Muon g-2 experiment hall design
Final Internship Report

Dario Lusso

September 25, 2015

Supervisor: Dr. Brendan Casey

1 Introduction: the g-2 experiment

The upcoming muon (g - 2) experiment at Fermilab will measure the anomalous magnetic moment of the muon to a relative precision of 140 ppb, 4 times better than the previous experiment at Brookhaven National Laboratory. The new experiment is motivated by the persistent 3 - 4 standard deviations difference between the experimental value and the Standard Model prediction, and it will have the statistical sensitivity necessary to either refute the claim or confirm it with a confidence level exceeding a discovery threshold. The experiment is currently under testing and scheduled to start running in 2017.
The first step of the experiment was moving the 14 meters diameter magnet from BNL to FNAL, giving it a new home in the newly built muon campus. The move took 35 days during summer 2013 and traversed 3,200 miles over land and sea. The ring was transported out of BNL using a specially adapted flatbed truck and a 45-ton metal apparatus keeping the electromagnet as flat as possible. A massive crane was then used to move it from the truck onto a waiting barge. The barge spent nearly a month traveling down the east coast, around the tip of Florida, into the Gulf of Mexico and then up the Mississippi, Illinois and Des Plaines rivers. When the barge arrived in Lemont, Illinois, the ring was moved to the truck again. And then over three consecutive nights that truck was used to drive the ring to Fermilab in Batavia. More than 3000 people welcomed its arrival at Fermilab, marking the beginning of an experiment that will lead to important discoveries.

(a) The magnet arriving at Fermilab. (b) Travel map.

Figure 1: The magnet traveled more than 3000 miles in a month long journey.

2 Experiment hall

As of September 2015, the experiment design phase is approaching the end, the majority of the instruments and equipment that are required were already established and so is the layout of the main elements. It is time to begin testing, consequently, a 3D model of the experiment hall is needed to check if the design is feasible and to assist the technicians who will actually put everything in place.
When the experiment will be ready to run, the room, and so the model, will contain:

- the 14 meters magnet
- the beam chamber
- the straw trackers [1]
- 24 calorimeters
- trolley garage and drive
- vacuum pumps [1]
- fiber harp monitors
- injection kickers [1]

- hall features such as the catwalk and the stairs
- the fake floor
- cable trays and racks for the electronics.

Figure 2: The experiment hall on 09/21/2015.

During the construction of the model, mainly two real-world constraints were kept in mind. The first one is obviously the limited amount of space inside the 14 meters ring, that forced to position as many items as possible on the outside. The second one is the magnetic flux density sensitivity of some instruments, like vacuum pumps, which had to be positioned accordingly. In the following sections, we will examine the main components in more detail.

2.1 Model structure

The model was built using Siemens NX 9.0, on of the most widespread high-end CAD software, that is adopted by Fermilab for its integration with PLM platform TeamCenter.
Up to now, the model includes more than 100 elements and they are organized as follows. The room and the parts referenced to it, like the catwalk and the stairs, are modeled directly inside the main assembly part. The

[1] These items, or some of these items, are still to be included in the model

ring is a subassembly and is added to the main part. It includes the beam chamber, which is another subassembly itself, and most of the equipment and features attached. Finally, the floor, the racks and all the other items are added to main assembly as single components.
Most of the items were modeled starting from technical drawings or blueprints. Drawings were not always available or, as we found out, sometimes were inaccurate. In those cases, we obtained the dimensions for the model by measuring the real features. Consequently, measurement errors were introduced in the model, slightly decreasing the overall precision and limiting the possibility of using the model as reference for mounting real components.

3 Ring

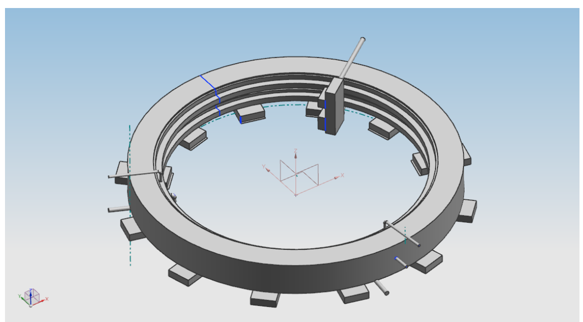


Figure 3: The main ring.

The ring is of course the main equipment needed for the g-2 experiment. It is 14 meters in diameter and it has a C-profile to accommodate the beam chamber. It also holds two superconducting magnets, that need to be cooled to superconducting temperatures and insulated, to generate the magnetic field. Insulation is provided by vacuum, which is pulled by pumps located radially around the ring. The system is cooled by flowing liquid helium. The 1.45T magnetic field is responsible for directing the muon beam, coming from the muon source, along its circular path. The ring is held in place by 12 adjustable concrete supports, to compensate the floor irregularities and keep the ring flat.

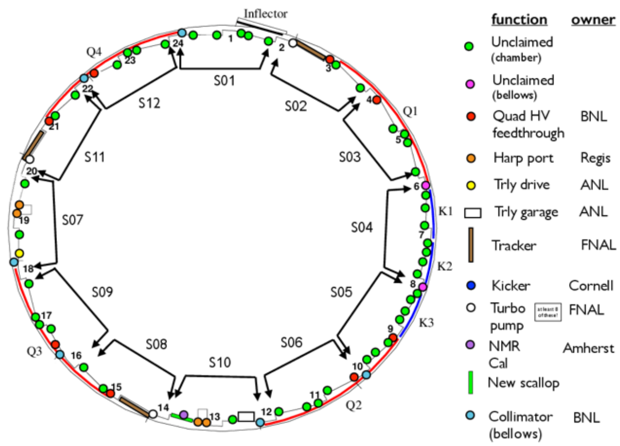


Figure 4: Port map of the ring.

4 Beam Chamber

The beam chamber ring is the second important component of the experiment. It is made of 12 different sections, almost each of those having a slightly different structure to be apt for different purposes. All the chambers have the same angular dimension, spanning 30 degrees, to form a ring. Every chamber is positioned exactly on the yoke between two supporting blocks. The beam chamber ring is referenced from the Chamber 1, which carries the beam inlet. The chambers also need to be airtight because vacuum will be pulled inside the beam chamber. Thus, they are connected with gaskets to ensure a perfect seal even if the shape is not ideal. Finally, a rail system will be mounted inside all the chambers to enable the trolley operation.

The chamber differences are related to the instrument connected to their ports. The port map of the ring is shown in Figure 4.

4.1 Calorimeters

After a muon decays into a positron and neutrinos, the positron has insufficient energy to remain on the orbit in the ring. It curls inward where its energy is detected by Cherenkov calorimeters. There are 24 electromagnetic calorimeters sitting on the inside radius of the storage ring to accurately measure the hit times and energies of the positrons. Starting from these information, positrons can be traced and the decay point identified. Each

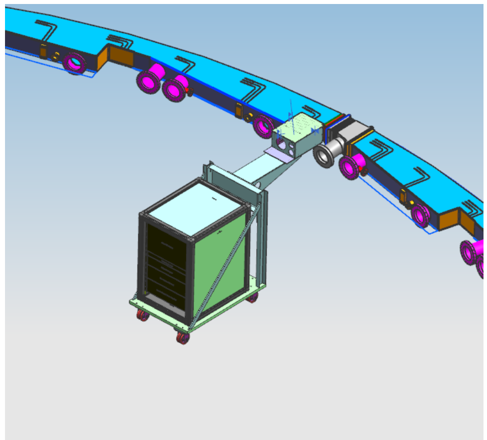
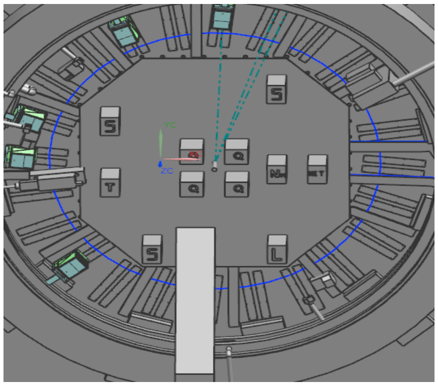


Figure 5: One of the calorimeters, coupled to a vacuum chamber.

calorimeter needs two rails to move towards the chamber and back, which need to be precisely lined up with the scallops on the vacuum chambers. The rails are orthogonal to the ring circumference, but due to the presence of the fake floor, some of them need a special position, at a larger radius, to avoid interference. In Figure 5, a calorimeter is shown in contact with the vacuum chamber. The calorimeter model, as can be seen, is very detailed and made of many components. Only a couple of calorimeters are present in the final assembly model, to keep it simple and manageable by a laptop computer.

4.2 Fake floor

A fake floor will be positioned to cover the cables and wirings needed for the instruments operating close to the beam chamber. It will be a 26 feet square, centered on the alignment monument, with cut corners to allow the positioning of items on the real ground. Several racks for the electronics of the different instruments will be positioned on top of it to be easily accessible by the operators.
Figure 9b shows the actual fake floor being put in place. In particular, we were interested in marking on the floor where each one of the supports will sit to keep the space free from other items and to properly design the cable trays going under the floor.



(a) Floor layout.

(b) Mounting the fake floor.

Figure 6: The fake floor covers cables and wirings.

4.3 Trolley equipment

As we mentioned earlier, the experiment requires two trolleys traveling inside the beam chamber on the rail system. Both trolleys are about 20 inches long and have a similar tubular shape. The first trolley is for maintenance and calibration. It will quantify the displacement of the Straw Detectors in order to calibrate them and will detect the warping of the walls of the vacuum chambers. It will carry a camera and other sensors and it's still being designed. The second one will mount 17 NMR probes and will be able to measure the magnetic field at 6000 locations along the ring over the course of one hour.
A drive mechanism with cables in order will run the trolley around the ring during dedicated measurement periods. The drive mechanism is bulky and will be located inside of the ring.
The last part of trolley equipment is the garage. The garage houses the trolley in a remote location during muon injection and provides the mechanism to move the trolley into the storage area for the NMR measurement.

5 Outside the ring

Up to now, we have only considered the inside part of the ring. That is because it is going to be the most critical and crowded with items, but still needs to be accessible by operators. On the other hand, most of the areas outside the ring can fit the equipment without problems, so, being low priority, they were not modeled in detail. There are a few spots, though,

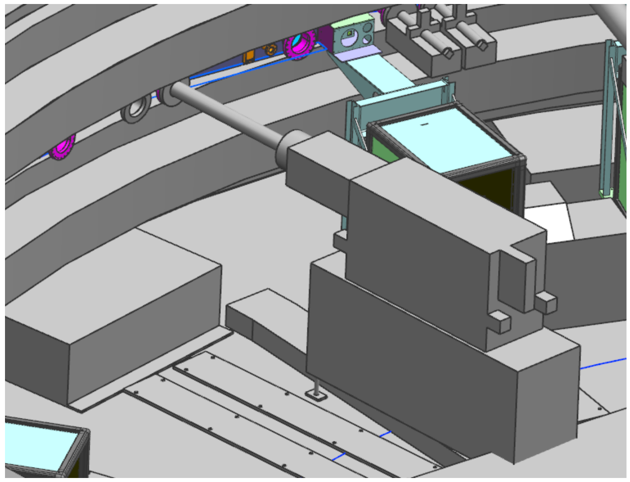


Figure 7: The trolley drive connected to the beam chamber.

that deserve a closer look and a precise layout model.
The most crowded spot outside of the ring is the corner between 3 and 6 o'clock[1], that is the corner located beneath the hall entrance. The main constraints to positioning in that corner are the presence of many fixed items such as:

- the sump pump pit on the ground
- the waterfall, with the main cable trays
- the catwalk located above the corner
- the stairs to access the catwalk.

Where the sump pump pit is represented in the model by a circle located in the very corner. The waterfall is the tall structure, close to the wall, laying two cable trays on the floor. Those are the main cable trays, the only ones carrying wiring from outside the ring to the inside.
Keeping in mind the above mentioned constraints, as well as other ones from the designers of the experiment, we positioned these other items in the corner:

- pipes for cooling system
- Blumlein generators for the kicker

[1]We assume 12 o'clock to be the beam inlet in the ring.

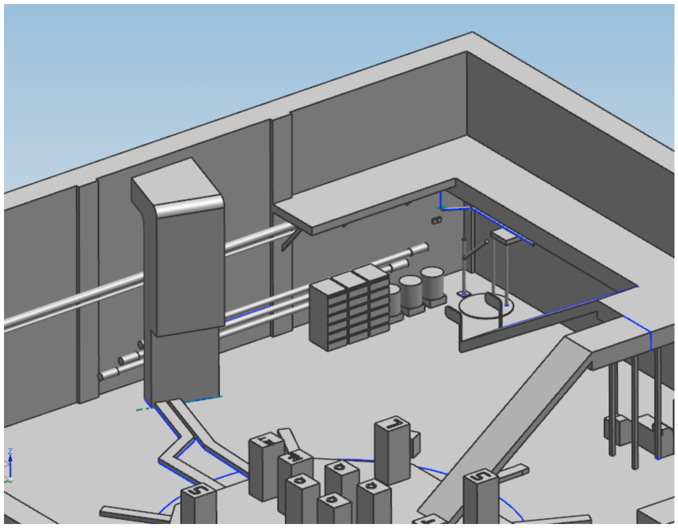


Figure 8: The kicker corner.

- racks for power supply and oil tanks
- vacuum pumps and controls

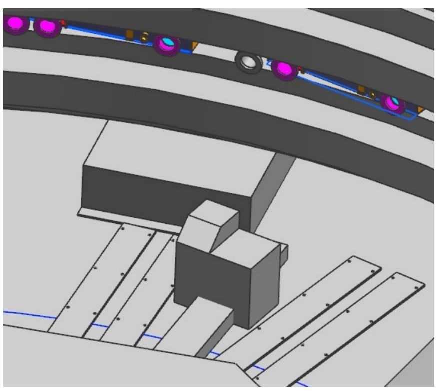
The position of these items is not yet definitive, and is still being discussed. On another corner, precisely the one between 6 and 9 o'clock, two prefabricated rooms are positioned. The rooms are small enough to fit below the catwalk and between its pillars.

6 Conclusions

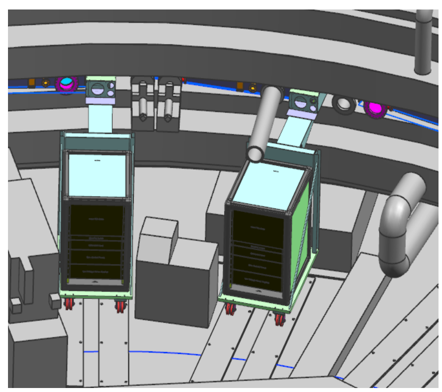
a. The experiment hall model is adequately detailed and mostly complete. All the main components in the critical areas of the hall are present, as well as many small components. Some of the missing items will be added in the coming months when dimensions and number will be available. The model is being used to check for interference in the most crowded areas of the hall and, in case an even more precise analysis of a certain part of the hall is needed, it can be used as a starting point for a more detailed one.

b. The experiment hall model is sufficiently precise. The difference between real measures and model measures is, in almost any case, below two inches. The precision reached is enough to determine if all the pieces of equipment needed for the experiment can fit inside the hall, while it may not be a good enough reference for the actual positioning.

c. No interference is present, according to the model, between already designed components. Some of the attempts to model other components, like cable trays, or pipes produced interference with fixed items, like the calorimeters. The position of the cable trays, is still to be defined properly. As we can see in Figure 9a, the vacuum pump control carts are sitting on top of the cable trays. Another issue is related to the vacuum pumps, since they require a pipe to connect with the vacuum chamber. The pipe, in the actual layout, shown in Figure 9b, would bring the pump in conflict with the calorimeter. This is an example of indications the model can provide to those who are designing the equipment for the experiment



(a) Vacuum pump controls are sitting on cable trays.



(b) Vacuum pump pipe on calorimeter.

Figure 9: The figures show some of the problems we observed.

Contents

List of Figures