Working With CUORE In Search for The Neutrinoless-Double Beta Decay

A Senior Project

By

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Approval Page

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Abstract

The neutrino, if found to be its own anti-particle, will reshape the Standard Model of physics. This paper will give some background information regarding CUORE's experiment to discover the radioactive process known as neutrinoless double-beta decay, how their experiment works, and my own involvement in their research during the installation phase of the project in the summer of 2017.

1 Introduction: The Standard Model

Through a collective effort since the 20th century, scientists have broken down the mystery of matter to its most fundamental particles– the Standard Model. The Standard Model is a list that contains what are presently known to be the fundamental particles that make up our universe[1]. Figure 1 is a chart of the Standard Model. These particles are classified into various groups. Firstly, there are Fermions and Bosons with half integer and integer spins, respectively. Fermions obey the Pauli exclusion principle, which states that no fermion can exist in the same quantum states. Bosons, on the contrary, obey Bose-Einstein statistics in which particles are allowed to occupy the same quantum states. Bosons include photons, W and Z bosons, gluons, and gravitons. The Higgs Boson is of its own category of bosons with a spin of zero. Fermions have two sub-categories: quarks and leptons. There are six different types of quarks (up, down, strange, charm, bottom, and top) with each having three different colors (red, green, and blue). Leptons include the electron, neutrino, muon, muon neutrino, tau, and tau neutrino. In addition, all of the subatomic particles mentioned have their own antiparticles— they are categorized as Dirac particles. Particles that are their own antiparticles are classified as Majorana particles.

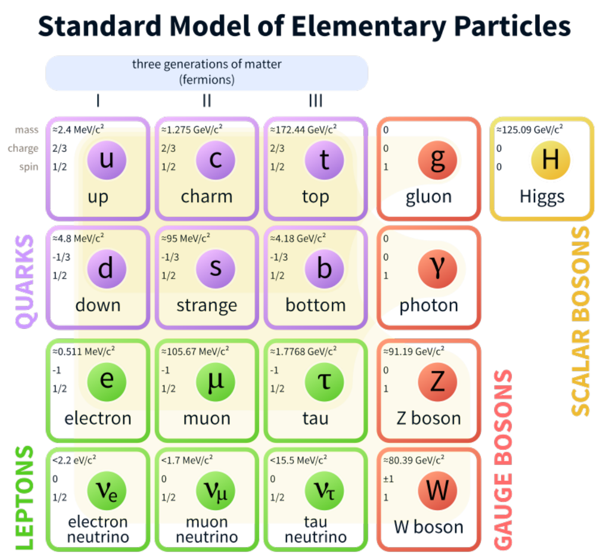

Figure 1: Chart of the Standard Model

There is particular interest in the study of neutrinos and determining whether or not they are Dirac or Majorana particles. Various institutions are trying to confirm the phenomena of neutrinoless double beta decay ($0\nu\beta\beta$), which, if discovered, will not only finally allow measurement of the neutrino mass in the standard model but also assert that the neutrino is its own antiparticle. Its discovery will give insight as to why there is more matter than antimatter in the universe.

This paper will give some background on the physics behind radioactive decay, the motivation behind CUORE's search for the neutrinoless double beta along with my involvement in the experiment.

2 Neutrinoless double beta decay and its significance:

Before we introduce ($0\nu\beta\beta$), we first need to understand radioactive decay. Radioactive decay occurs when there exists an unstable atomic nucleus[2]. In an attempt to reduce to a lower potential, the atom will emit radiation in the form of an alpha, beta, gamma, or neutrino particle. Beta decay occurs when an atom emits a high energy electron followed by an electron-neutrino. Figure 2 is an example of the different types of beta decay. In beta decay, an atom emits an electron and an electron-neutrino. Likewise, double beta decay involves the emission of two electrons and two electron-neutrinos. All radioactive decays obey the conservation of various quantum numbers. For this context, lepton charge number is conserved[3]. However, ($0\nu\beta\beta$) would violate lepton number conservation. Electrons have a lepton number of $+1$, while electron anti-neutrinos have a lepton number of -1. Thus, with the absence of neutrinos in the right hand side of the radioactive process, there is a net lepton charge of $+2$. If violation of lepton number is possible, this can lead to the implication that there is a bias between matter and anti-matter—nature would seem as if it favors one matter over the other.

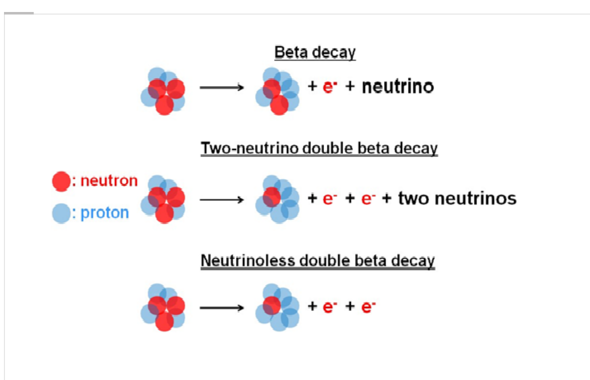

Figure 2: Types of Beta Decay


CUORE
INFN

3 CUORE's Experiment

The Cryogenic Underground Observatory for Rare Events is an experiment in progress at the Gran Sasso National Laboratory(LNGS) locate in Assergi, Italy[4]. Through bolometry, the experiment hopes to detect a radioactive phenomena known as neutrinoless double-beta decay. The experiment consists of 24 lattice structures of tellerium dioxide crystals. Figure 3 shows the tellerium towers suspended by the crostat. Although there are other elements to consider, Te-130 is the candidate isotope for this bolometric technique because of its 30 percent in abundance and its feasibility. However, due to the fact that the half-life of Te-130 is on the 10^{24} orders of magnitude years (many times larger than the current age of our universe), the experiment requires a large quantity of the material in hopes of increasing the probability if its decay. These towers are suspended below a cryostat and are sealed over by a bag and will be flushed with nitrogen to keep them clean.

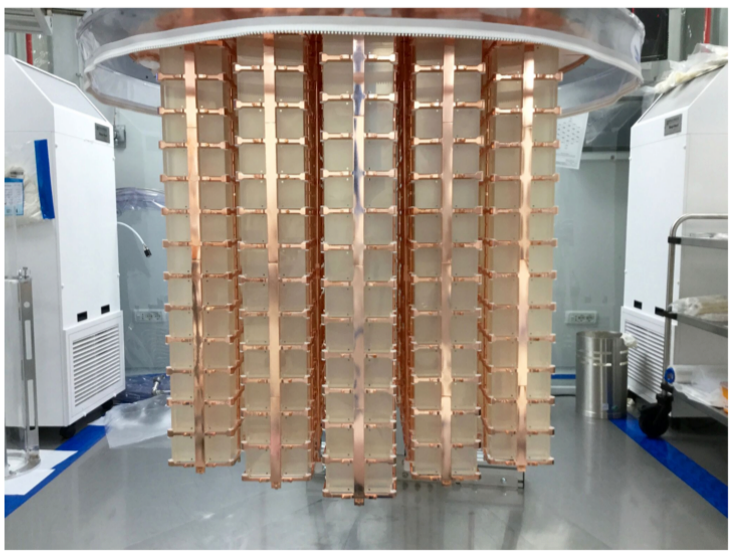

Figure 3: Tellerium towers suspended on the cryostat

Because the particle interactions are very low energy, in order to detect such small changes in temperature due to a single radioactive decay process, the material needs to be supercooled down to the millikelvins. This is done so through a helium dilution refrigerator.

3.1 How the helium dilution refrigerator works

There are two different isotopes of helium—helium-3 and helium-4. He-3 and He-4 both become superfluids at 1 millikelvins and 2.2 Kelvins, respectively. At just the right temperature in which the He-4 is a superfluid but the He-3 is not, pumping away the He-3 causes the temperature to be even cooler. This is because there are two phases in the mixture— the dilute phase, in which it contains more He-4, and the concentration phase, in which there are more He-3. As He-3 is being pumped out of the dilute phase, in an attempt to retain equilibrium, the He-3 from the concentration phase changes its phase to replace the He-3 that was pumped out. This change in phase of the atoms causes them to absorb heat due to the change in lower enthalpy. Figure 4 Shows the different phases of the two isotopes. Through this dilution process, the cryostat can approach temperatures in the tens of millikelvins [5].

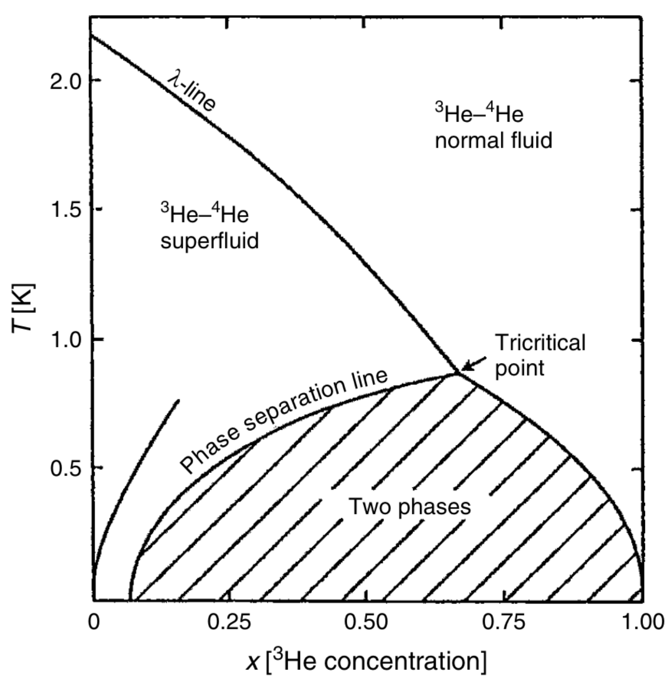

Figure 4: Different Phases of He-3 and He-4 mixture

3.2 My involvement with CUORE

During August of 2016, I was flown to the National Laboratory of Gran Sasso (LNGS) as a research assistant for CUORE.The experiment was in its installation phase and my job was to primarily help out with monitoring various aspects of the environment the experiment was facilitated in and ensure that both the cryostat and workers were safe.Before I jump into the specifics, I will describe the the typical routine that I followed during my days working for LNGS.

The work day started at 8am. My colleagues and I were stationed in a bed and breakfast, Il Parco, not too far of a walk away from the main offices. Upon arrival, we would grab our helmets and await for a shuttle to transport us into the mountains of Gran Sasso where the actual laboratory is located in. The reason for an underground laboratory is to reduce the amount of noise picked up in experiments due to cosmic radiation.

The National Laboratory is divided into three sections, as observed in Figure 5.

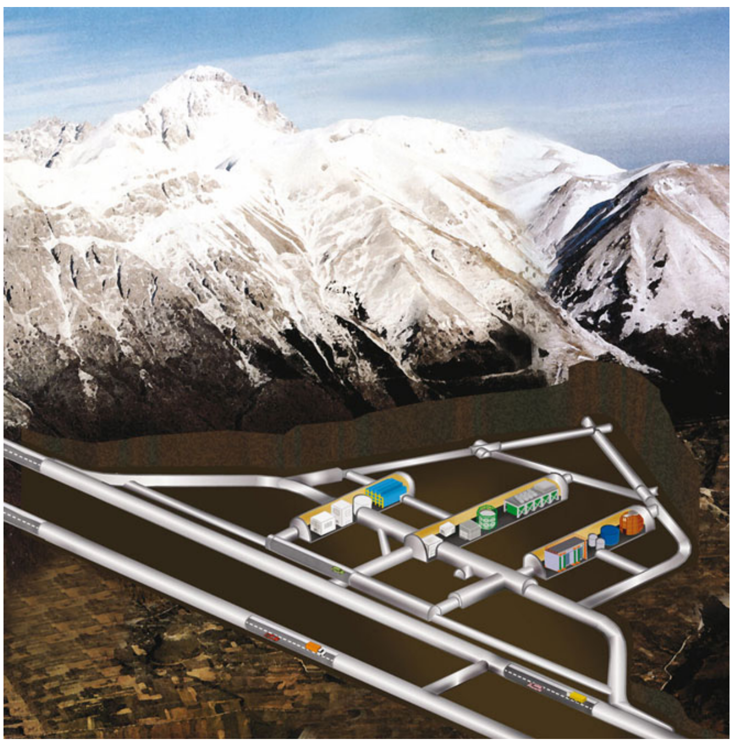

Figure 5: LNGS Underground Laboratory

Each section of the underground laboratory is dedicated to a different experiment. CUORE is stationed first from the left; the other two sections run various experiments including XENON which focuses its search for dark matter in our universe.

Before starting the monitoring shift, the nitrogen level of the nitrogen needs to be checked. To ensure that the experiment will be safely cooled, the nitrogen levels have to be above a certain threshold. Figures 6 and 7 are pictures of the pressure levels within the tank. The online status check is primarily for those who are off-site shifters.

Figure 6: Physical Status of Nitrogen level

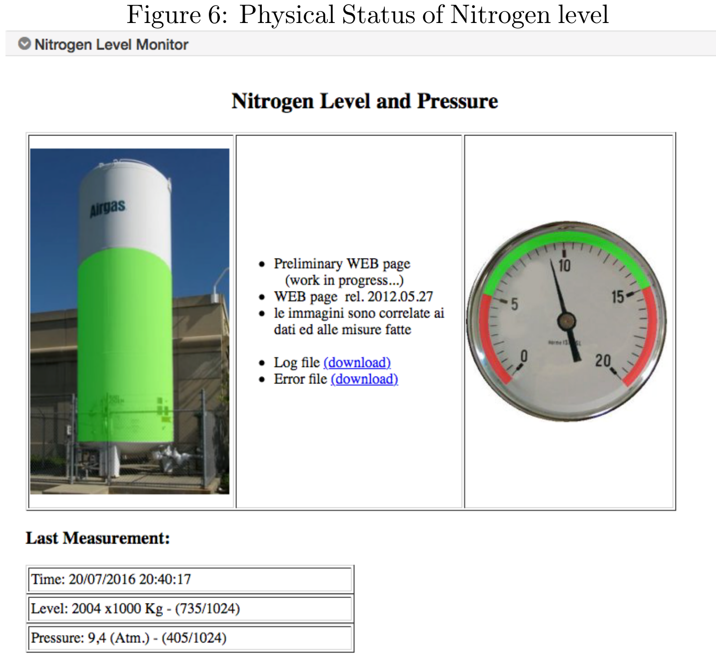

Figure 7: Online status of nitrogen tank

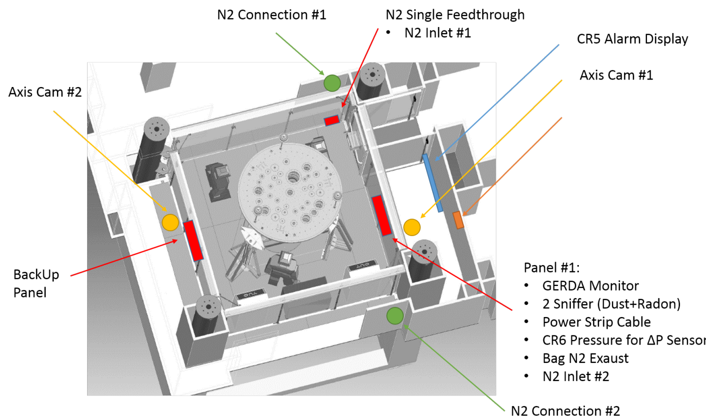

Figure 8: Layout of the experiment environment

Figure 8 is a layout of the different rooms and monitors surrounding the cryostat. Cameras are positioned throughout the clean rooms (CR) in order to monitor either the crew or the pressure levels within the towers and the bag. Figure 9 is a snapshot of what we would see through the video cameras located in clean room 6 (where the cryostat is located). On the left, we are able to observe there is bubbling in the flask which will indicate whether or not nitrogen is being flushed through the towers to clean them. On the right, pressure levels tell us whether or not the towers are sealed tight. If the pressure level is below a certain point, that is an indicator of a leakage.

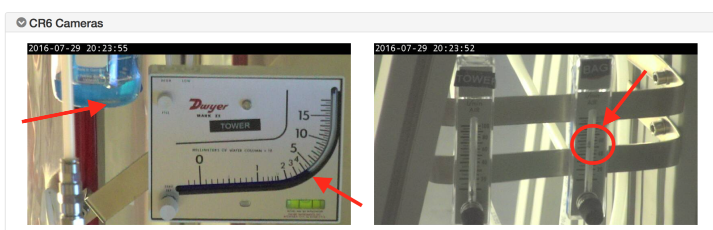

Figure 9: CR6 Cameras

Inside the monitoring room, the on-site shifter's responsibility is to submit a detailed elog–essentially a status report– every half-hour of the climate in the experiment room.. At the start of the shift, my responsibility is to guide a team through multiple clean rooms before they enter the room with the crystotat. Communication is made through skype and cameras located throughout the room. Any anomalies and events must be recorded. This is the bulk of the work day until evening. However, the on-site shifter is on-call 24/7. Should any alarms go off during out of work hours, we are to analyze the situation remotely by accessing the lab computer through VPN. If anything was out of the ordinary, a higher-up (generally, one of the post-doctorates) would be contacted to diagnose the problem.

Once a week, the experiment environment must be cleaned. Before entering the clean rooms, we must put on a full-body clean suit in order to prevent any possible contaminations within the workspace. Figure 10 is an image of me taken before entering the main rooms.

Figure 10: Clean suit required during entry of clean rooms

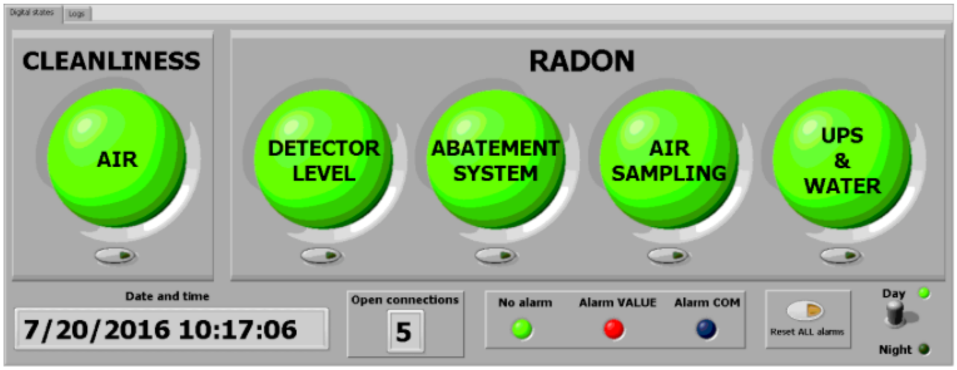

Figure 11: Alarm Status UI

Figure 11 is the alarm display corresponding to critical factors within the cryostat environment that needs attention. These aspects include :

- The cleanliness of the room. This is essentially monitoring the amount and size of unwanted free floating particles.
- Radon content in the room that is naturally reoccurring. A lot of effort is put into keeping the experiment radon free to reduce the amount of noise
- Status of the abatement system. The abatement system is responsible for draining the room of any radon.
- Air Sampling. This detector is utilized to ensure that the air flow is adequate enough for an appropriate analysis of the environment.
- The UPS and water system is responsible for the backup power and cooling of the equipment. In the case that the power does go out, the backup battery will be able to run for a couple of hours.

During my on-site shift, I am to monitor all of the above factors and ensure that nothing rises above critical level. Figure 12 is similar to a visual interface that I work with. The radon detector essentially measures the concentration of polonium 214 and polonium 218, both daughters of radon. Polonium is problematic because it decays into lead, and the fact that it decays at all is hindering to the project because it will contaminate the signal of noise. Should any of these alarms go off during installation hours, I am to notify the crew in the cryostat room to stop what they are doing until the levels drop back down.

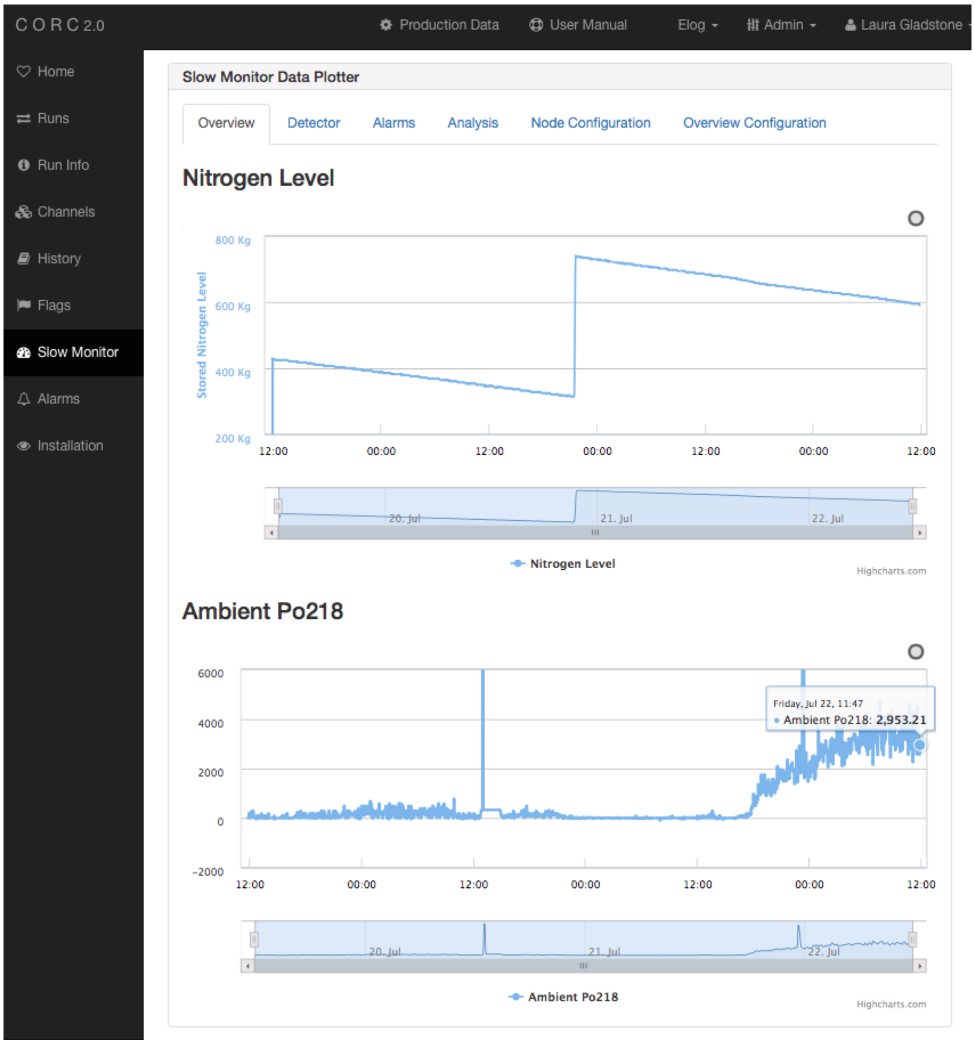

Figure 12: Display of polonium concentration

Aside from just the on-site shifter responsibilities, I have also aided in a variety of tasks during my time with CUORE. Such tasks include learning LaTeX and reformatting the shifter manual from a .docx to .tex file, helping to repair broken thermistors that are used as bolometers for the experiment, and measuring flex lines that are used to pump coolant in and out of the cryostat.

4 Concluding Remarks

The discovery of the ($0\nu\beta\beta$) will be a huge milestone for our knowledge of particle physics. Scientifically, if discovered, it will reveal that the neutrino is its own particle thus changing the Standard Model and the way we interpret physics. Philosophically, it will provide a better understanding as to why there are more matter than anti-matter in our universe— why do we, or anything for the matter, exist at all? It was an honor being able to contribute even in the slightest to such a large collaboration. After my return from Italy, the installation phase of the towers were practically finished and a two-month long cooling process was started. To my knowledge, the experiment will start collecting data sometime later this 2017.

5 References

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[3] "Law of Conservation of Lepton Number." http://www.nuclear-power.net/laws-of-conservation/law-conservation-lepton-number/. Accessed 15 May 2017.

[4] Green, Kate. "For Ultra-cold Neutrino Experiment, a Successful Demonstration." News Center, 9 April 2015. http://newscenter.lbl.gov/2015/04/09/for-ultra-cold-neutrino-experiment -a-successful-demonstration/. Accessed 15 May 2017

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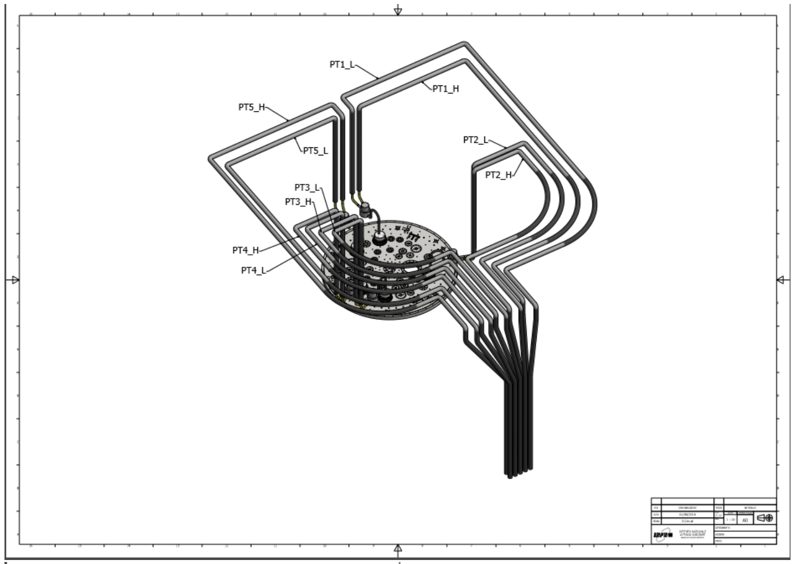
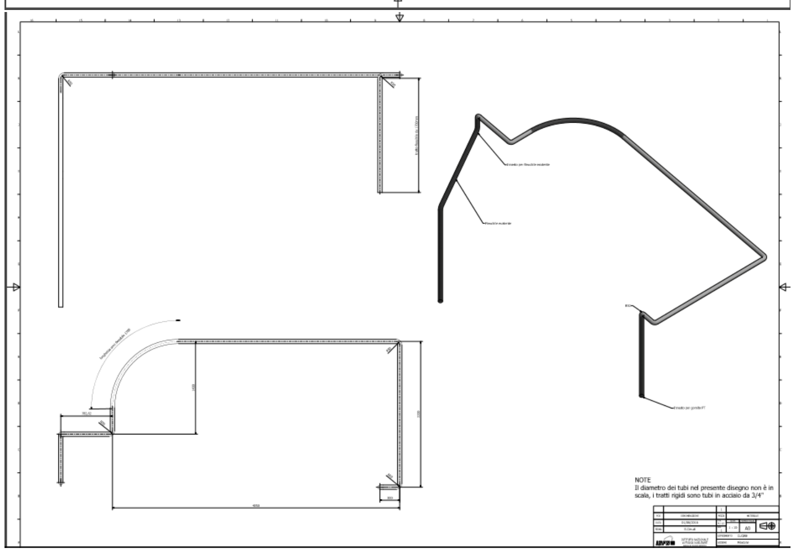
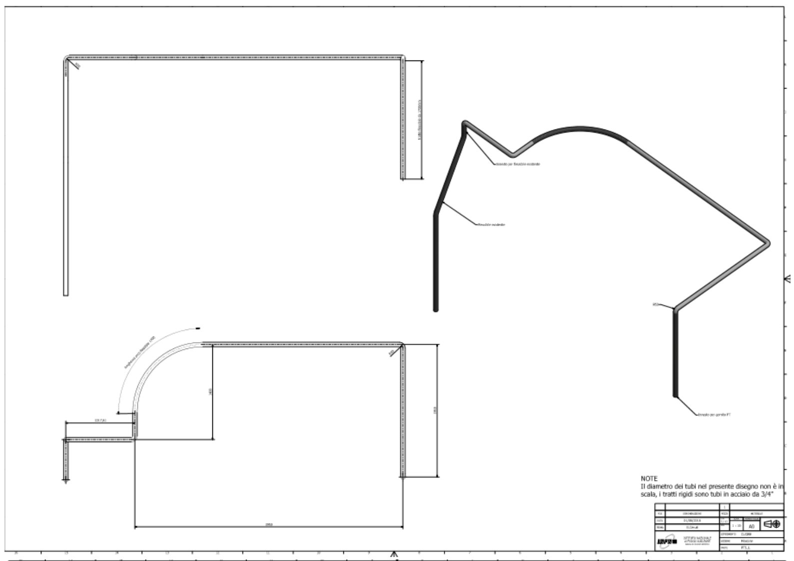
6 Extras (diagrams of the pipelines used for the cryostat)



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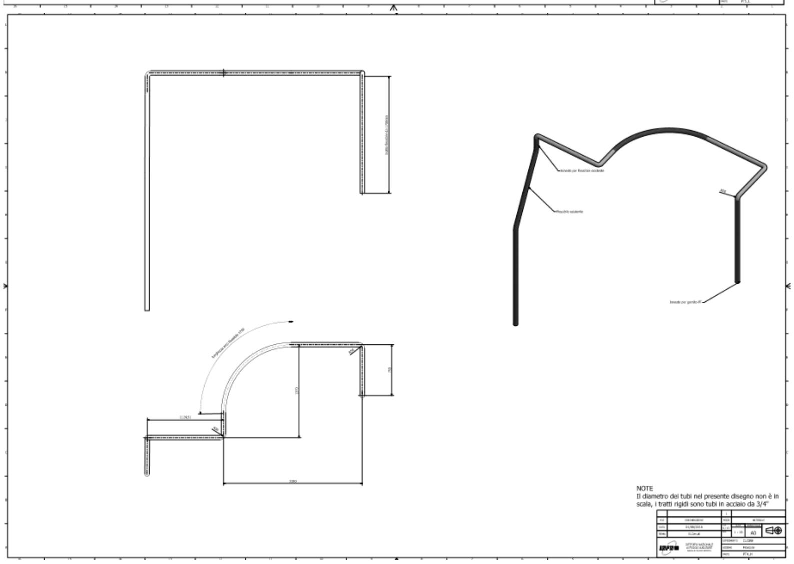
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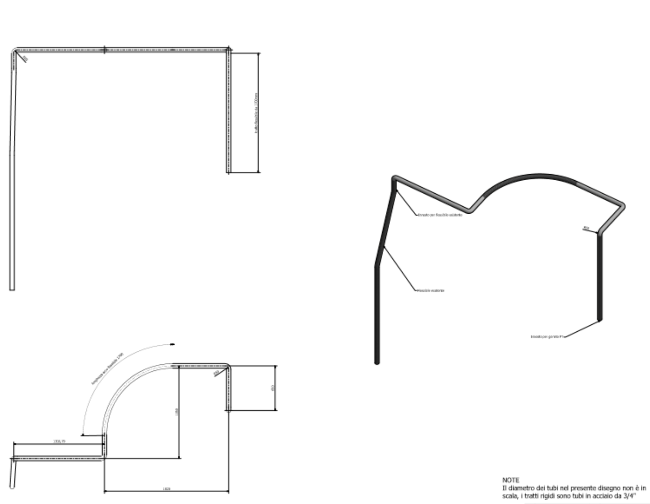
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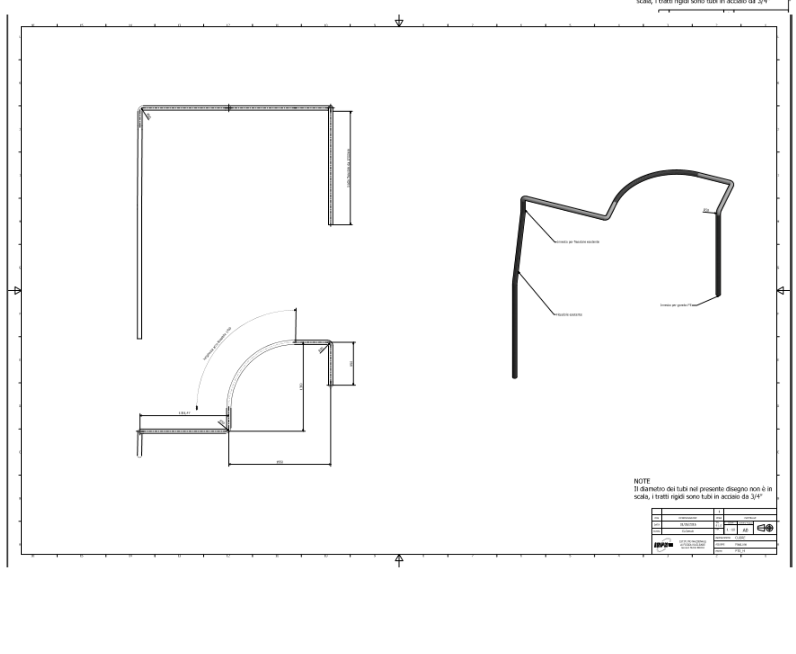
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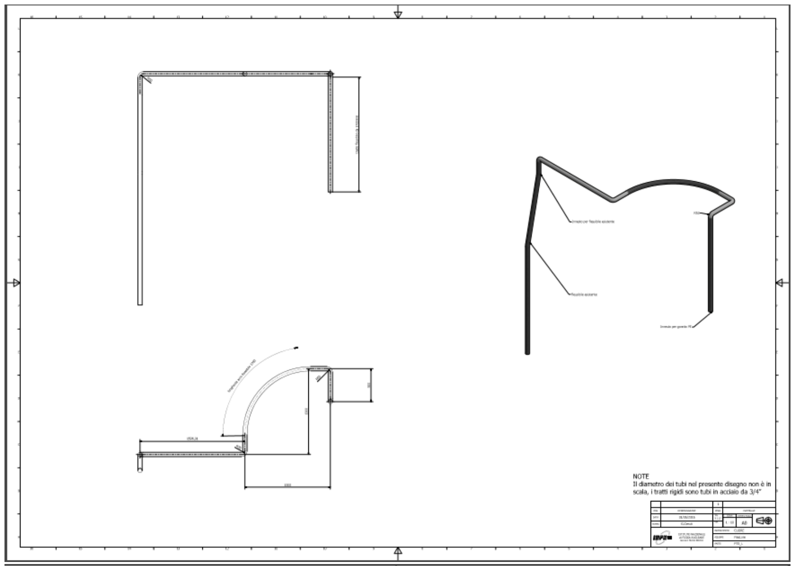
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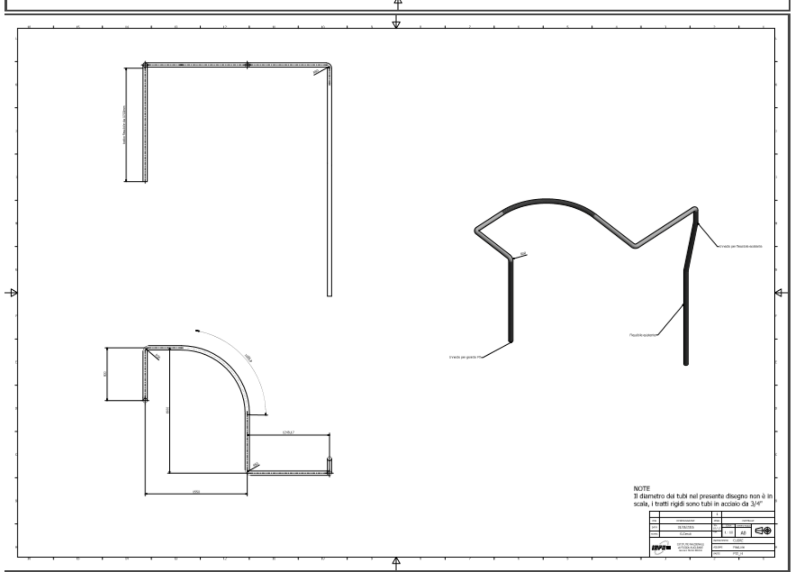
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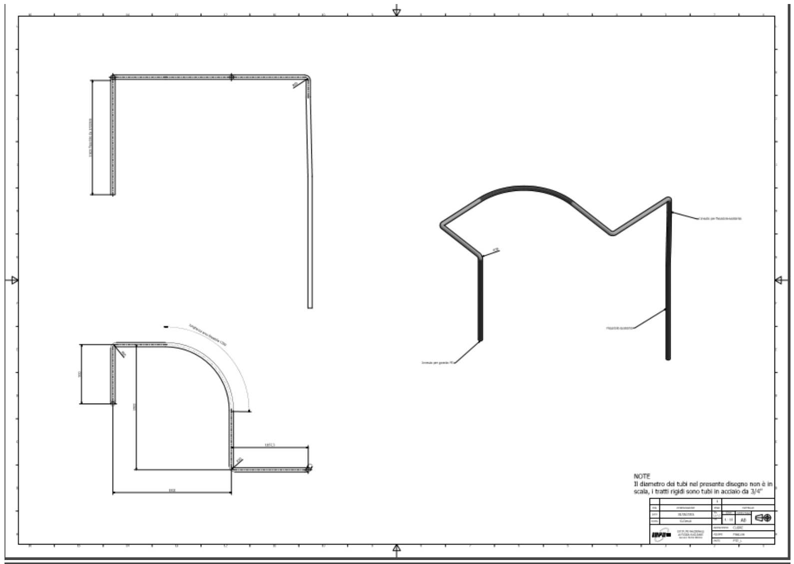
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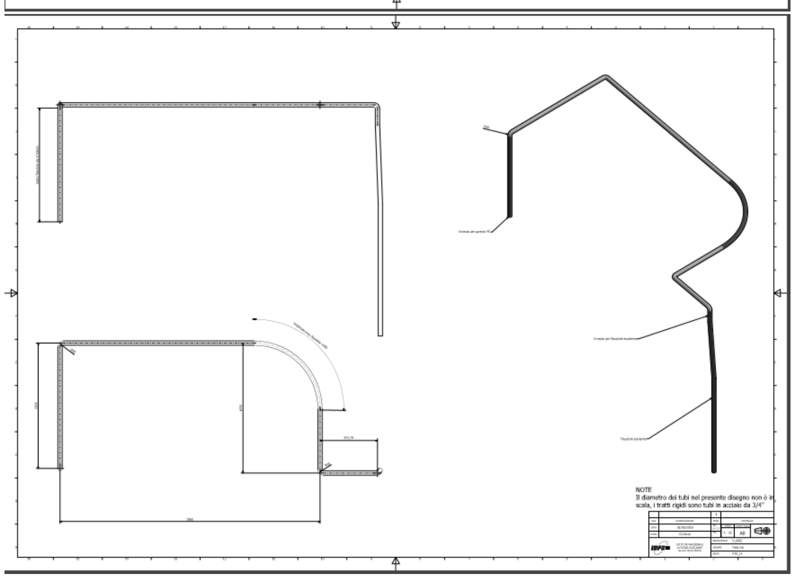
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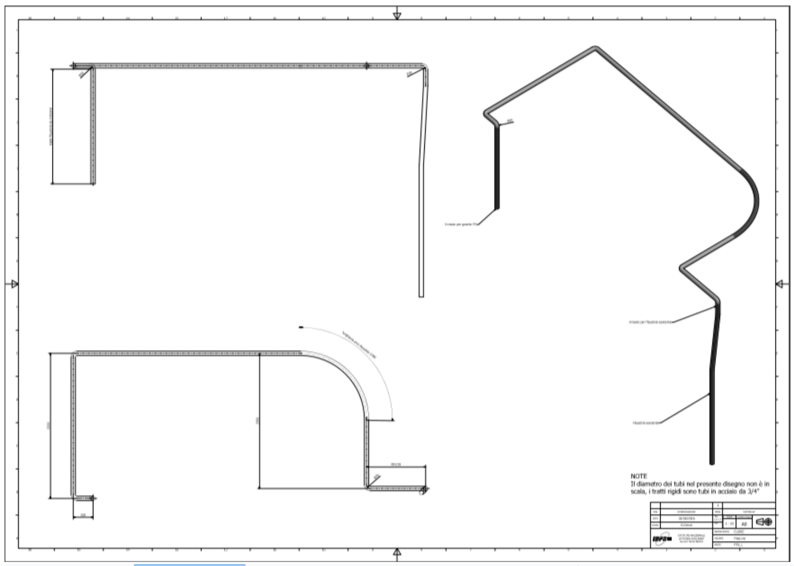

Excel Online

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	A	B	C	D	E	F	G	H	I	J
1	FLEXIBLE LINES	LENGTH (mm)		EXISTING FLEX LINES (METERS)	# of					
2	5H	3400		10.2	1					
3	5L	3400		12.5	5					
4	4H	3400		20.5	4					
5	4L	3400		Total:	154.7					
6	3H	3400								
7	3L	3400								
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Flexline (Flexible part) measurements

KP kevin phung
Tue 8/2/2016, 2:27 AM
Paolo Gorla (paolo.gorla@lngs

Flex Line Lengths (Flexib...
10 KB

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Hey Paolo,

So the total length (including measurements from Vivek) turned out to be about 188601 mm.
If you were to wrap Armaflex around BOTH the flexible parts and the steel parts you would need about 233850 mm long of the material.

Let me know if this is what you wanted.

-KP