NOvA Medium Energy Target Assembly and NuMI Target Horn System

Zac Espinosa

Stanford University

SIST Intern, Summer 2016

Fermi National Accelerator Laboratory

Supervisors: Chris Kelly and Bob Zwaska

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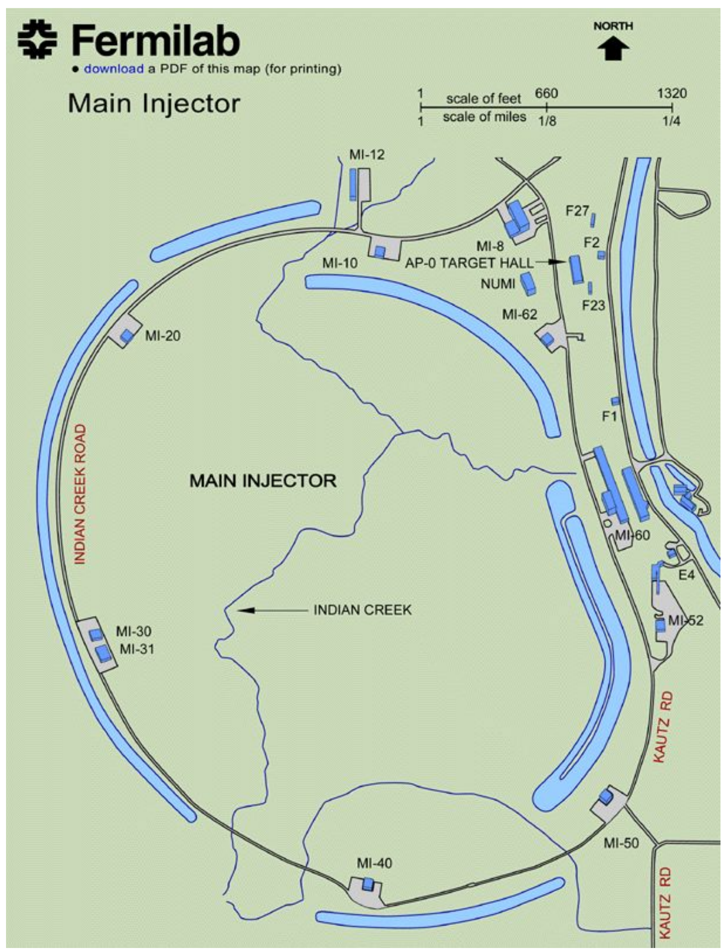
Abstract

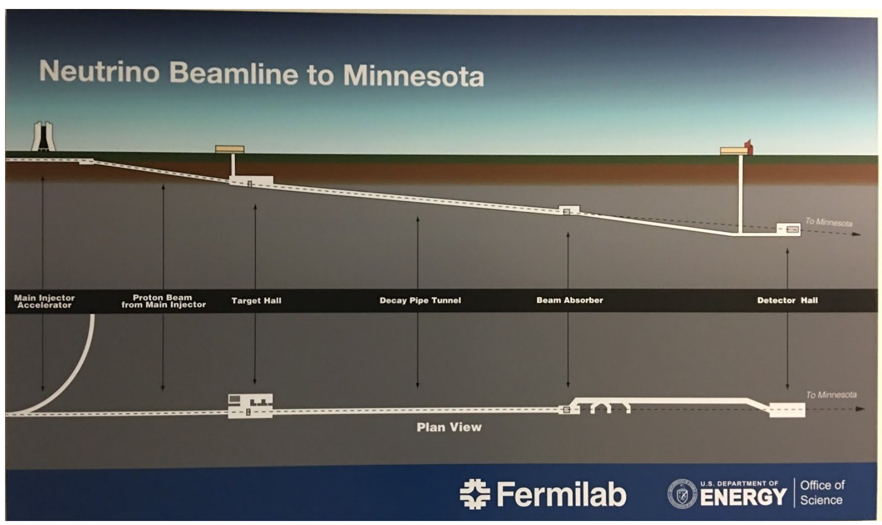
The NOvA Neutrino experiment is designed to explore three fundamental questions: By what process do muon neutrinos oscillate into electron neutrinos? What is the neutrino mass hierarchy and by what process do neutrinos get their mass? Do muon neutrinos and muon antineutrinos break charge-parity symmetry? In order to explore these fundamental questions Fermilab uses its two mile synchron and the NuMI beamline facility to first create the world's most powerful neutrino beam. This neutrino beam is then aimed at two massive detector, one in Minnesota and the other at Fermilab. In this paper I will explain NuMI's (Neutrinos at Main Injector) Target & Horn focusing system converts protons into neutrinos. I will also explain the design and construction of NuMI Targets. This summer I spent several weeks aiding in the assembly of NuMI Targets 04 and 05 and in the construction of MiniBooNE Horn 2.



Overview

Here at Fermilab names and acronyms can get quite confusing, so before continuing we should clarify some acronyms. NOvA stands for Neutrino Oscillation Appearance. NOvA explores the oscillation of muon neutrinos into electron neutrinos. The v in NOvA is the symbol for neutrinos. Unlike the oscillation between muon and tau neutrinos, this oscillation is rare and continues to puzzle physicists. NOvA is part of the Intensity Frontier of modern day physics, because it works with high intensity particle beams and high sensitivity detectors. The Fermilab Main Injector is a high energy two mile proton synchrotron. The injector is designed to accelerator protons to near the speed of light in order to conduct a variety of experiments. NuMI stands for Neutrinos at Main Injector, and the u in NuMI is the symbol for muons, because NuMI creates muon-neutrinos. NuMI is the system responsible for converting the Main Injector's proton beam into a neutrino beam. NuMI is located one hundred and fifty feet beneath MI 65.

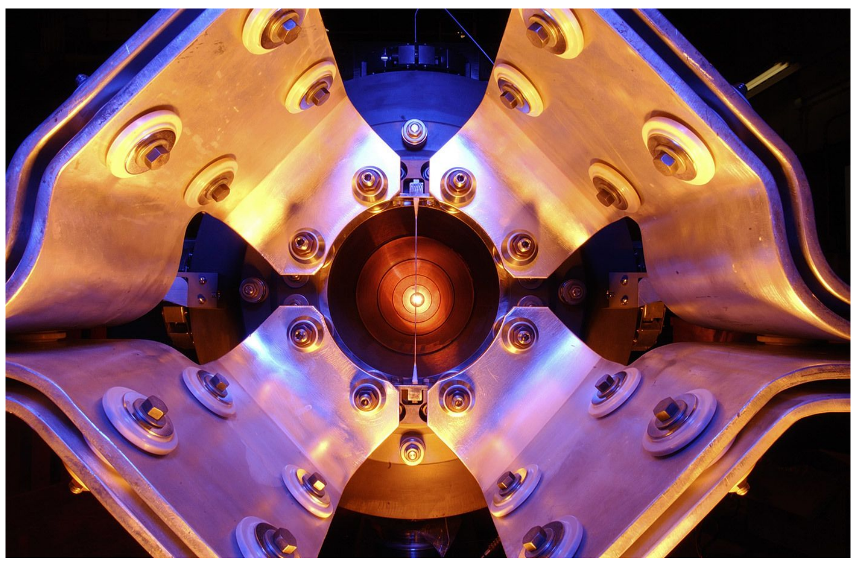
The NuMI beamline is aimed at a detector "450 miles away in northern Minnesota, at the Soudan Underground Mine State Park in Tower-Soudan" (http://www-numi.fnal.gov/). Fermilab utilizes the curvature of the Earth and neutrinos' low interaction rate in order to achieve incredible precision. The beamline is aimed at a 3.3 degree downward slope and at its lowest point this beam will travel more than 6 miles beneath the surface of the Earth. The entire trip of 500 miles takes less than three milliseconds. The figure above compresses and juxtaposes an aerial view of the beamlines path. In this we see that the conversion



process from proton to neutrino beam occurs in the Target Hall and Decay Pipe Tunnel. The Target Hall is home to the Target and Horn focusing system.

Target and Horn Focusing System

Fermilab scientists create the NuMI neutrino beamline through a Target and Horn system. The proton beam from the main injector pulses 4.9E13 protons every 1.33 seconds into a row graphite fins resembling tall dominos. When NOvA first came online each pulse contained 400 kilowatts of power. Scientists at Fermilab over time have raised the power to a record setting 700 kilowatts of power. At higher powers scientists are able to create a more intense neutrino beam. The collision of protons and graphite creating a spray pions, kaons, and other particles. Physicists then recollect and focus these pions (positively charged) through the Horn focusing system.



The Horn system is comprised of two modules, Horn 1 and Horn 2. Both Horns are similar in shape to an hourglass, while Horn 2 is simply a larger design of Horn 1. Horn 2 is designed to increase neutrino beam intensity. The figure to the right features an upstream view of Horn 1. Surrounding its hourglass shaped core are eight strip lines, four for power and four for ground. These strip lines accept create a magnetic field encompassing the horns core. The Target's scattered pions are caught in the magnetic field and then follow its curvature, essentially narrowing the beam of pions.

The Horn system is made almost entirely of aluminum. Other than being cheap, highly conductive, and very durable aluminum helps minimize radioactive materials. Aluminum is less dense than typical metals such as stainless steel. The half-life of neutrino radiation is dependent on the density of the material it interacts with. For this reason, aluminum is a perfect alternative to stainless steel, because it is equally durable yet less dense. Additionally, the entire Horn focusing system is cooled by a 25 mph circulating wind tunnel. Cooling air is sent through filters and then chillers in order to remove thermal heat from the Horns, while Munters keep the system free of excess humidity. When the beam enters the Target and Horn system it transitions from vacuum to free air. Creating a vacuum large enough for the Target and Horn system is incredibly difficult; Physicists have opted to place the modules in free air, however a major challenge of creating a narrow beam in air is that particles will collide and interact with atoms in the air. This increases radioactivity necessitating additional radiation protection. Once the focused beam of pions exits Horn 2 it enters the decay pipe. By the end of the decay pipe the pions have decayed into neutrinos, creating a six foot beam of high intensity neutrinos. From here the neutrino beam hits two detectors. The first is a 330 metric-ton scintillator detector and the second, located in Minnesota, is 14 metric-kilotons. When neutrinos collide with scintillation liquid the resulting energy is captured by photodetectors. Scientists are able to trace both the path and collision location of neutrino interactions.

Target Assembly

This summer I spent much of my time working to understand the NOvA system described above and aid in the assembly of two NOvA medium energy Targets. These Targets are considered medium energy, because they are designed to withstand 700 kilowatts of energy. Although considered medium energy, this neutrino beamline is the most intense in the world. Fermilab is currently preparing for the construction of LBNF which will create a neutrino beam carrying 2.1 megawatts of energy.

Forty-eight graphite fins, approximately 24.00 mm wide, 150 mm tall, and 7.4 mm thick create one target. The proton beam will pass through the narrowest edge of these fins (7.4 mm). These graphite fins come in three variates: upstream, downstream, and normal. All three variations are nearly identical in dimension, except that the upstream fins have a .4 mm

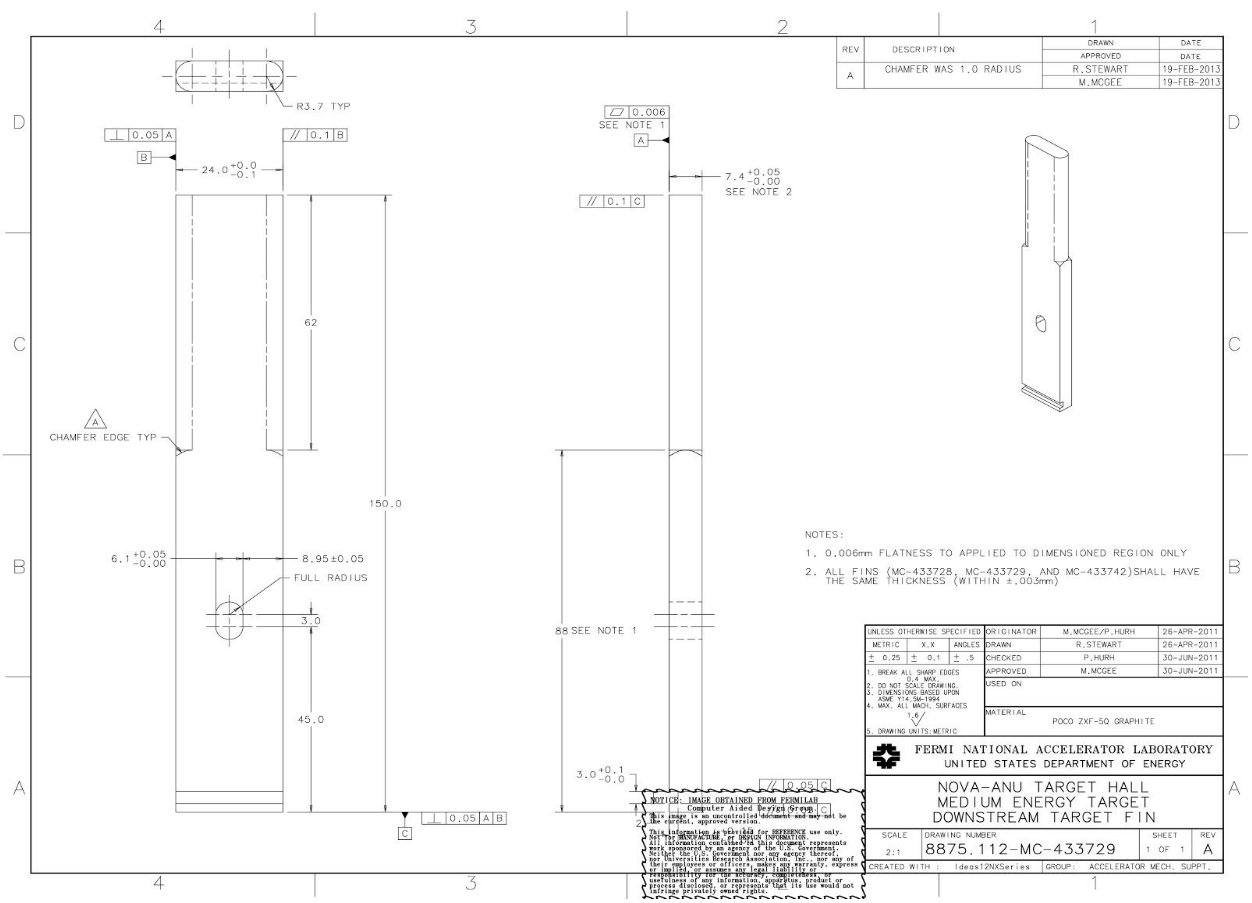
bevel and both upstream and downstream fins have a hole to mount the pressure plate. The graphite fins are mounted in groups of four, one upstream, one downstream, and two normal. Due to thermal expansion each set of fins is mounted using a pressure plate, two springs, two bolt, and two spring centering washers. This system allows for a tight fit without fear of cracking.

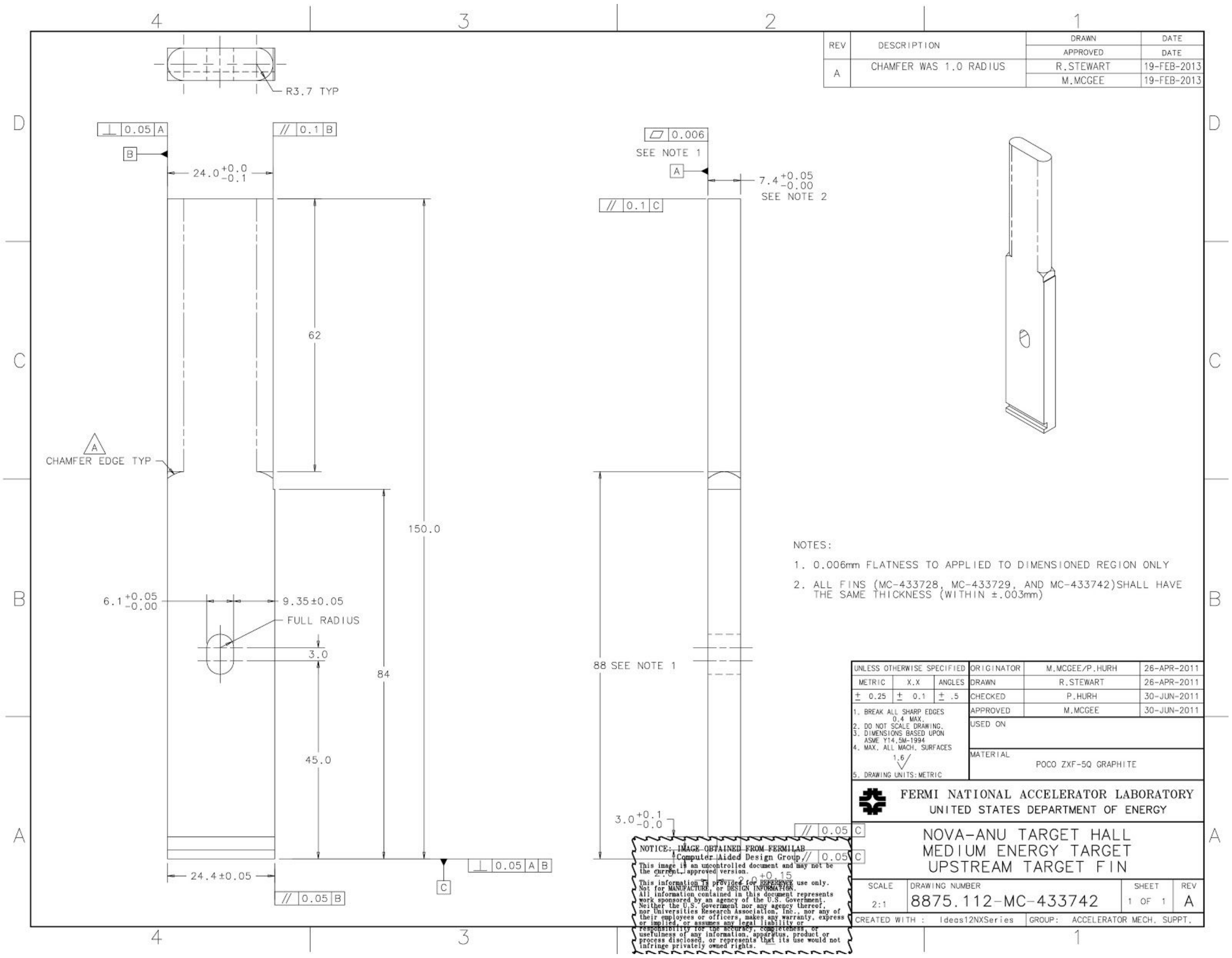
Near the end of the cooling rail two tubes protrude in order to carry deionized cooling water. Graphite has the tendency to absorb any surround moisture. Before assembly, I spent nearly two weeks triple washing each part using alcohol, soap, and a bransonic rinser in order to destroy manufacturing oils. We then bagged each piece and kept them under vacuum along with graphite fins. This procedure avoids unnecessary exposure to moisture when constructing the Target. When graphite and moisture come in contact at such high energies they create carbonic acid. Similar to the Horn focusing system, dehumidifiers pull moisture away from the Target and helium is blown through and around the Target.

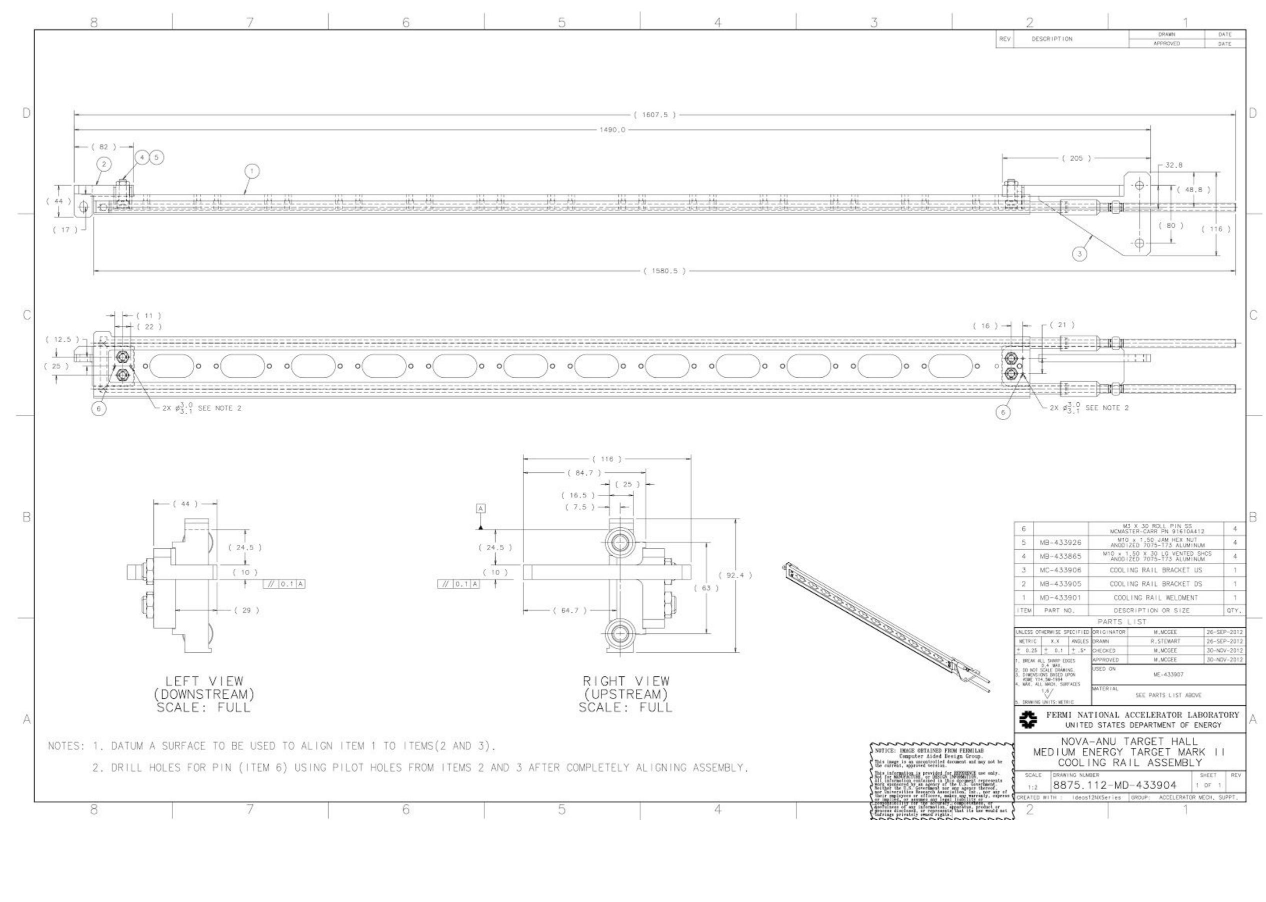
Reflection and Acknowledgments

Targets 04 and 05 are currently being used as spares for NuMI. With any luck, either 04 or 05 will eventually be installed into the Target hall. My experience at Fermilab has been a very unique, yet enlightening one. As a computer science and math major I have never been exposed to the type of technical, mechanical skills required as an assistant technician. Perhaps the coolest part of this internship has been the immediate impact of my work. No matter how small, most of the work I did while at Fermilab will have a direct influence on the NuMI facilities and its operations. A big thanks to Ralph Ford for teaching me about the Target/Horn system and acting as a mentor throughout my stay at Fermilab. Thank you to Chris Kelley for being a conscientious and flexible

supervisor, as well as a constant source of information. A huge thank you to Mike Stiemann, Jim Zahurones, Heip Le, Robert Albrecht, Frank Schneider, Cervando Castro, Paul Schild, Keith Gollwitzer, and Henry Schram for welcoming me into MI-8 and teaching me everything I know about being a technician. Thank you to Bob Zwaska for lending me his college books on quantum mechanics and explaining the physics of Target beamlines. Thank you to Sandra Charles, Judy Nunez, and the entire SIST committee for giving me this amazing opportunity. This summer has been an incredible journey, and I wish you all the best of luck. Hope to see you next summer!




CHAMFER WAS 1.0 RADIUS
R.STEWART 19-FEB-2013
M.MCGEE 19-FEB-2013
R3.7 TYP
CHAMFER EDGE TYP
FULL RADIUS
SEE NOTE 1
SEE NOTE 2
88 SEE NOTE 1
NOTES:
1. 0.006mm FLATNESS TO APPLIED TO DIMENSIONED REGION ONLY
2. ALL FINS (MC-433728, MC-433729, AND MC-433742)SHALL HAVE THE SAME THICKNESS (WITHIN ±.003mm)
ORIGINATOR M.MCGEE/P.HURH 26-APR-2011
DRAWN R.STEWART 26-APR-2011
CHECKED P.HURH 30-JUN-2011
APPROVED M.MCGEE 30-JUN-2011
MATERIAL POCO ZXF-5Q GRAPHITE
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY
NOVA-ANU TARGET HALL
MEDIUM ENERGY TARGET
UPSTREAM TARGET FIN
SCALE 2:1
DRAWING NUMBER 8875.112-MC-433742
SHEET 1 OF 1
REV A
CREATED WITH : Ideas12NXSeries
GROUP: ACCELERATOR MECH. SUPPT.
NOTICE: IMAGE OBTAINED FROM FERMILAB Computer Aided Design Group.


LEFT VIEW
(DOWNSTREAM)
SCALE: FULL
RIGHT VIEW
(UPSTREAM)
SCALE: FULL
NOTES: 1. DATUM A SURFACE TO BE USED TO ALIGN ITEM 1 TO ITEMS(2 AND 3).
2. DRILL HOLES FOR PIN (ITEM 6) USING PILOT HOLES FROM ITEMS 2 AND 3 AFTER COMPLETELY ALIGNING ASSEMBLY.
6 M3 X 30 ROLL PIN SS MCMASTER-CARR PN 91610A412 4
5 MB-433926 M10 x 1.50 JAM HEX NUT ANODIZED 7075-T73 ALUMINUM 4
4 MB-433865 M10 x 1.50 X 30 LG VENTED SHCS ANODIZED 7075-T73 ALUMINUM 4
3 MC-433906 COOLING RAIL BRACKET US 1
2 MB-433905 COOLING RAIL BRACKET DS 1
1 MD-433901 COOLING RAIL WELDMENT 1
PARTS LIST
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY
NOVA-ANU TARGET HALL
MEDIUM ENERGY TARGET MARK II
COOLING RAIL ASSEMBLY
8875.112-MD-433904

Sources

Amati, Alan. *Shades of Winter*. 2016. Fermilab, Batavia. *Femilab Today*. Web. 11 Aug. 2016.

"NOvA." *Fermilab*. Fermi National Accelerator Laboratory, 30 July 2015. Web. 11 Aug. 2016.