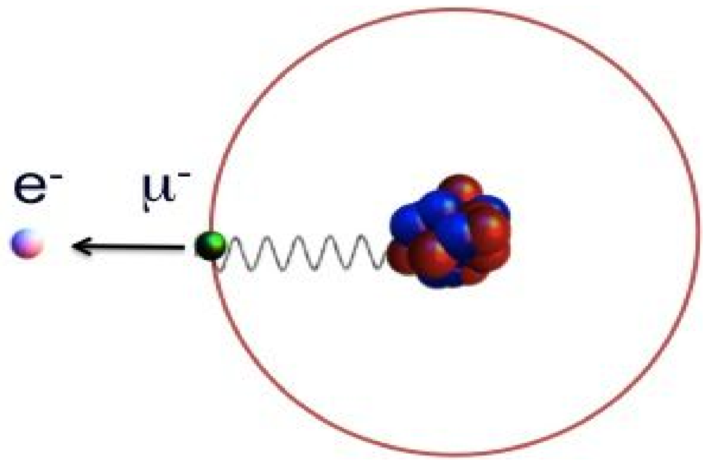


Figure 1 - Mu2e conversion

Mu2e SOLENOID SYSTEM

The Mu2e experimental setup is composed of three solenoids, as shown in the figure 2.

In the Production Solenoid we have $3\ x\ 10^7$ protons per pulse coming from the delivery ring that hit the tungsten target producing pions. These pions decay into muons that are focused into the Transport Solenoid. Only negative muons are sent to the Detector Solenoid, where they hit the Aluminum Stopping Target. The electrons emerging in this solenoid are reconstructed by two detectors: the Tracker and the Calorimeter that have to measure momentum and energy with high resolution.

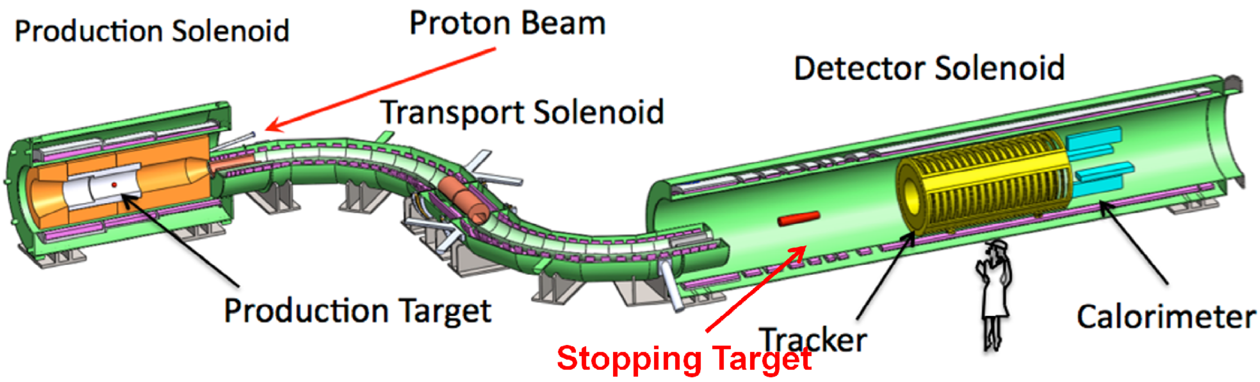


Figure 2 - Mu2e solenoid system

Mu2e CALORIMETER

The Mu2e Calorimeter consists of two aluminum annuli filled by 674 scintillating crystals each. The crystal's light is collected by Silicon Photomultiplier and the mechanics has to be a support for the crystals, the electronics and the cooling system.
In order to design and model the lifting fixture of the Mu2e Calorimeter, it has been important to know the Calorimeter dimensions and features, showed in the figure 3.

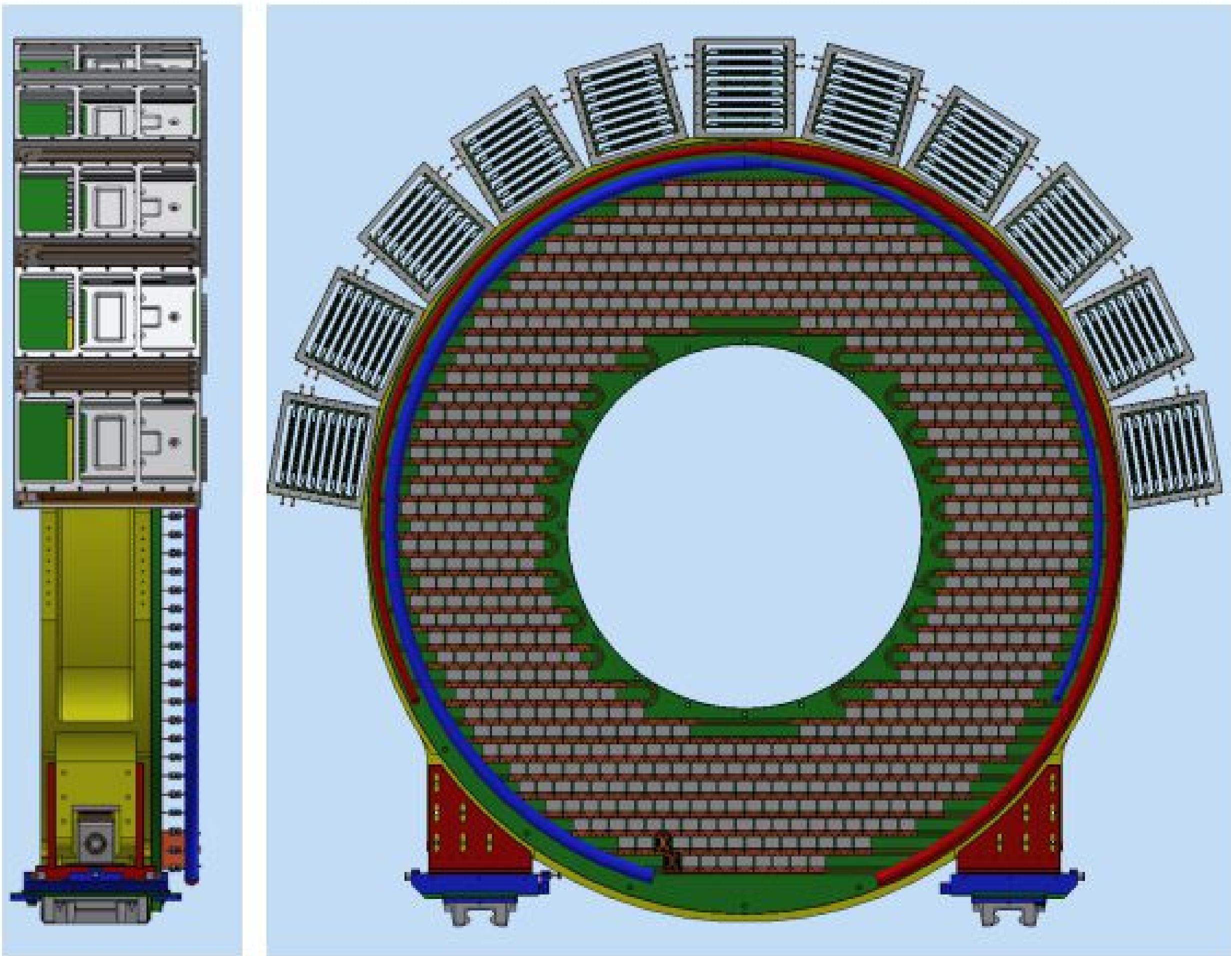


Figure 3 - Mu2e Calorimeter

On the upper part of the Calorimeter there are the crates with electronic devices. From the frontal view showed we can recognize the 674 crystals located in each Aluminum disk. The external diameter, from the disk center to the crates, measures 1840 mm while the internal diameter measure 1570 mm. An other important dimension to know is the distance between the feet of 1000 mm.

Each disk wieghs about 1200 kg and the thickness is 350 mm. The arrows in the figure 4 show these dimensions.

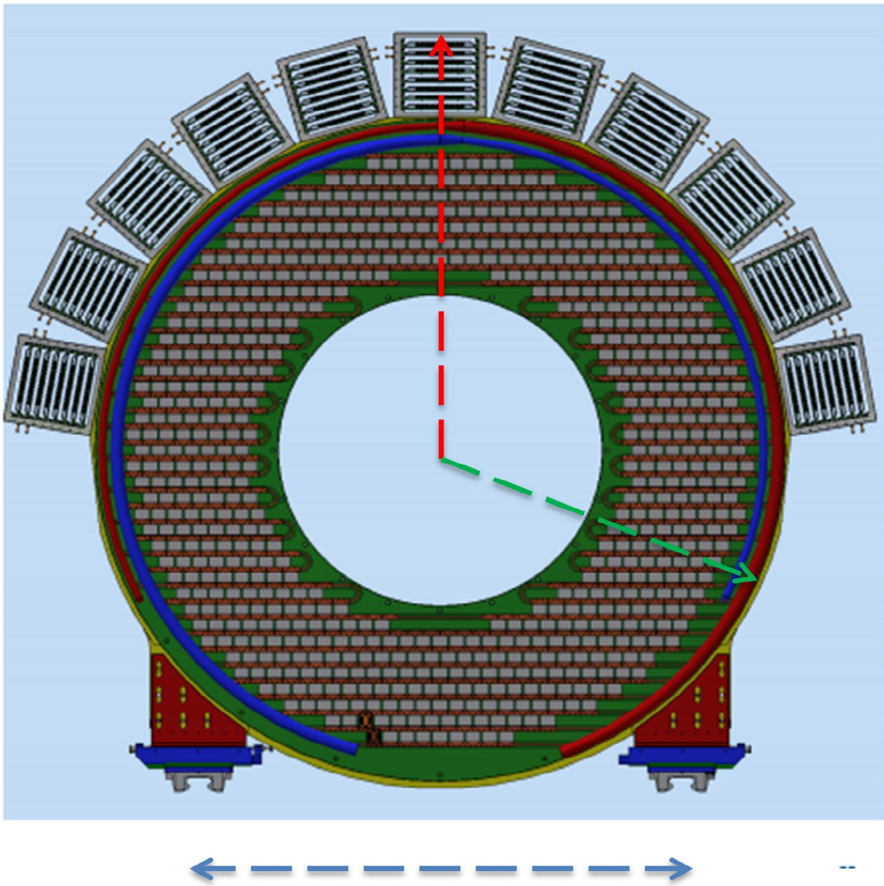


Figure 4 - Main dimensions of the Mu2e Calorimeter

Notice that the distance between the feet is taken from the center of the grey components

Mu2e BUILDING

In the first weeks of my experience it has been also important to take informations about the Mu2e building where the Calorimeter will be placed after its assemble.
The Calorimeter has to be trasported by truck to the Mu2e building and it is important to ensure that the truck can enter from the garage door. In the figure 5 there is an external view of this building and the yellow arrow shows the entrance for the truck. So the door dimension - 13' (width) x 16' (height) - represents a constrain to consider and respect during the modellation of the lifting structure and the transport process.

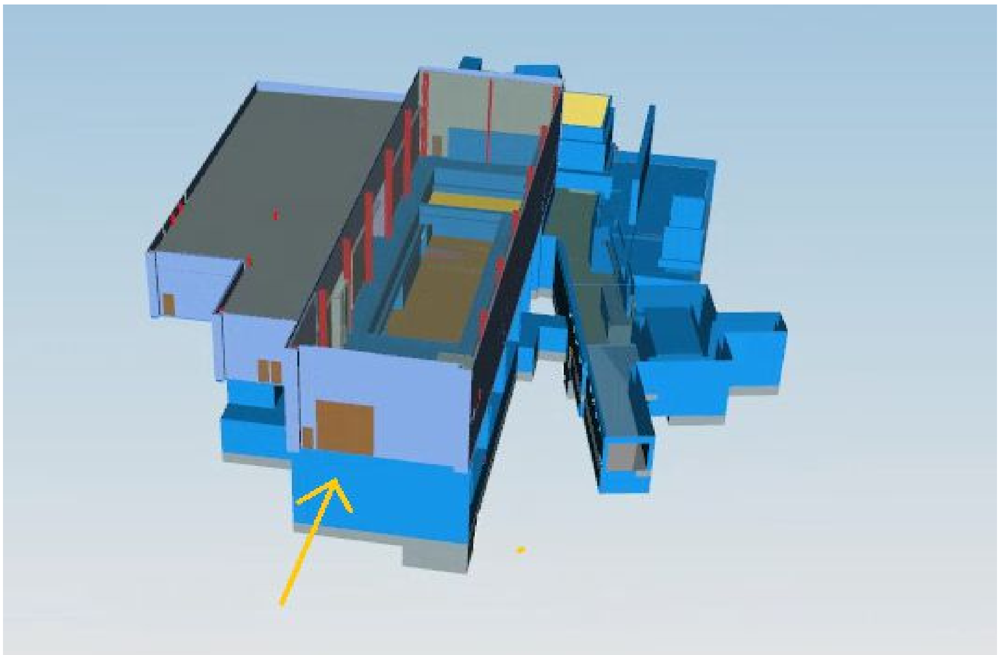


Figura 5 - External view of the Mu2e building

The calorimeter has to be placed into the hatch located downstair in the building. From the top view of the building we can see better the hatch where there will be the detector rail that will support the calorimeter once that the hoisting procedure ends.

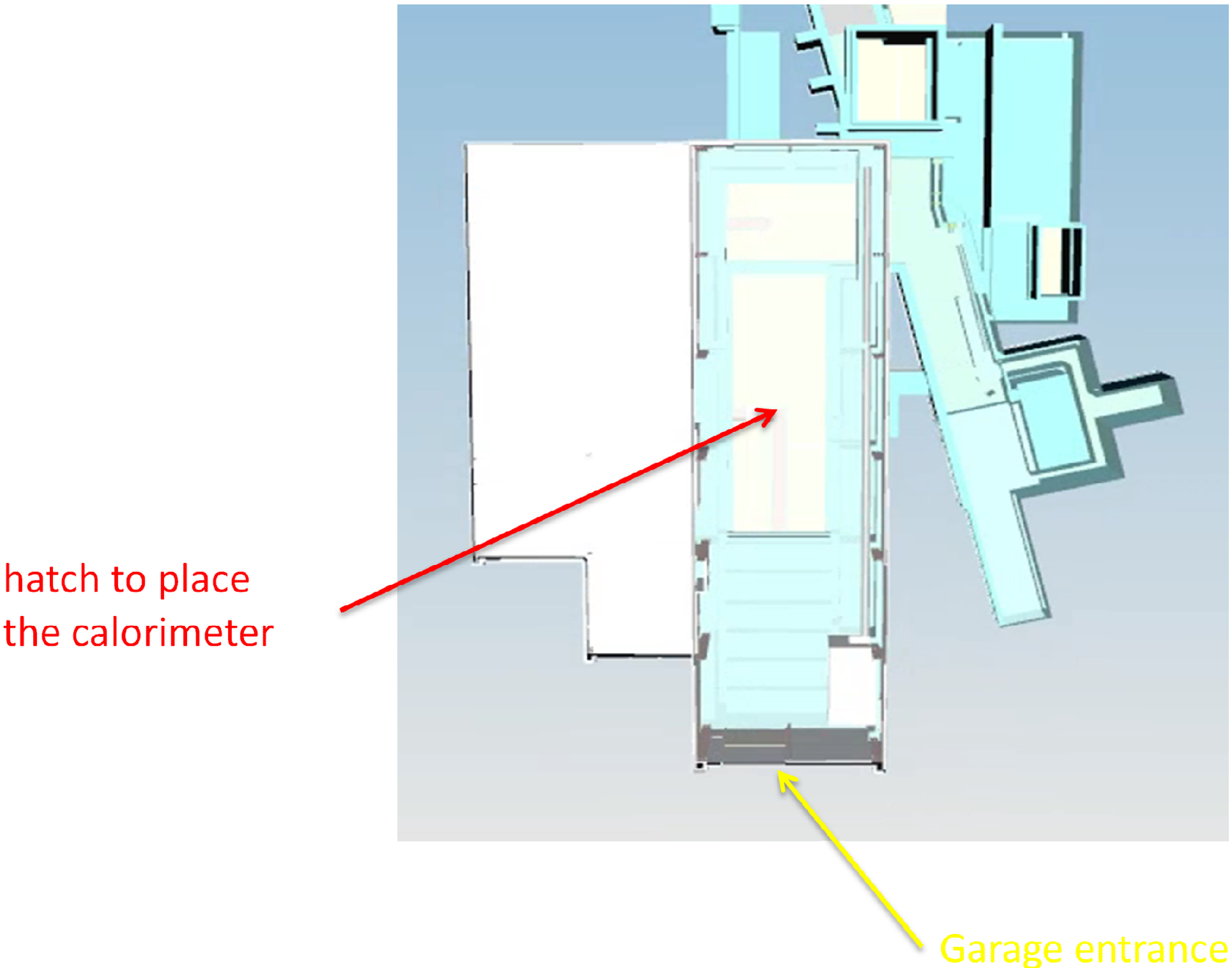


Figure 6 - Top view of the Mu2e building

The calorimeter has its place over the detector rail, between the Tracker and the Muon Beam Stop and the available room (yellow square in figure 7) that we have ho place both the disks is 1,4 m.

Considering the thickness of each disk there should be problems to remove the lifting structure once that the hoisting procedure ends, also because there is a fixed distance of 350 mm between the two disks to respect.

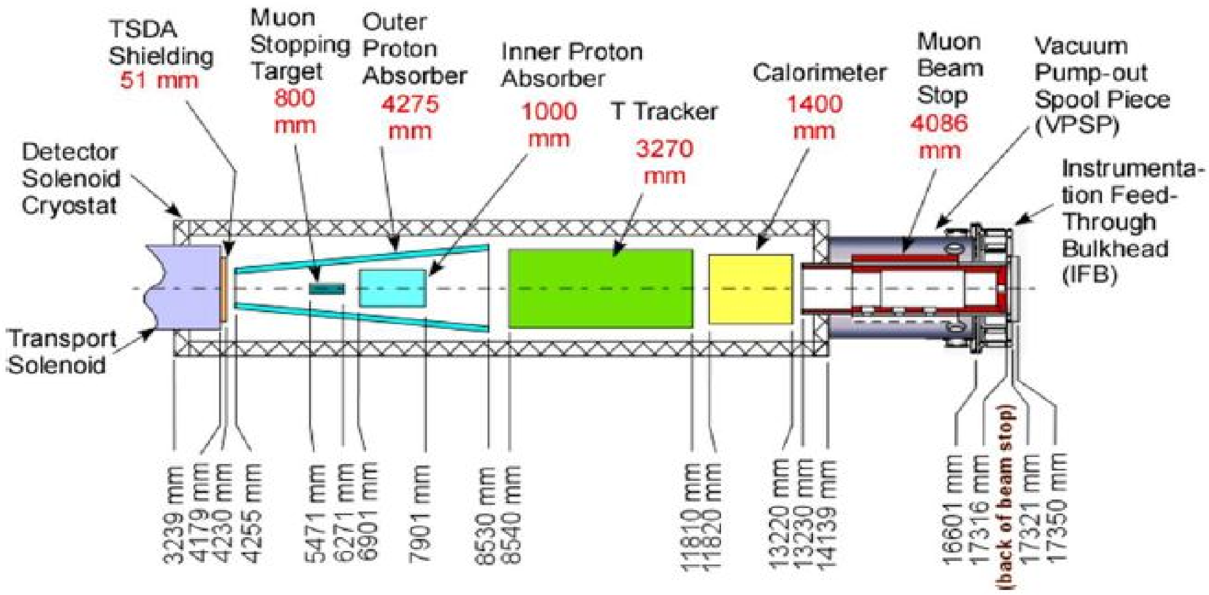


Figura 7 - Components place

The figure 8 is the lateral view of the annuli in the cavity with all the distance to respect (distance from the Tracker to the first disk, distance between the two disk and distance between the second annulus and the Muon Beam Stop)

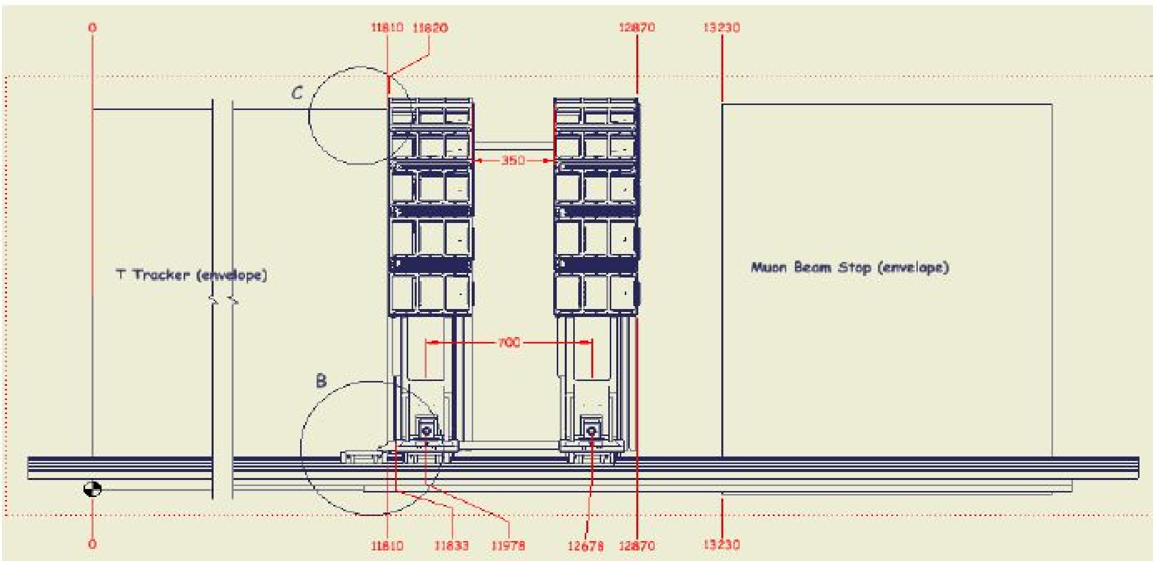


Figura 8 - Cavity lateral view

LIFTING FIXTURE

In this paragraph we introduce the lifting fixtured modeled with CAD NX 9.0 in order to lift up the Calorimeter and place each disk over the detector rail.

There are some features to fulfill:

- Need to pick up the calorimeter from points close to its feet
- Do not compromise the stability of the disk
- Be sure to assure the vertical position of the calorimeter during the hoisting procedure
- Necessity to have available room to remove the device

The structure realized is pointed out in the figure 9

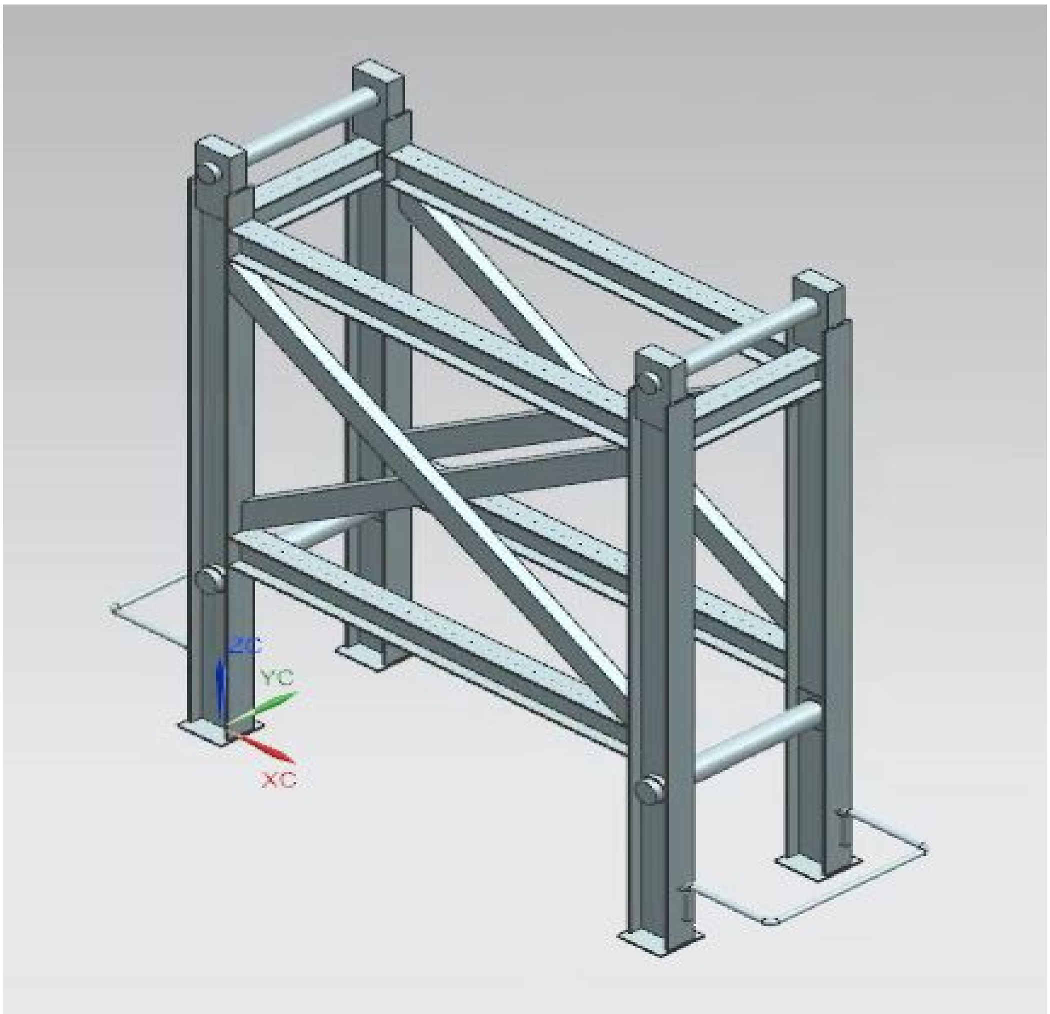


Figura 9 - Lifting fixture realized

the lower rods represent the connection between the lifting structure and the Calorimeter. The fixture has its own feet and the idea is to build it around the Calorimeter once it is assembled (figure 10).

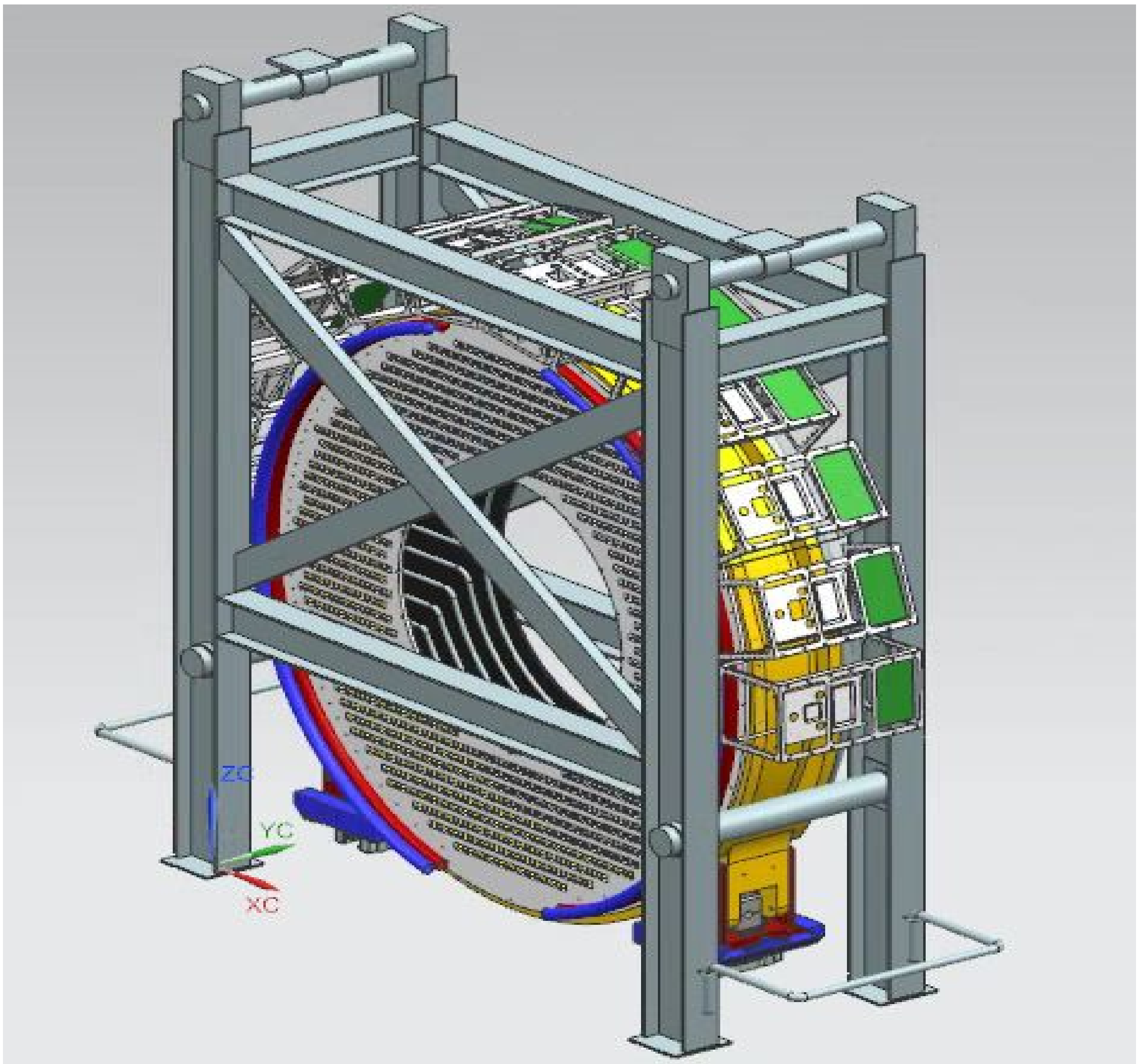


Figura 10 - Lifting fixture around the Mu2e Calorimeter

It is possible to lift up the structure putting some straps around the upper cylindrical beams. We have to choose the right position of the straps in order to balance the disk weight and keep the vertical position during the hoisting procedure. An other possibility to avoid the fluctuation of the annuli is to fix both the disks with some stabilizing screws pushed against the aluminum part (these components have not been modeled).

In the following lines are itemized the advantages of the modeled fixture:

- The lifting device and the calorimeter symmetry are such that the two barycenters are lined up along “XC” direction
- The hoisting structure has its own feet, so it can be built around the calorimeter after each disk is assembled
- The feet of the structure are external to the detector rail, so there will not be interference problems during the hoisting procedure
- Facility to remove the cilindrical beams once the disk is placed over the rail, respecting the hatch constrains

HOISTING PROCEDURE

In the following paragraph we are going to describe the whole hoisting procedure:

- Step 1: set up the calorimeter disk
- Step 2: assemble the lifting device around the calorimeter disk
- Step 3: roll out the whole assembly
- Step 4: transport the whole structure by truck to the Mu2e building where the calorimeter will be placed into the hatch.
- Step 5: pick up the structure using some straps and place the calorimeter over the detector rail (figure 11)

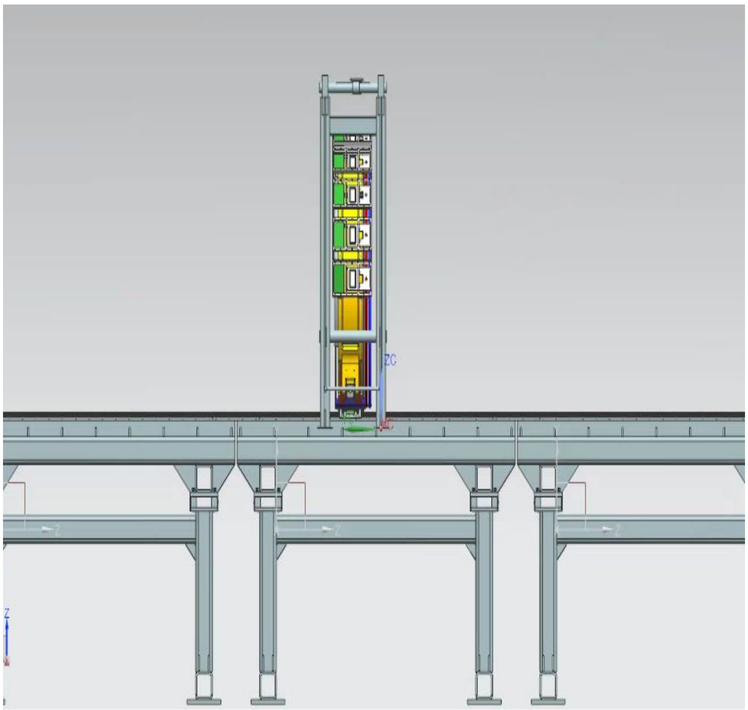


Figure 11 - Step 5

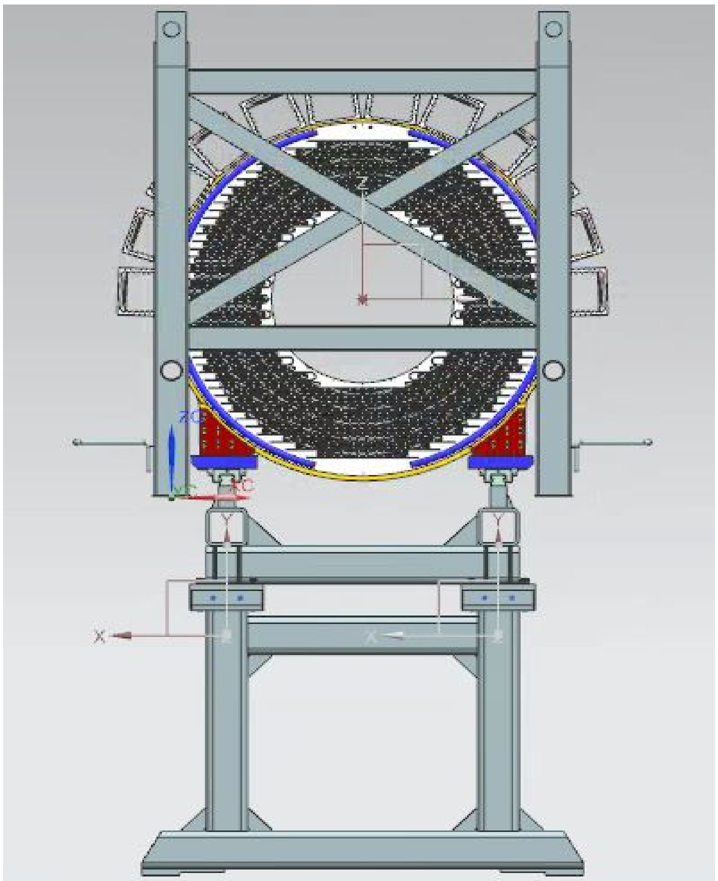


Figure 12 - Step 5, frontal view

- Step 6: remove the rods (20 Kg each) in order to remove the lifting structure

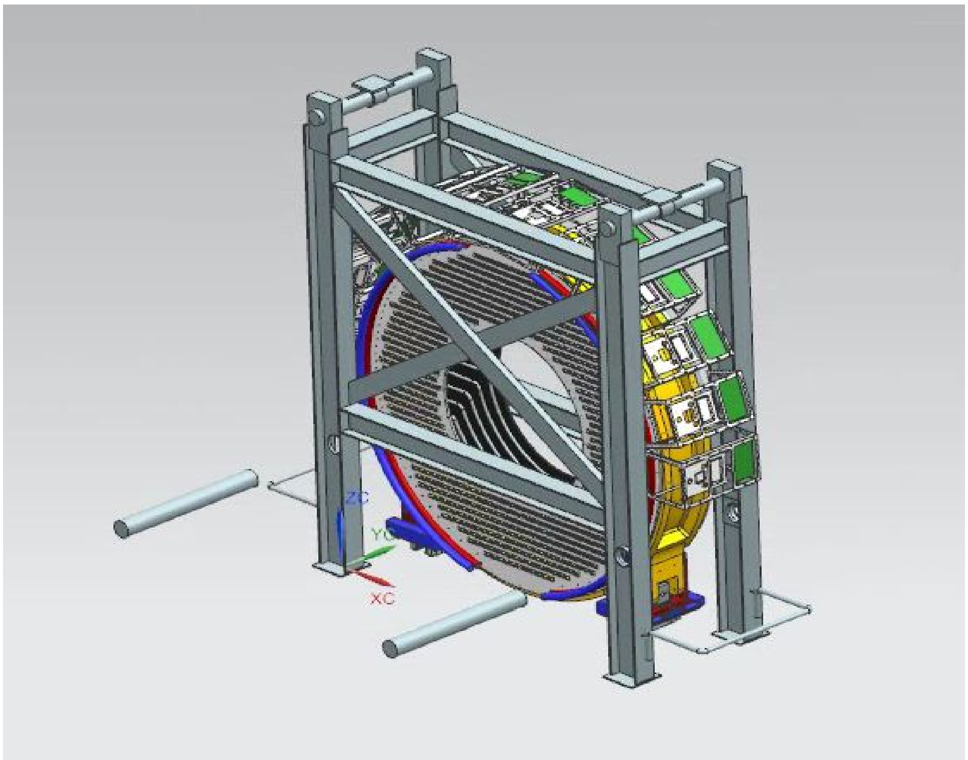


Figura 13 - Step 6

- Step 7: lift up the lifting fixture

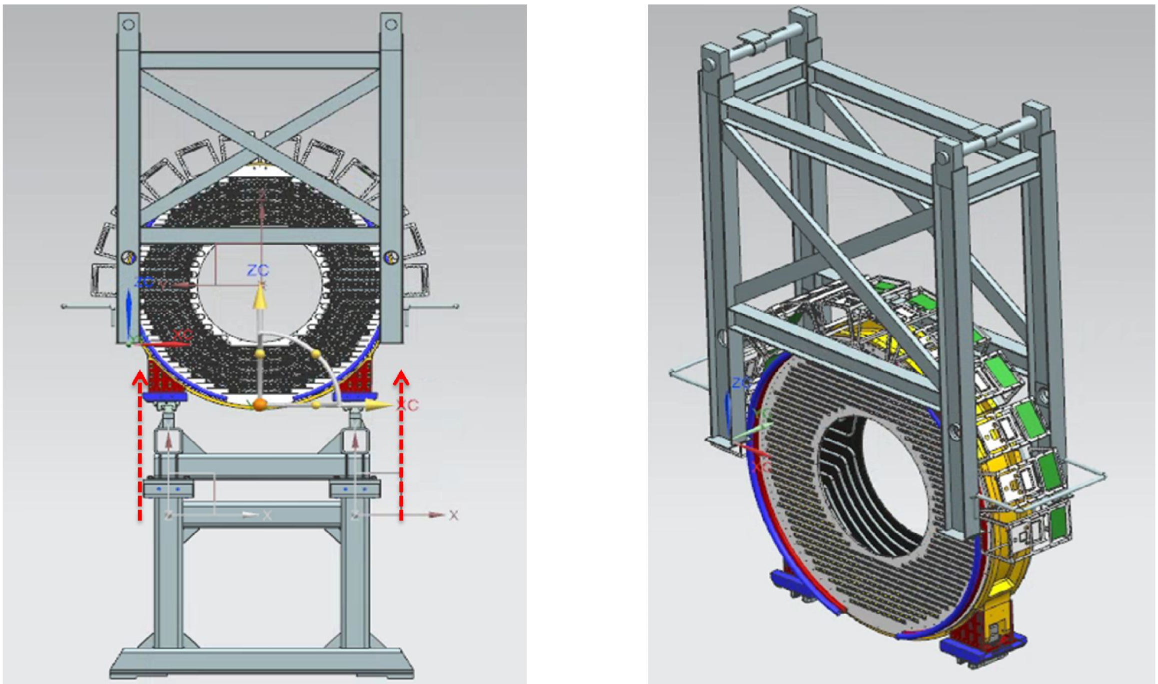


Figure 14 - Step 7

The external lower outriggers are needed to avoid the fixture feet opening during this step.

- Step 8: move the calorimeter over the rail in order to place it in the required position and repeat the same procedure for the second disk

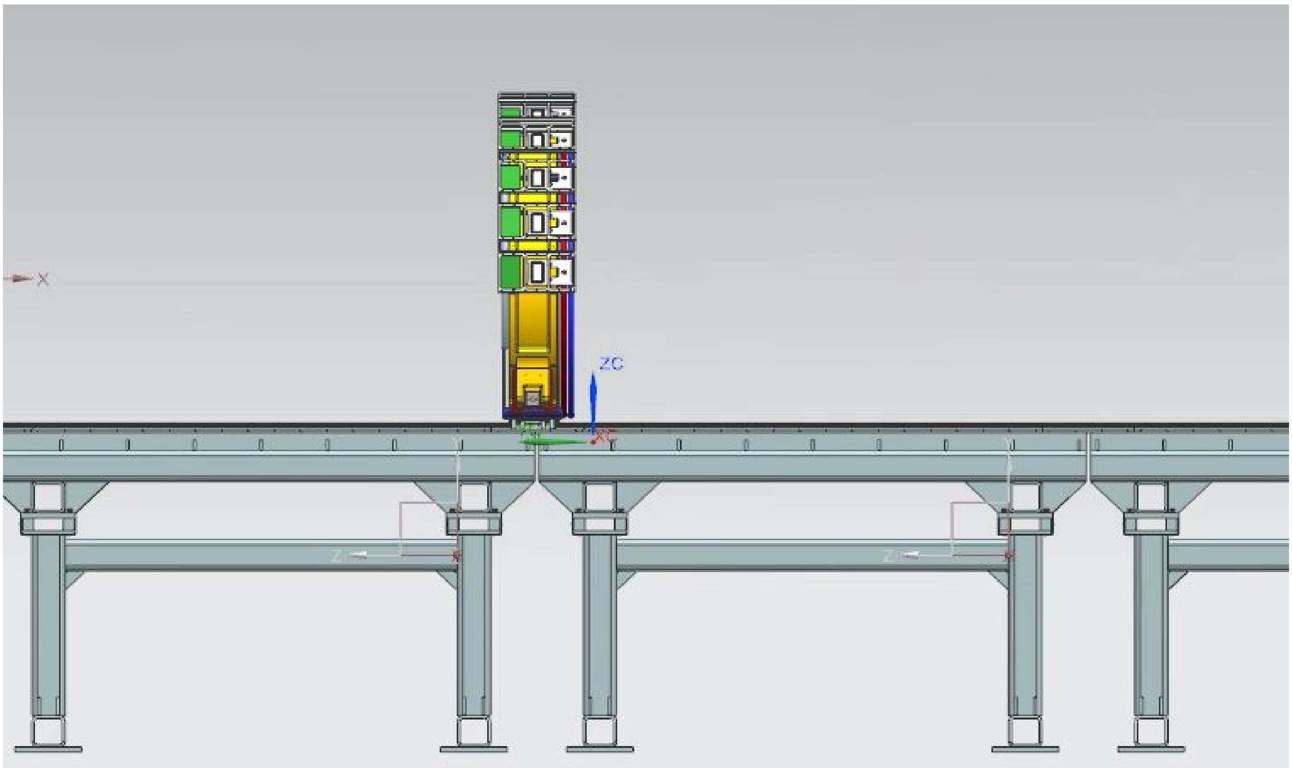


Figure 15 - Step 8

The beams profiles used for the lifting fixture are the following:

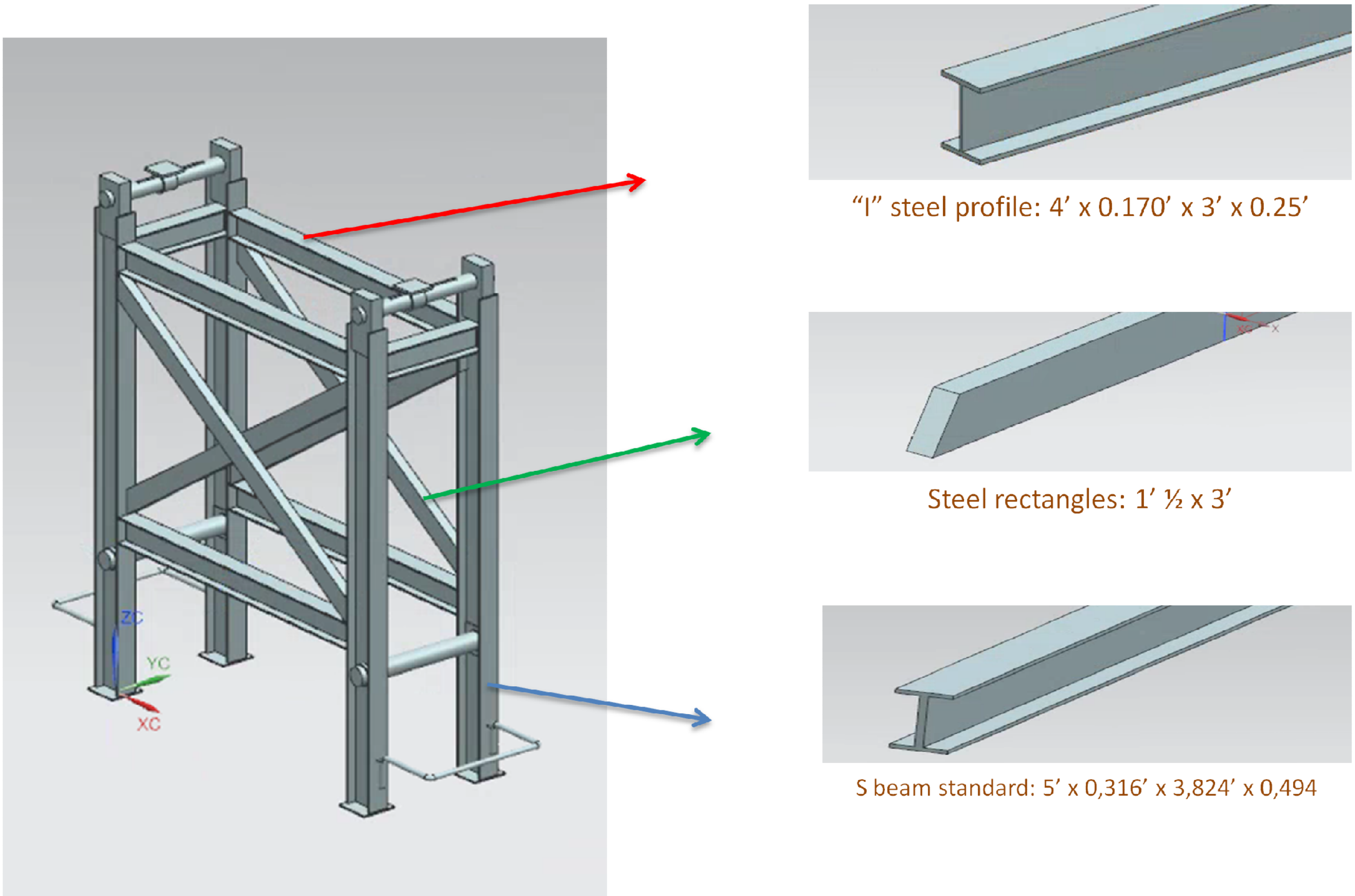


Figure 16 - Beams profiles

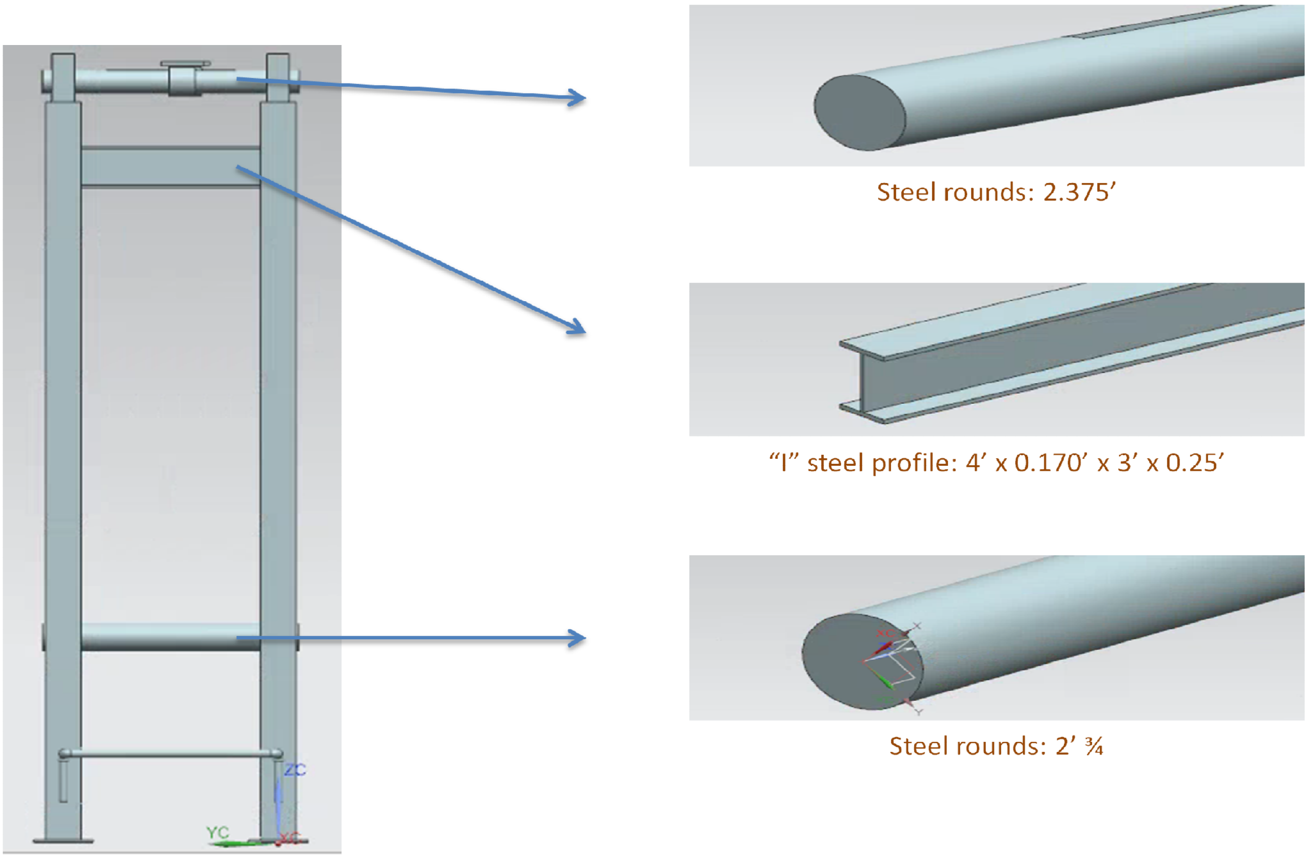


Figure 17 - Beams profiles

It is also important to describe the connection elements of the structure:

- Strengthening of the contact area between the feet and the rods

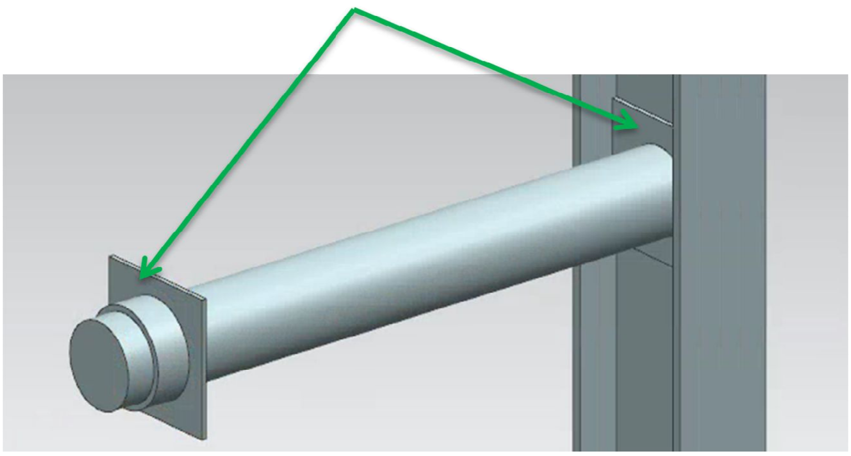


Figure 18 - Strengthening elements

- Support elements in order to ensure a better connection between the aluminum disk and the rods .
  These elements are not included in the following ansys simulation

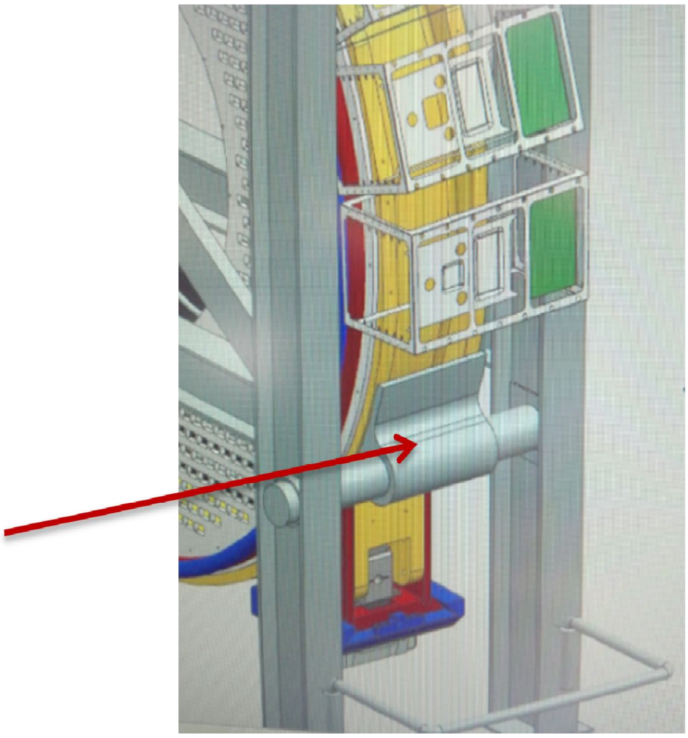


Figure 19 - Supports

We can conclude the description itemizing the fixture features:

- Total lenght: 1535 mm
- Total height: 1945 mm
- Total thickness: 585mm
- Lifting structure weight: 480 kg
- Material: structural steel

STRUCTURAL STATIC ANALYSIS

In this paragraph we will discuss about the stuctural static analysis of the lifting structure made with the program ANSYS 17.2.

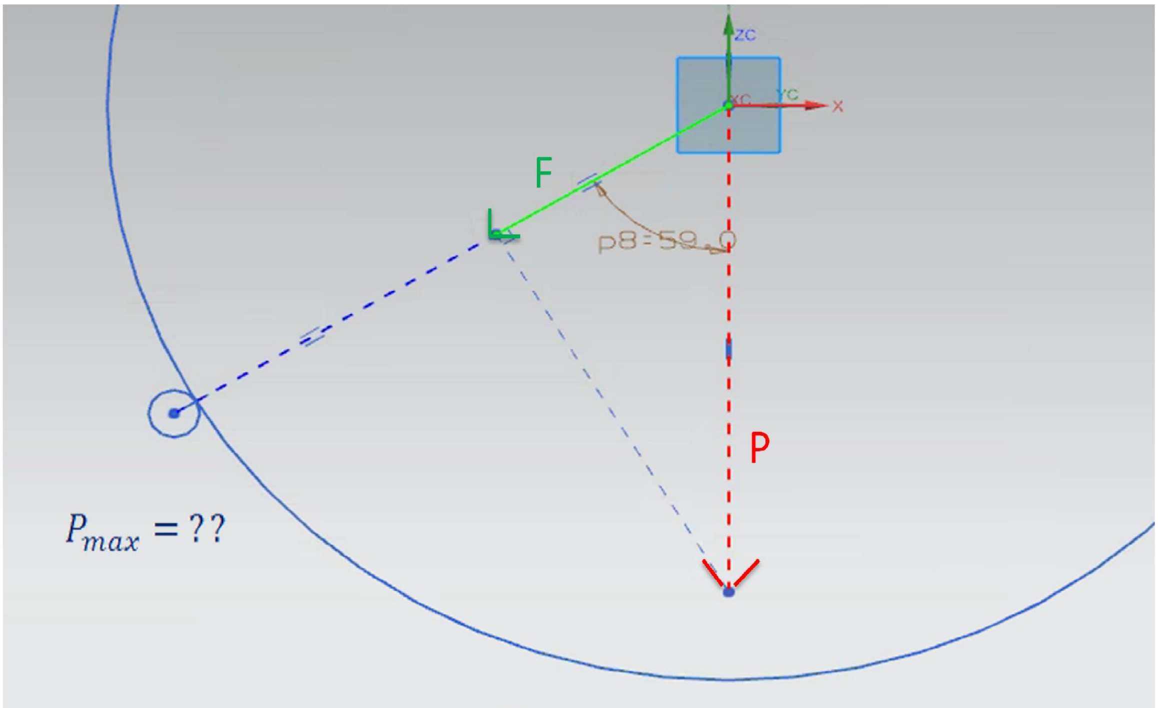
I made some semplified calculates to evaluate approximately the pressure and the deformation of the main components.

We can use the Hertz theory to evaluate the pressure trasmitted by the weight force of the calorimeter to each lower rod. So the maximal pressure Pmax is given by:

$$P_{MAX} = 0,64 * {}^{q}/_{a}$$

where "q" is the ratio between the radial force over each rod and their lenght while "a" is a parameter that depends from the radius of each cylinder and from other parameters of the material chosed.

The radial force F has been calculated as shown in figure 20:



$$F = {}^{P}/_{2} * \cos(59°)$$

Figure 20 - Radial force F and weight force P

The maximal pressure over each rod calculetad in this way is 100 MPa but we can consider this number as a maximum limit for the pressure because the Hertz theory supposes to put in contact two cylinder of unlimited lenght, while in our case we have a 350 mm thickness cylinder in contact with a 550 mm lenght rod. The true pressure expected in the contact zone is 12-13 MPa considering the weight of the Calorimeter.

In order to evaluate the lower rods deformation i supposed to have an uniformly distributed load over a negligible thickness beam, as shown in figure 21

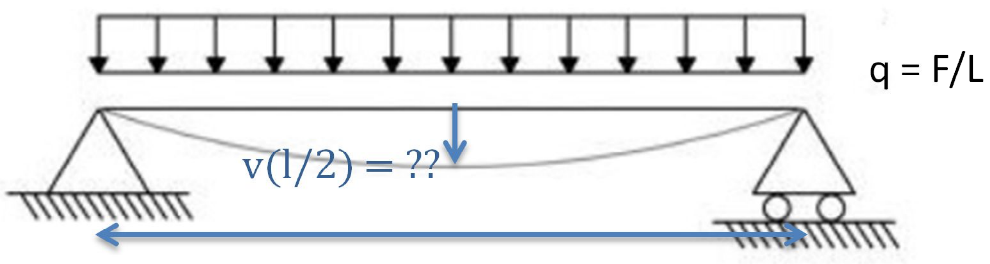


Figure 21 - Uniformly distributed load over the beam in the contact area between the aluminum disk and the same rods

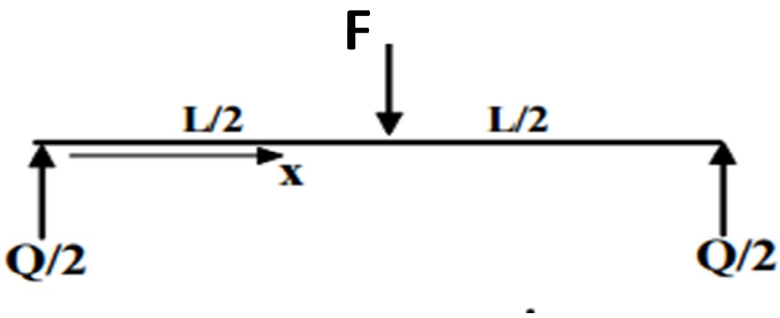


Figure 22 - Force system over the beam

with this semlification the maximum deformation *v(x)* is given by:

$$v''(x) = \frac{M(x)}{E * I}$$

$$\longrightarrow \qquad v''(x) = \frac{(\frac{Q}{2} * x + \frac{q}{2} * \frac{x^2}{2})}{E * I}$$

So we have the maximum deformation when x = l/2 and it measures approximately 0.01 mm.

In order to semplify the ANSYS analysis i used a semplified model of the calorimeter, that is a cylinder with the same weight and the same external diameter of the Mu2e calorimeter.

The other setting used are standard earth gravity ("ZC" direction) and fixed upper rods (figure 23)

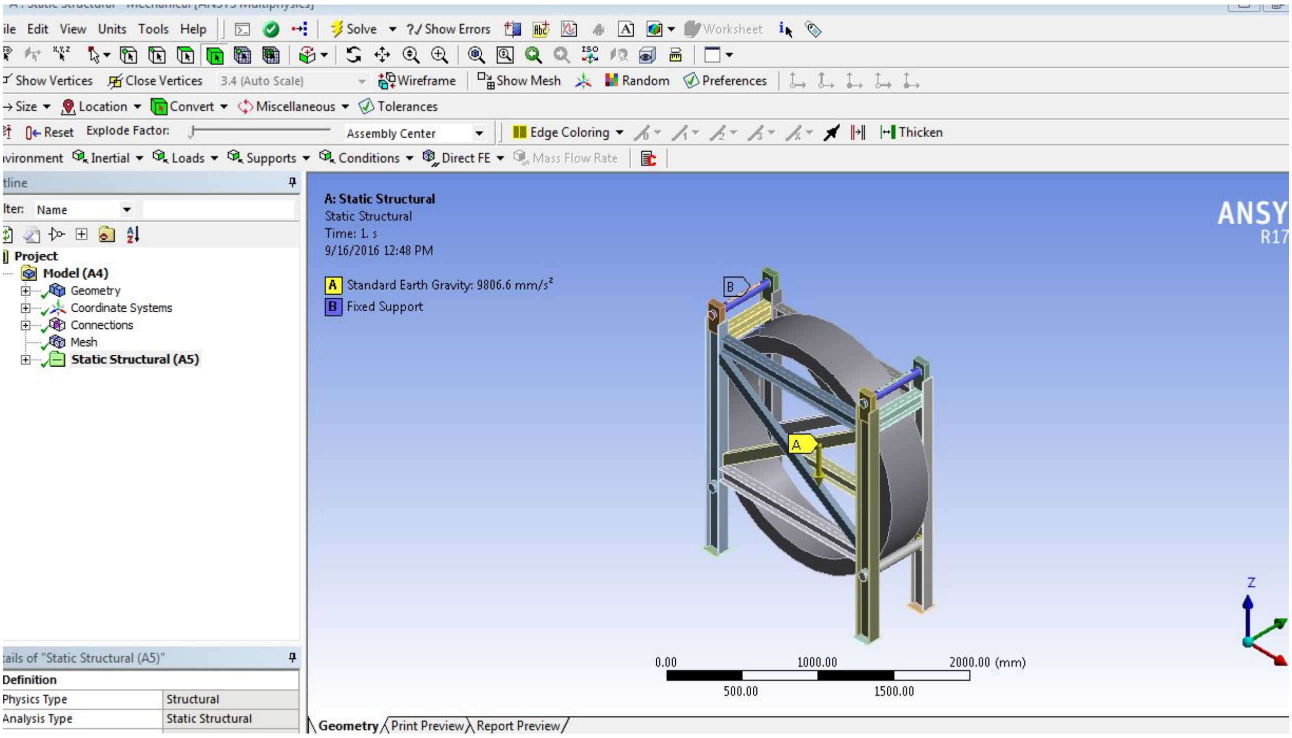


Figure 23 - Ansys setup

the following figures show the ANSYS analysis results:

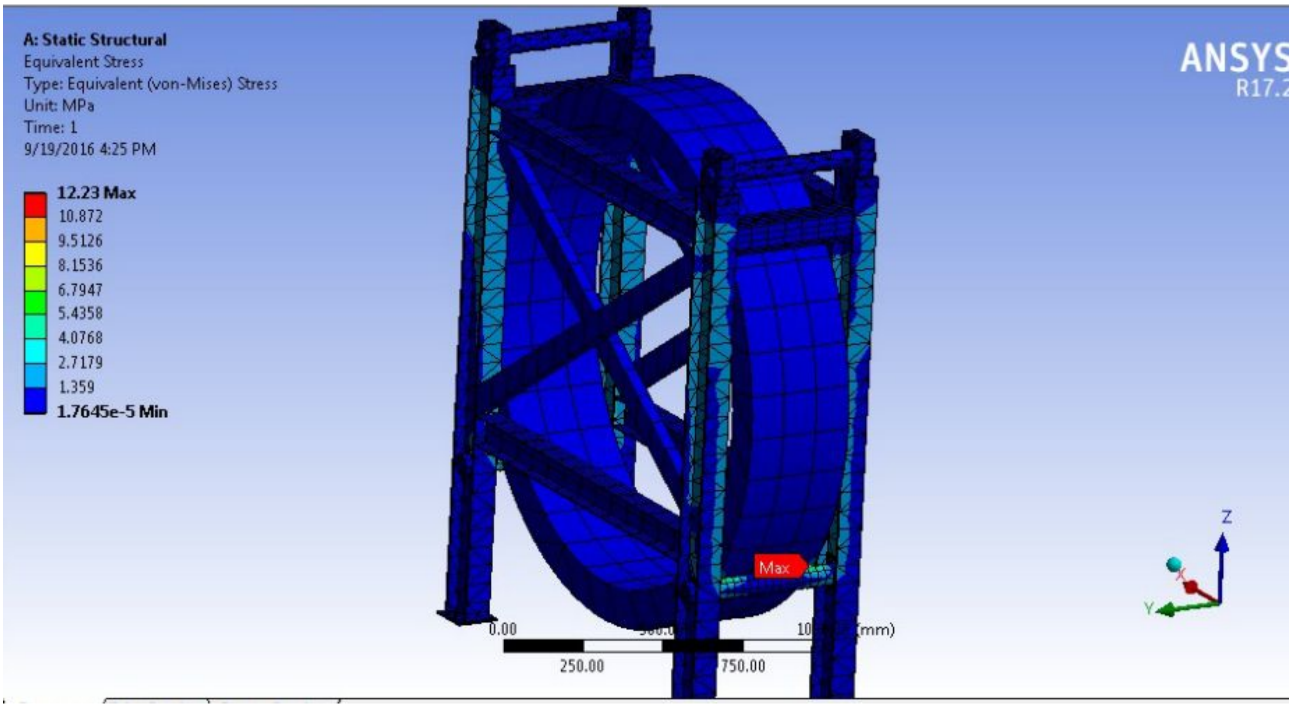


Figure 24 - Structure equivalent stress

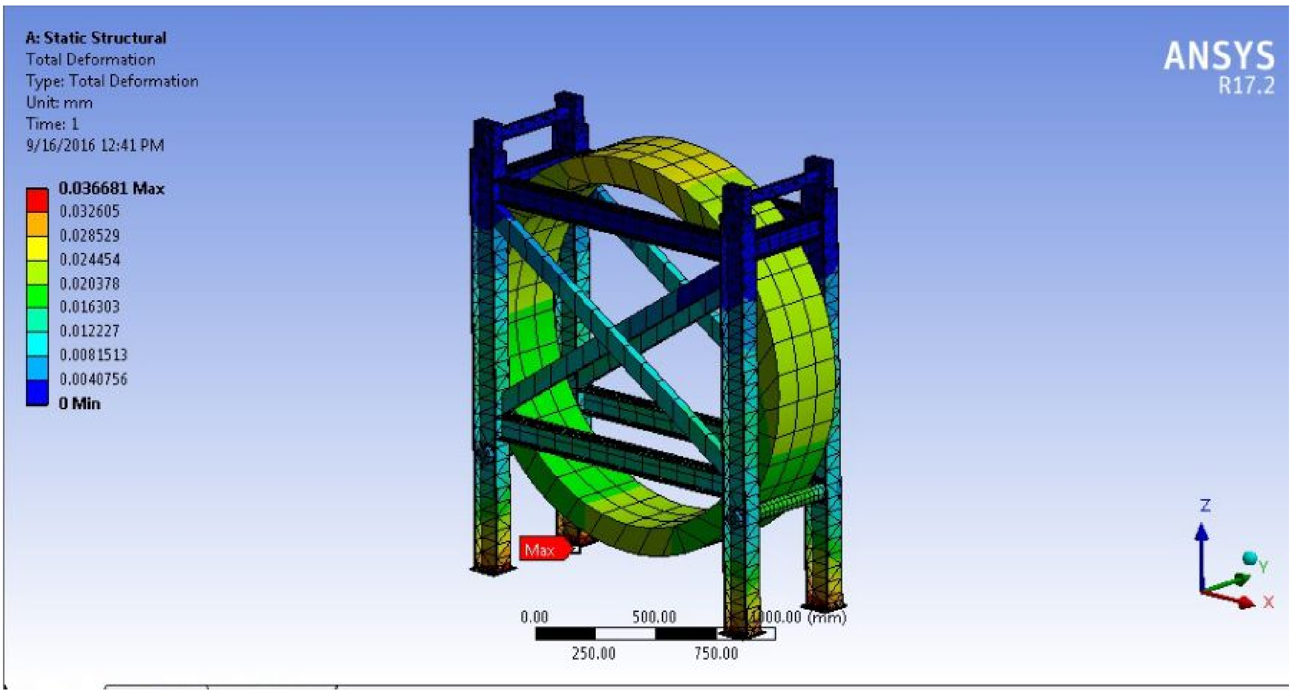


Figure 25 - Stucture total deformation

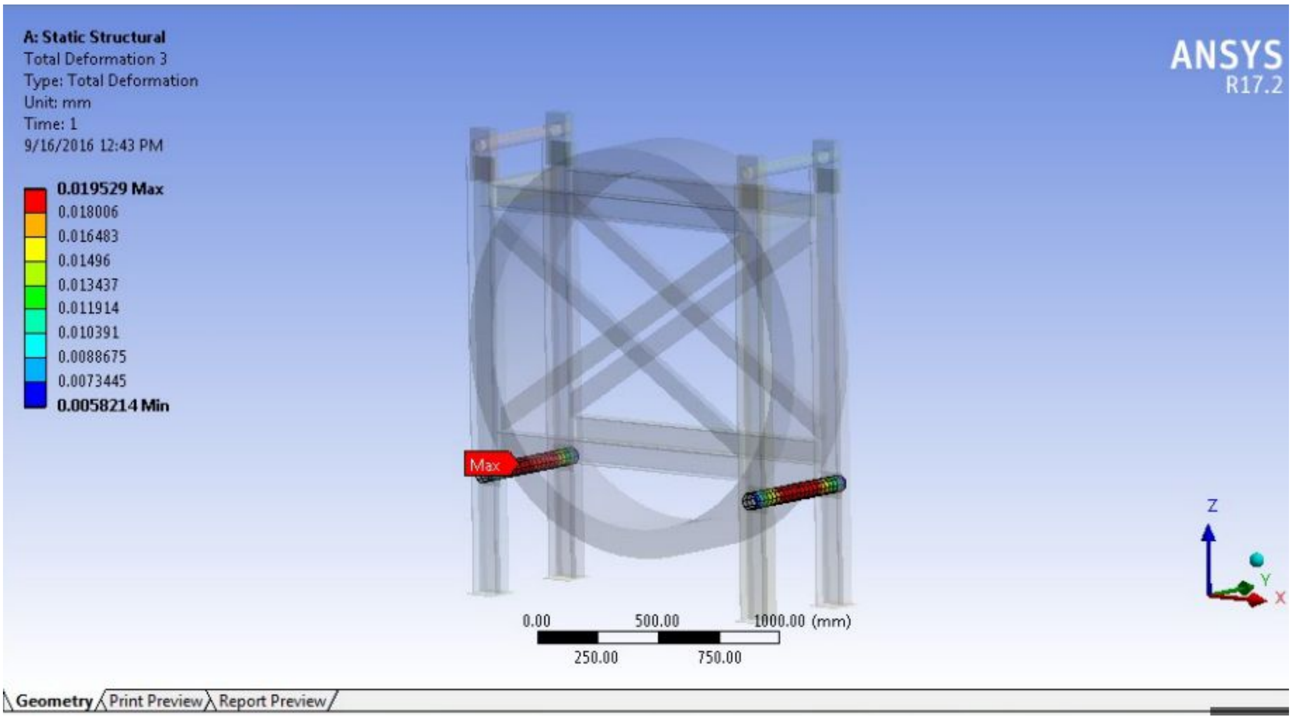


Figure 26 - Rods deformation

CONCLSIONS

- The maximum pressure is 12 MPa in the contact area between the Calorimeter aluminum disk and the lower rods as expected
- The maximum deformation of the structure is about 0.03 mm that is an acceptable value
- the maximum deformation of the lower rods is 0.01 mm as calculated
- The structure can support the weight of the Calorimeter
- i really enjoyed working with people at Fermilab and this experience has been a great oppotunity of personal growing! GRAZIE!