FERMILAB-TM- 2577-DI
January 2014

Accelerator/Experiment Operations - FY 2013

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Edited by S. Geer and H. Ramamoorthi

This Technical Memorandum (TM) summarizes the Fermilab accelerator and accelerator experiment operations for FY 2013. It is one of a series of annual publications intended to gather information in one place. In this case, the information concerns the FY 2013 MINOS and MINERvA experiments using the Main Injector Neutrino Beam (NuMI), the MiniBooNE experiment running in the Booster Neutrino Beam (BNB), and the Meson Test Beam (MTest) activities in the 120 GeV external Switchyard beam (SY120).

Each section was prepared by the relevant authors, and was somewhat edited for inclusion in this summary.

Accelerator Operations (R. Dixon, S. Henderson)

FY 2013 Accelerator Operations

The low-energy and high-energy neutrino beams, the SeaQuest beam, and the Test Beam in the Meson area were shutoff on May 1, 2012 to begin work on the accelerator upgrades for NOvA (ANU), and for overall accelerator system maintenance. The shutdown of the Main Injector ended July 30, 2013, with the startup of the Accelerator systems for commissioning. Vacuum issues in the Main Injector delayed Commissioning and neutrino running until September.

Early in FY13 a new RFQ was installed and commissioned in the Proton Source. It was running for Booster operations by the end of 2012. Booster beam was used to improve orbits and to test collimation improvements for the Proton Improvement Plan.

At the end of the year the NuMI beam came up quickly for physics and for Recycler commissioning, which required interleaved downtimes to investigate and repair aperture and alignment problems. In addition, the SeaQuest beam is also being commissioned in FY14, and one test beam to the Meson Lab has been running steadily while the other waits to be commissioned. Figure 1 shows the integrated beam to NuMI in FY14. There was no beam integrated in FY13.

Operated by Fermi Research Alliance, LLC under Contract No. De-AC02-07CH11359 with the United States Department of Energy.

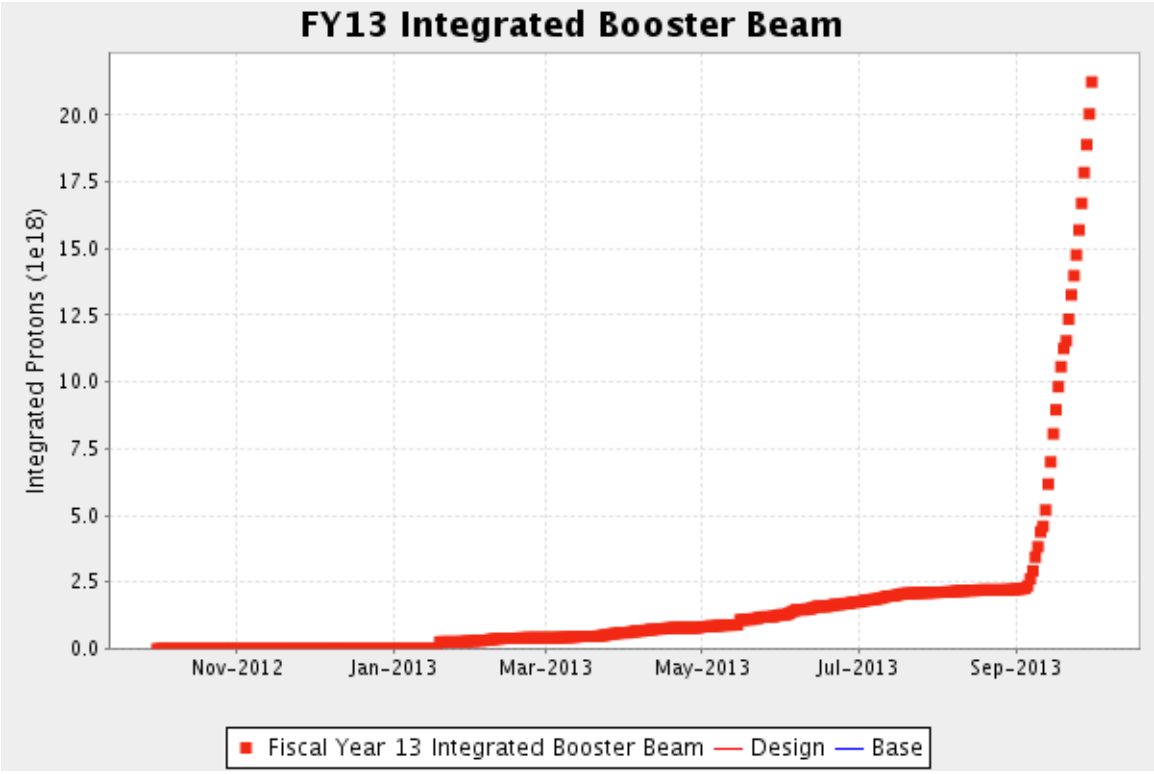

Figure 1: Fiscal year 2013 integrated Protons through Booster.

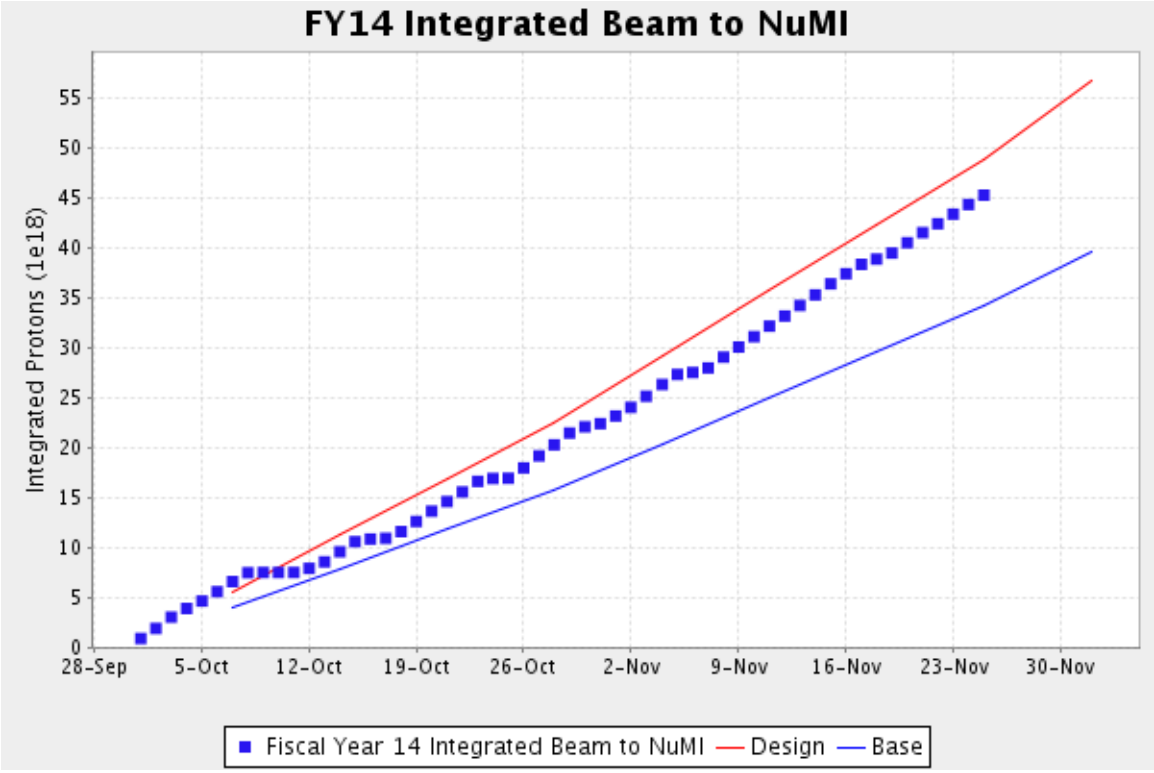

Figure 2: Fiscal Year 2014 integrated proton beam delivered from to NuMI.

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NuMI Beam and MINOS Operations (D. Torretta, R. Plunkett, B. Pahlka)

NuMI and MINOS operations in FY 2013 were dominated by the shutdown of the accelerator complex until a relatively smooth startup occurred in September of 2013. Here we summarize the work that was done to ready the MINOS detectors for the running conditions of the NOvA era. Much of this work was done while the NOvA near detector cavern was under construction. However, adequate access allowed for the work to be completed and tested, including maintenance of the near detector magnet system.

A principal activity was replacement of many components of the MINOS near detector DAQ system. This was motivated by the increasing age and decreasing reliability of the previous, custom-built DAQ, and a desire to use industrially available solutions. In addition, replacement of the older components created a large spares pool for the MINOS far detector, located in Soudan, Minnesota. The front-end electronics and timing systems of the detectors were unchanged.

-The new near detector refurbished DAQ uses GigaBit Ethernet communication and data transfer between new VME CPUs (Motorola) and the DAQ computers, replacing a copper & optical fiber dedicated PVIC bus in the old DAQ system.

- To host the new DAQ computers a new enclosed DAQ rack was prepared and installed to keep underground dust off the equipment. The newly installed DAQ rack passed ORC in early Dec 2012.

- Since ORC clearance the system was left on continuously; this increased the commissioning speed of the DAQ using remote logins.

- The new DAQ rack hosts 8 1U quad computers running multiple processes: only three computers are used for the DAQ; the others are hot spares.

- The Fermilab CD Scientific Workstation Support group now manages systems issues on these computers.

- The CD Network Service group has installed a new Network Switch rack together with new switching hardware. This received ORC clearance in June 2013.

Data taken with the refurbished DAQ was certified and signed off on in early 2013 by MINOS Offline and Calibration groups by comparing data taken with old and new systems. The system was ready to take data when beam returned at the end of FY2013 and has functioned with minimal downtime and only repairs of a few minor issues.

The MINOS far detector and magnet are under constant supervision by staff at the Soudan Laboratory. If needed, repairs are performed promptly. During the shutdown all electronics was checked and made ready for beam. Soudan crew were trained by Fermilab staff to repair VARC intermediate level event builder boards on site, improving availability of this component. An

upgraded chilled water system was commissioned, and maintenance was performed on the MINOS magnet and its power supplies.

At the end of the shutdown the far detector was ready for data taking with uptimes near 99% for atmospheric neutrinos. Refurbishment of the far detector DAQ is possible - new DAQ computers and new Motorola CPUs have already been deployed at Soudan in March 2013 to facilitate this work when appropriate.

Beam was restored to the NuMI beamline at the beginning of September, 2013. A total of 1.8 x 10^{19} protons on target were recorded in the remainder of FY2013, all in the new medium-energy NuMI configuration. After a brief period (one week of usable beam) of 85% uptime fraction due to readout problems, the uptime of the MINOS far detector returned to greater than 94% before the end of FY 2013, and the uptime of the MINOS near detector was at or above 93% throughout the period.

In FY 2013, the MINOS experiment continued to exploit the large dataset collected with neutrino and antineutrino settings of the NuMI beam, as well as a significant and growing sample of events induced by cosmic rays. The activities focused on completing publication of analyses, extension of the range and interest of analysis by combination of datasets, and new results.

Earlier studies of muon neutrino disappearance in a two-neutrino approximation were published during FY2013 as Phys. Rev. Lett. 110, 251801 (2013). Illustrating further work, Fig. 3 shows spectra from the full MINOS dataset used in a combined analysis of muon neutrino disappearance and electron neutrino appearance samples for 14.1 x 10^{20} protons on target (POT) taken by MINOS. A wide variety of samples have been used, including muons from charged-current (CC) events occurring in the surrounding rock of the MINOS cavern ("non-fiducial muons"), as well as beam-induced ("fiducial") and atmospheric samples. The best fits shown use a full 3-neutrino description of the oscillation process, with a value of q_{13}, the mixing angle which governs electron-neutrino participation in the oscillations, taken from precise recent reactor experiments.

In a three-neutrino analysis, the measurement of CC ν_μ disappearance is affected by unknown areas of the mixing sector. In particular, we see in Fig. 4 that the results may be presented as a function of the neutrino hierarchy. The MINOS data have their best fit for inverted hierarchy and a non-maximal value of the mixing angle θ_{23}. The limited statistical significance of the result will improve with further data taking in MINOS+.

Electron neutrino appearance in the MINOS far detector allows a determination of the mixing angle θ_{13}, and can give some information on the CP phase delta in various scenarios of mass hierarchy and octant of θ_{23}. As an example of this interesting technique, Fig. 5 shows MINOS data from Phys. Rev. Lett. 110, 171801 (2013).

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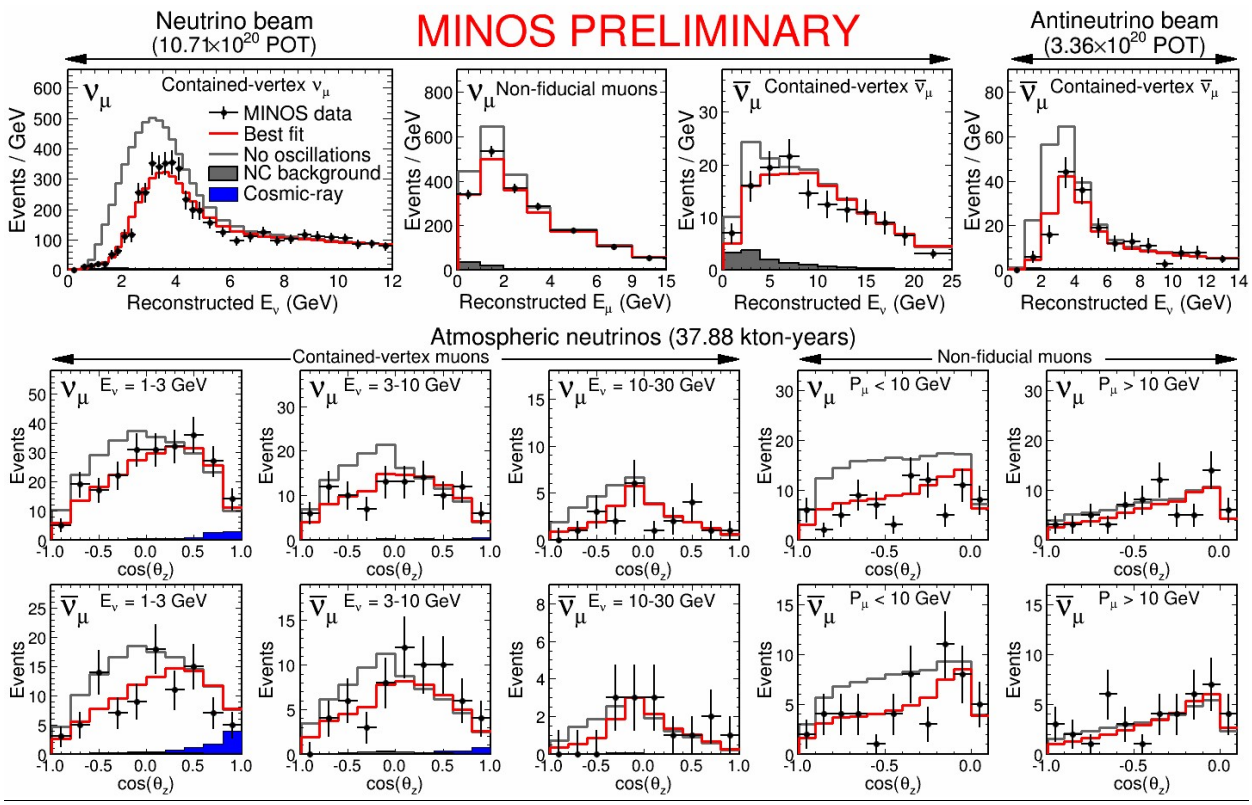

Figure 3: CC spectra from samples used in combined MINOS neutrino oscillation studies.

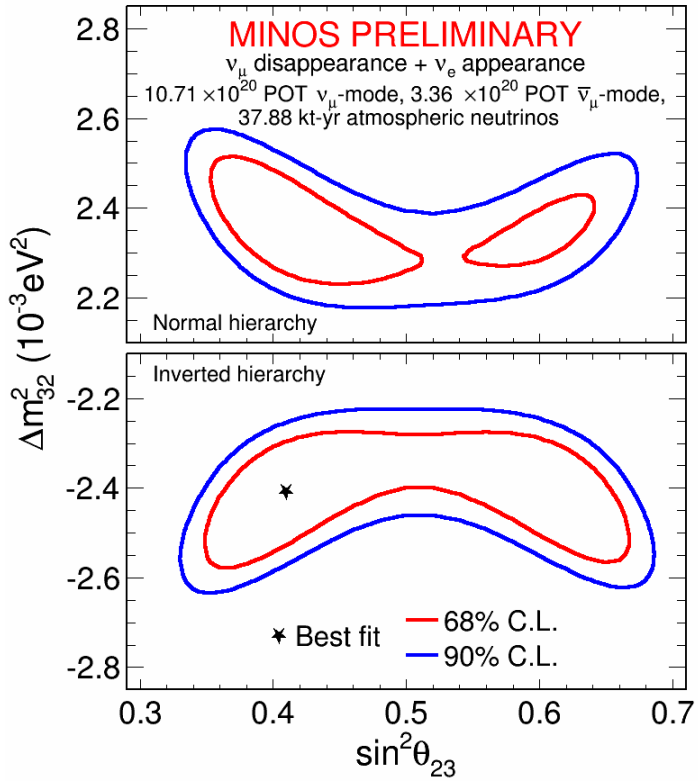

Figure 4: Confidence contours for muon neutrino disappearance parameters, evaluated in a 3-neutrino framework.

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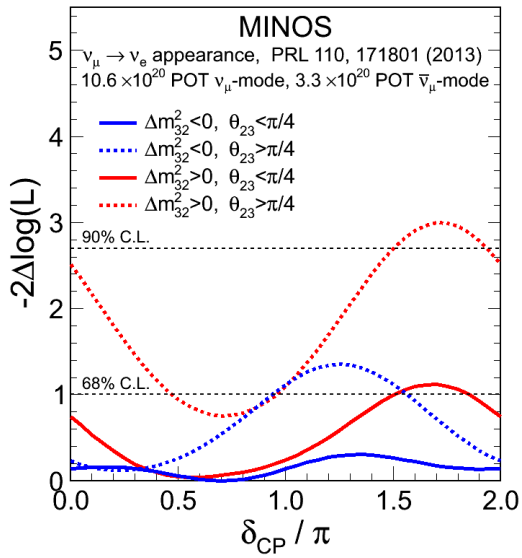

Figure 5: Fitted values of the likelihood -2 ln(L) for various configurations of mass hierarchy and octant of θ_{23}.

By using neutral-current events (NC) together with the CC events discussed above, MINOS can set limits on potential sterile neutrinos. In FY2013 this work obtained limits on the possible four-neutrino mixing angles θ_{24} and θ_{34} at a mass-squared value of $\Delta m^2_{34} = 0.5$ eV^2. Extension of this work to a large range of possible sterile neutrino masses is ongoing. Additional studies of fundamental symmetries include a completed paper on non-standard neutrino interactions (which has appeared in FY2014) and a search for direct neutrino-antineutrino transitions. Also, owing to the proximity of the MINOS detector with the GoGeNT experiment at, the muon rate at the FD was investigated as a possible source of the seasonal variations observed in CoGeNT. There was no evidence to support this as published in Phys. Rev. D83, 032005 (2013).

In addition to data analysis, the experiment prepared its analysis tools for the new data to be taken in the MINOS+ period with the new medium-energy NuMI beam. The higher energy NuMI beam for the NOvA era increases the interaction rate in the MINOS detectors. The collaboration has mounted a significant effort to rewrite its reconstruction code to cope with increased occupancies and more complicated event topologies, without compromising speed. Major problems are not expected. Validation of this new analysis tool began in FY2013 with the onset of the NuMI beam in September, and is continuing into FY2014.

E-944 / MiniBooNE (R. Van de Water)

For FY 2013 the Booster Neutrino Beamline (BNB) was off during the accelerator complex upgrades. The BNB itself received two upgrades to improve the beam line monitoring and physics reach of the experiment. Two new low mass multiwires were installed one meter upstream from the target/horn. The multiwires are separated from each other by 1 m, and can remain in place during beam running (see Fig. 6). This allows for improved positioning of the proton beam on the target. It also significantly improves the beam angle determination, which is

required to reconstruct the projected proton beam spot position in the MiniBooNE and MicroBooNE detectors. Knowing the location of the projected proton beam spot is important for exotic physics searches such as low mass dark matter, axions, paraphotons, etc. Another upgrade is the high rate digitization of the Resistive Wall Monitor (RWM) timing waveform and installation of a new high-speed discriminator and fiber optic transmission line from MI12 to the MiniBoonE detector hall. These upgrades significantly improves the measurement of the time of flight of particles from the target to the detector, which allows for a test search of >50 MeV long lived particles being produced by proton interactions in the target (or 50 m absorber). These upgrades will be crucial during the MircoBooNE era.

In August 2013, the BNB was turned on after the long shutdown. There were some issues with vacuum pumps and various seals that needed replacing, but the turn on went well and soon began routinely running beam to the target with the horn in antineutrino mode. All subsystems checked out and appear to be running normally with beam rates of 3Hz and $3x10^{12}$ protons per pulse, resulting in a rate of $3.5x10^{16}$ protons/hr. The beam throughput established was similar to that before the shutdown. The final proof that the target, horn, and decay pipe are working normally was to look at antineutrino events reconstructed in the MiniBooNE detector. Figure 7 shows the reconstructed antineutrino energy from $5x10^{18}$ POT taken in a one-week period after the beam was re-established. Also shown is the antineutrino data from before the shutdown. The rates and energy are in agreement, indicating that the entire beamline chain is operating normally. The new multiwires and RWM fiber timing system were commissioned, and after some tuning, is operating as expected and delivering the desired improved performance.

After this initial re-commissioning period, the BNB was reconfigured to run in a beam-dump test mode. In this mode the proton beam is steered past the target where it then travels the length of the 50 m decay pipe and impacts the fixed absorber. Since the protons are now interacting in a thick iron absorber, the charge mesons are quickly absorbed before they can decay into neutrinos. This effectively suppresses the neutrino flux by almost two orders of magnitude. This allows a systematic check of our flux predictions, and also permits a sensitive search for low mass weakly interacting particles such as dark matter, axions, paraphotons, etc. The results of the fall 2013 test run with 0.35×10^{19} POT will provide important information for a proposal to be submitted to the PAC in early 2014. The proposal requests an extended beam-dump run up to 1.50×10^{19} protons on target collected by the summer of 2014 when MicroBooNE is expected to turn on and run in neutrino mode. The test run was started at the very end of FY2013 and all indications are that the run is progressing well and the run objectives should be met by the end of the calendar year 2013.

Physics results produced in FY2013 include publications on antineutrino charge current muon and neutral current cross-sections, an update on the antineutrino electron appearance, and a new joint SciBooNE+MiniBooNE muon antineutrino disappearance result, summarized in Figure 8. All these recent results are interesting and continue to motivate and guide experimental and theoretical work on neutrino and antineutrino cross-sections and short baseline oscillation.

An important aspect of continued running of the BNB for MiniBooNE and MicroBooNE is the reliability of the beamline and horn. During the FY 2012 antineutrino run period, the combined BNB beamline and detector uptime was over 95%. The most crucial element, the horn, operated for over 390 million pulses surpassing the first horn, which failed seven years ago with 94 million pulses. Both these numbers were world records at the respective times. In the unfortunate event of complete failure, a spare horn and target are available. It would require four to six

weeks to install the replacement system. As well, the pieces for a forth target and horn (horn #1 is dead, horn #2 is operating, horn #3 is the immediate spare) are being assembled and will be available by FY2015 should the need arise.

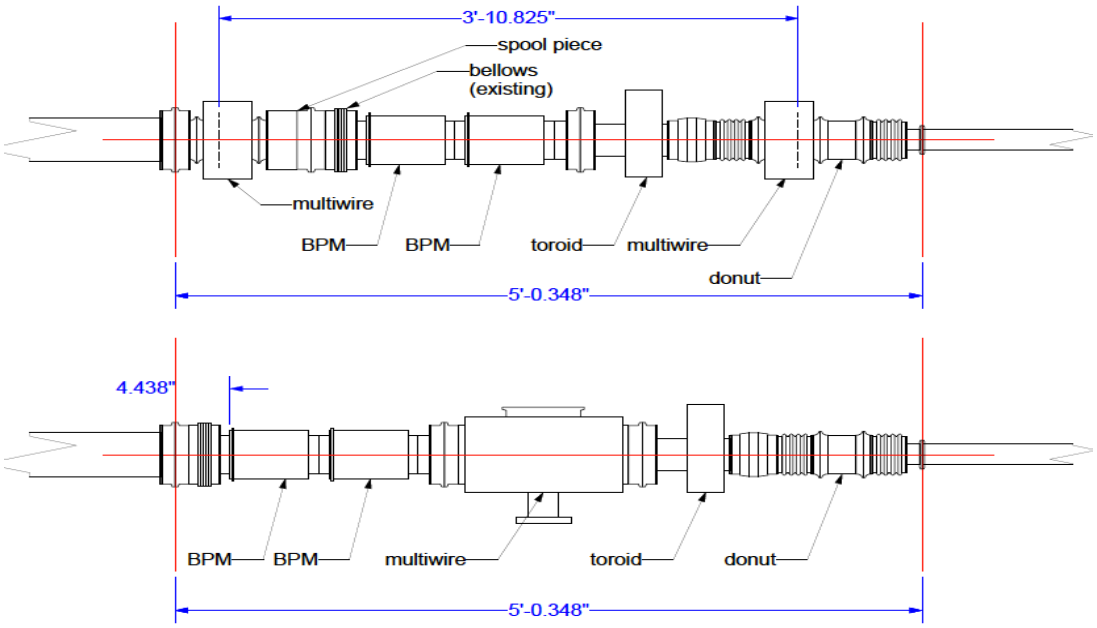

Figure 6: Top figure shows the new dual multiwires installed at the 875 position in the BNB. The bottom figure shows the old configuration at 875 that has been replaced. With the new configuration we will be able to project the position of the proton beam at the MiniBooNE/MicroBooNE detectors with 0.5 mrad resolution, or about 20 cm spatially in the detectors.

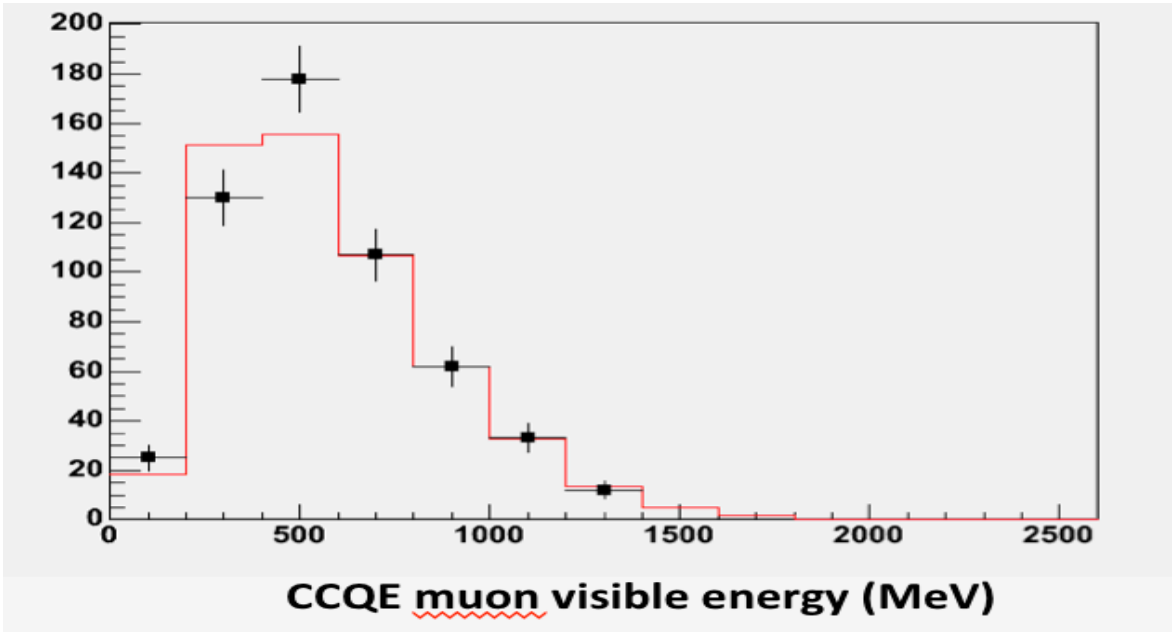

Figure 7: MiniBooNE muon antineutrino event rates from the $5x10^{18}$ POT post shutdown test run (error bars) compared to muon antineutrino events from before the shutdown (red line). The agreement indicates the BNB beamline, target, horn, and decay pipe are operating normally.

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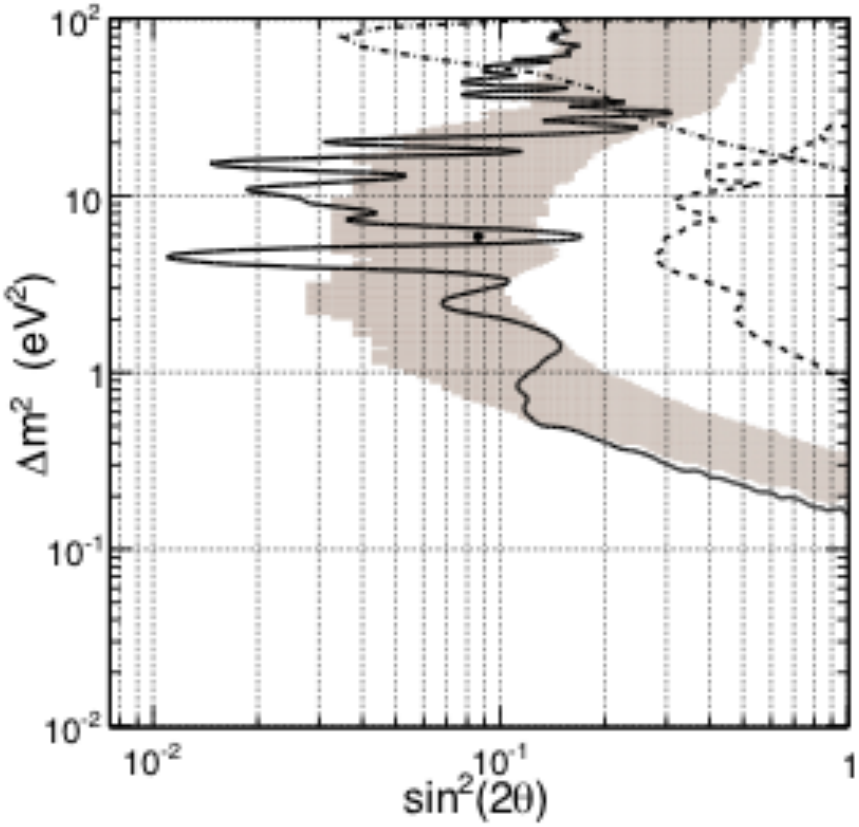

Figure 8: 90% C.L. exclusion region (solid line) and best-fit point for the joint MiniBooNE+SciBooNE muon antineutrino disappearance analysis. Also shown is the 90% C.L. result from the 2009 MiniBooNE disappearance analysis (dashed line) and the CCFR experiment (dot-dashed line). From Phys. Rev. D86 (2012) 052009.

E-938 / MINERνA (D. Harris, K. McFarland)

MINERνA Construction and Installation Activities in FY 2013

The MINERνA experiment began taking data on the partially completed detector in November 2009 while the last components were being built and commissioned. By mid-March 2010 the installation was completed and the experiment switched over to a new data acquisition system and started taking data with the full active detector, and all of the solid targets installed. By the beginning of FY 2012 the cryogenic target was filled with Helium, and the veto wall upstream of that target was fully commissioned and operational. In FY 2011 the experiment, with the help of the Fermilab PPD, also completed the design and fabrication of a new Kevlar and steel-based water target. The experiment took data on this target throughout FY 2012. By the beginning of FY 2013 the MINERνA experiment had accumulated it entire "Low Energy" data set and was doing final calibrations on the entire set, working on several physics analyses concurrently, and preparing for the "Medium Energy" run by upgrading its slowest component in the Data Acquisition chain to be able to handle the faster Main Injector cycle time that was started in the middle of FY2013. Medium Energy data taking began in earnest just before the end of FY 2013, with beam returning over Labor Day weekend 2013.

One upgrade that occurred over FY 2013 is the approval of an additional institution to staff remote shifts for the MINERνA experiment. The necessary hardware infrastructure was developed in early 2011 at the University of Rochester, duplicated and sent to several remote institutions based on interest and need, and by April 2011 the University of Rochester had completed the necessary tests to be certified as a remote shift location. By the end of FY 2012 there were five remote sites qualified: University of Rochester, Tufts University, University of Texas at Austin, University of Pittsburgh, and the University of Santa Maria in Valparaiso, Chile. In FY 2013 the College of William and Mary qualified as well to staff remote shifts. By the end of the Low Energy run in April 2012 the experiment was running approximately 40% of its shifts remotely, and this level of remote shifting is again in place for the Medium Energy run, which started at the end of FY 2013.

By the end of the FY 2013 shutdown the roof that was originally placed over the detector to keep water and debris from accumulating on the front end electronics was upgraded to include hard shielding that would allow the water to drip off the side of the roof, allowing better drainage.

MINERνA's most important upgrade of FY 2013 was the upgrade of the data acquisition system, using an Ethernet-based Chain Readout Controller (CROC-E). The original controller required almost a second to read out an event, which meant that for a 2.2 second cycle time, a calibration trigger could be taken in between beam spills. However, with the ANU upgrade the Main Injector cycle time was upgraded to 1.7 seconds by the end of FY 2012, and is expected to be reduced further to 1.3 seconds over the course of the medium energy run. The PPD Electronics Engineering Department designed, commissioned (with MINERνA collaborators) and installed these new boards in the spring of 2013 and the boards were fully operational by the start of beam on Labor Day 2014. The readout time was improved by over a factor of 10 which means that there is a considerable safety margin for taking one or more calibration triggers between each neutrino beam spill.

Physics Goals for MINERνA in Low Energy Beam

The goal during the low-energy neutrino running is to provide exclusive cross-section measurements on a variety of nuclei. The data will help in understanding the details of neutrino interactions. Low energy events tend to have few final state particles – which allows the MINERνA detector to identify single particles and the exclusive channels important for current and future oscillation experiments. MINERνA's detector is about a factor of 10 more fine-grained than the NOνA detector, and can identify processes that will contribute backgrounds to NOνA. MINERνA sees a higher neutrino beam energy than T2K's near detector, and measures reactions that contribute backgrounds to T2K from the high-energy tail of the beam (where "high energy" in the T2K case means above 1 GeV). Low energy data will also allow a study of exclusive channels as a function of target nucleus. Various processes are expected to have different nuclear dependencies, which in turn can modify the measured neutrino energy compared to the initial neutrino energy. MINERνA should be able to see those different dependencies clearly if they are at the 5-10 per cent level, as they are in charged lepton scattering.

MINERνA achieved the first of its physics goals by publishing a high statistics measurement of the quasi-elastic neutrino interaction, for both neutrinos and antineutrinos. By measuring the outgoing muon momentum and angle of events identified as having little other outgoing energy, the experiment was able to measure the shape of the cross section as a function of the square of

the momentum transferred to the nucleus, assuming that the initial state nucleon was at rest (Q^2_{QE}). That distribution is quite different from the one predicted by the standard neutrino event generator, which assumes a simple model for the initial state nucleons. In reality the nucleon distribution is different from that simple model, and additionally, the energy near the event interaction is also not in agreement with that simple model. These results, published in Physical Review Letters (2013, volume 11, 022501, and 00022502) favor models where there is some correlation between the nucleons in the carbon nucleus.

Over the course of FY 2013 MINERvA completed the extensive description of the detector and its calibration and submitted that for publication in Nuclear Instruments and Methods. The article was accepted for publication by the time of this writing and will appear in FY 2014.

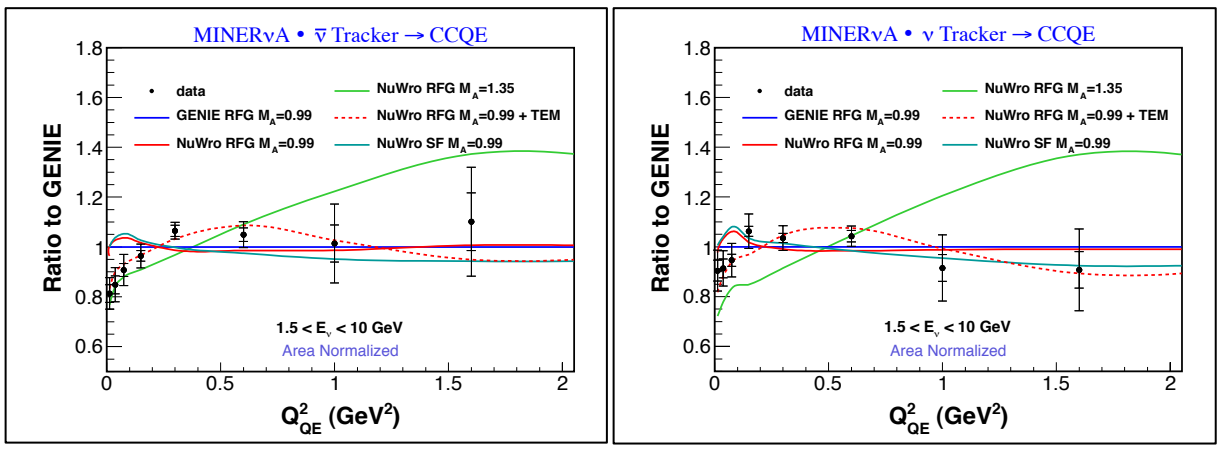

Figure 9: Simulated ratio of the quasi-elastic cross section shape as a function of the momentum transferred squared.

Figure shows the data to simulation ratio of the quasi-elastic cross section shape as a function of the momentum transferred squared (Q2QE) for both anti-neutrino (left) and neutrino (right) interactions in the plastic scintillator of the MINERvA detector. The default simulation assumes that the nucleons in the target behave in as a simple relativistic Fermi Gas (RFG). Other predictions are shown which vary the assumptions of the target nucleons.

Time Line of MINERvA Operations

MINERvA started taking physics-quality data with its partially completed detector in November 2009. For this detector, the entire downstream hadron and electromagnetic calorimeters were installed, as well as about half the active target modules. Between November and January there was also one nuclear target containing both iron and lead, and a veto region before the active tracker volume, allowing first nuclear target studies with antineutrinos. After January the nuclear target and veto region were removed to continue installation of the remaining 45% of the detector. During the second installation period, from January 2010 through March 2010, the downstream detector components remained in a stable configuration and the experiment continued to take antineutrino data. Unfortunately, during this period of time the Argoneut detector was situated between the MINERvA and MINOS detectors, making energy reconstruction for muons passing between the two detectors very difficult to model accurately enough for a precision cross section experiment. As a result the data taken during this period could not be used for MINERvA's first physics publication.

On March 22, 2010 the detector installation and checkout was completed and the neutrino running began. This run includes all of the solid nuclear targets that are planned for the experiment. The livetimes quickly reached the 95% level and above after about a week of running, and have been stable and high since that time. Over the entire Low Energy run (March 22, 2010 through April 26, 2012) the integrated livetime of MINERvA was 97.1%. When beam returned for the last month of FY 2013, MINERvA once again ran with high livetimes, averaging above 98% on a weekly basis.

The data taken in FY 2013 was all Medium Energy neutrino data. Between September 6, 2013 and September 30, 2013, the experiment received 1.78×10^{19} POT. During this time the veto wall system was operational and the helium target was empty, in order to measure backgrounds in the helium cross section measurement. The cryogenic target is scheduled to be filled in January 2014.

FIXED - <u>Target Switchyard 120 GeV (SY120) and MTest</u> (A. K. Soha, C. Moore, M. Geelhoed)

Neutrino Muon Bermpipe Sleeving Operation

After the grout removing operation in the beginning half of the 2012 AD shutdown, we attempted to pump down the bermpipe with the grout inside to look for acceptable operational levels of vacuum. This ultimately did not work once water filtered into the pipe and over powered the vacuum pumps. The next direction was to sleeve the bermpipe with a new pipe made from duplex 2205 stainless steel. This composition of stainless steel was proven to be more corrosive resistant than standard stainless steel. Based on the cost and scheduling of the manufacturing mill, this was the most opportunistic approach to our solution.

In order to properly sleeve the casing, our new bermpipe would have to be able to meet certain criteria. Its aperture large enough to transport beam, small enough to fit in the casing, and rigid enough to support itself across the three transitions as seen in Fig. 10.

To begin this process AD went with a 12” diameter pipe to easily fit in the 16” diameter casing. The wall thickness of the pipe was minimal to reduce welding time. Application of this pipe was more difficult than standard pipe sleeving. The welding was completed in the G2 enclosure because its length was sufficient and the pull was from the NM1 end because of its access from the Target Service Building’s spur. The enclosures dictated the direction that this pipe would be assembled and pulled.

Our access was limited to the size of those adjacent enclosures, equipment size was dictated by the access, and failure would ultimately mean excavation. Because of these difficulties we spent a great deal of time and effort with our contractor on developing a plan taking measurements and making calculations.

Once the type of pipe was chosen and all calculations were completed we began this process on July 8th by lowering materials and pipe. The process was completed in four iterations. An iteration involved welding 5 or 6 sticks of 35 foot long sections of pipe. Leak checking each weld, and then pulling that addition section through the casing leaving several feet for the next.

Aligning large sections of pipe with minimal thickness proved to be a difficult task and that was the most time consuming part. However as the crews had more practice and gained experience, the setup time reduced. The last pull was completed on Sept 3rd.

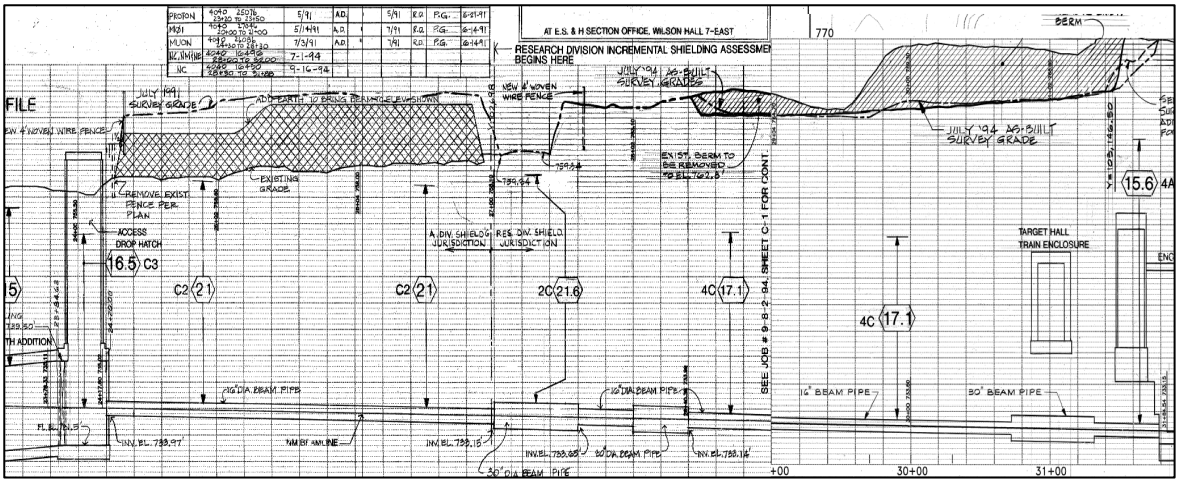

Figure 10: Cross section view of G2 to NM1 Bermpipe

Figure 11: A welder welds the next section of pipe, the 80 Ton pulling machine waits to be used.

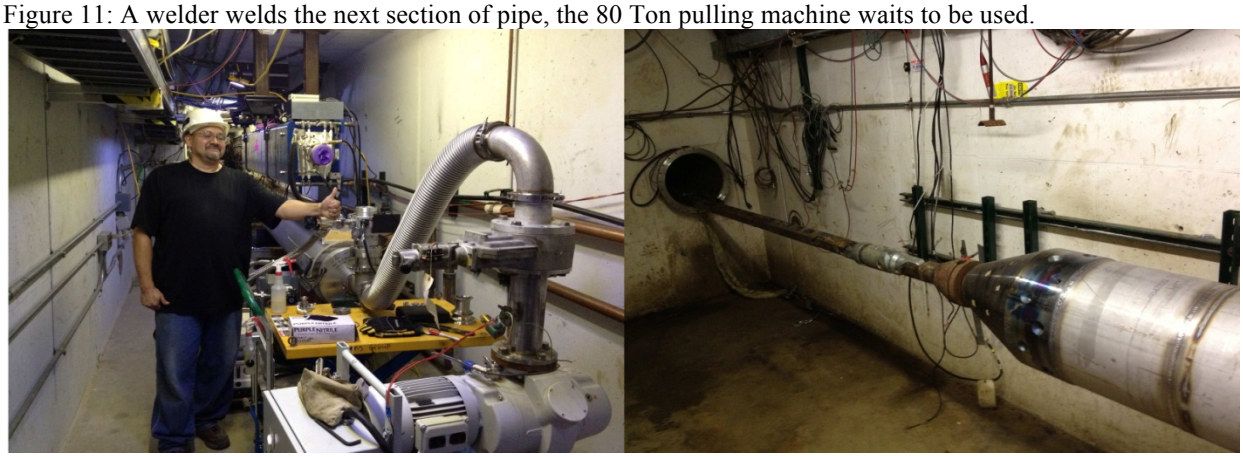

Figure 12: Fermilab Vacuum Technician leak checks new Bermpipe section

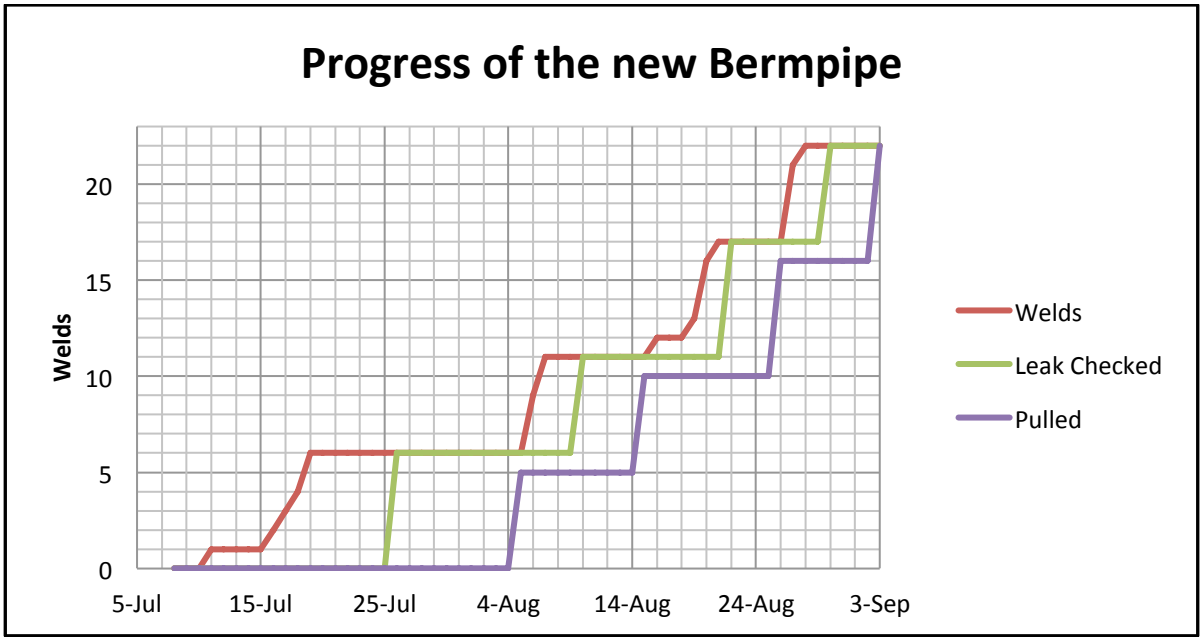

Figure 13: Plot of progress for the new Bermpipe's welding, leak checking, and pulling into position

Figure 14: Beginning nose cone led to the final welded flange

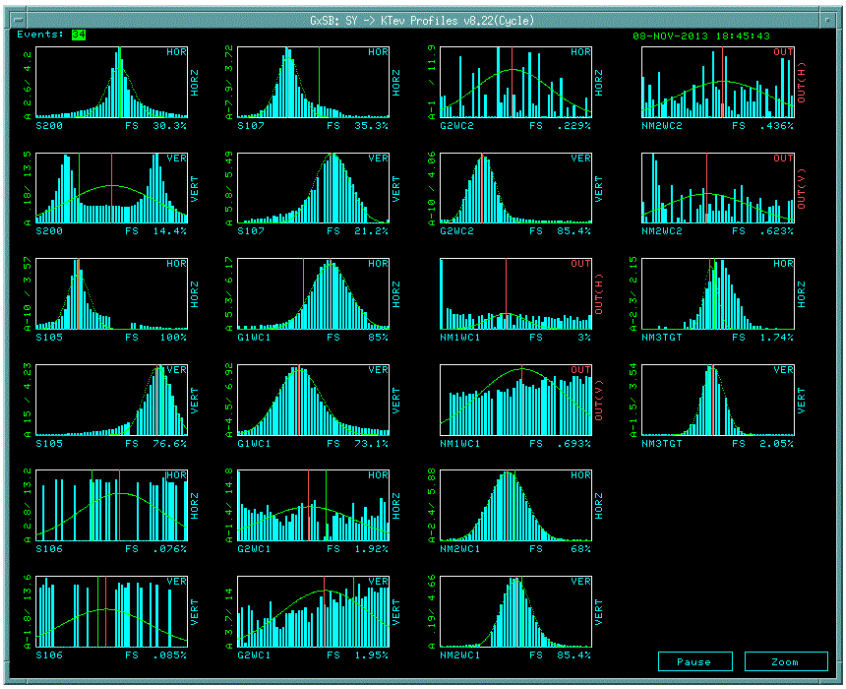

Figure 15: Beam on the SeaQuest target SWIC

Neutrino Muon Commissioning for E-906 SeaQuest

The final product was a success. Once the nose cone reached the NM1 side, the excess pipe was cut and removed. Both ends of the bermpipe had welded flanges to connect the beamline as seen in Fig. 14. After the sleeving, equipment was removed and the remaining beamline components were installed. This included 6 magnets, 150 feet of beam pipe, and multiple instrumentation devices. By Nov 8th at 10:44 we were given permission to run beam. Eight hours later the experiment had beam on target, Fig. 15.

As of today the Neutrino Muon Beamline is being operated in order to achieve the necessary intensity for foil calibration on the instrumentation devices, SWIC plane orientations, and for SeaQuest electronic troubleshooting. The consistency of the Main Injector slow spill is being worked on in conjunction with the SeaQuest Beam Cerenkov for feedback.

The Fermilab Test Beam Facility

The Fermilab Test Beam Facility (FTBF) gives users from around the world an opportunity to set up their particle detectors in a variety of particle-beams. A plan view of the facility is shown in Fig. 17. The web-site URL for the facility is www-ppd.fnal.gov/FTBF. Since it began operation is 2005 the facility has served 45 experiments, consisting of 633 individual experimenters from 139 institutions, in 24 countries.

Research Performed at the FTBF in FY 2013

Each test-beam experiment is required to prepare a Technical Scope of Work (TSW) with the Laboratory, in which the beam, infrastructure, and safety requirements are spelled out in detail.

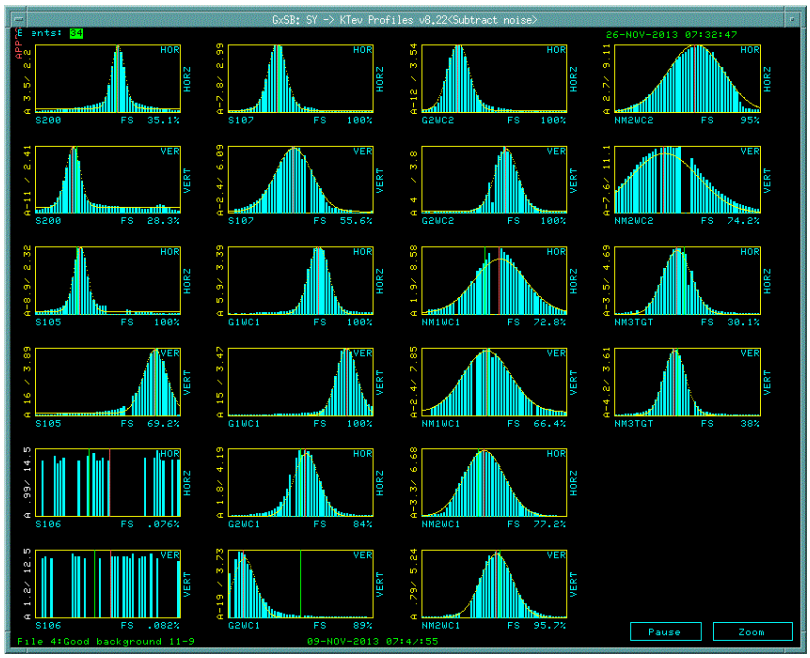

Figure 16: Beam cleanly down the Neutrino Muon Beamline.

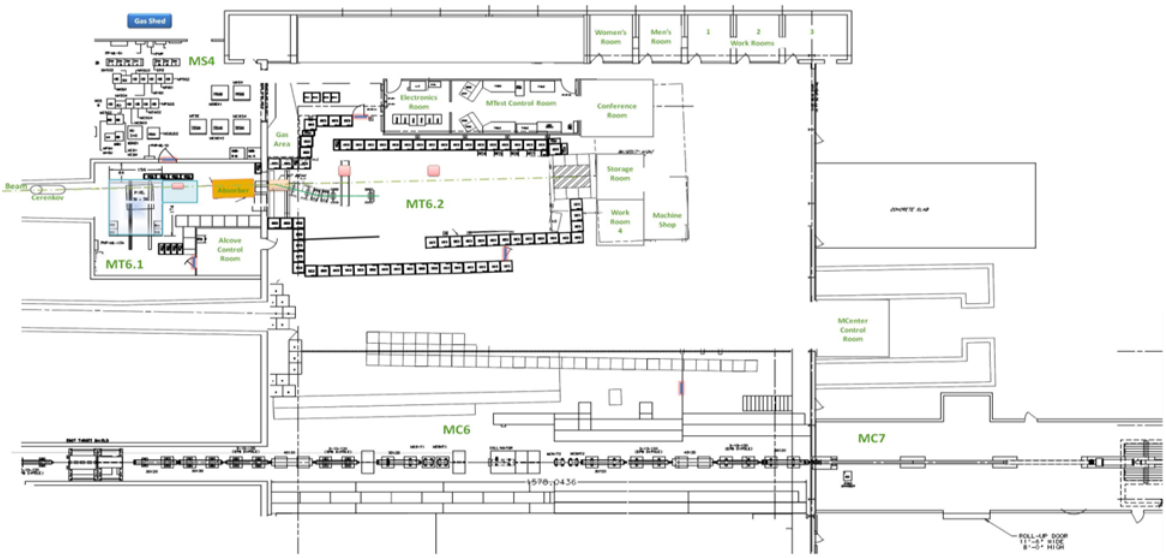

Figure 17: View of the Fermilab Test Beam Facility.

Although there was only three and a half weeks of beam, seven new TSWs were approved in FY2013, and four new experiments took data during FY 2013. An additional one experiment returned from previous years to take more data in FY 2013. These five experiments are listed in

Table I, and represent 85 collaborators from 26 institutions in 3 countries. The chart in Fig. 18 shows the growth in these numbers over the last 5 years.

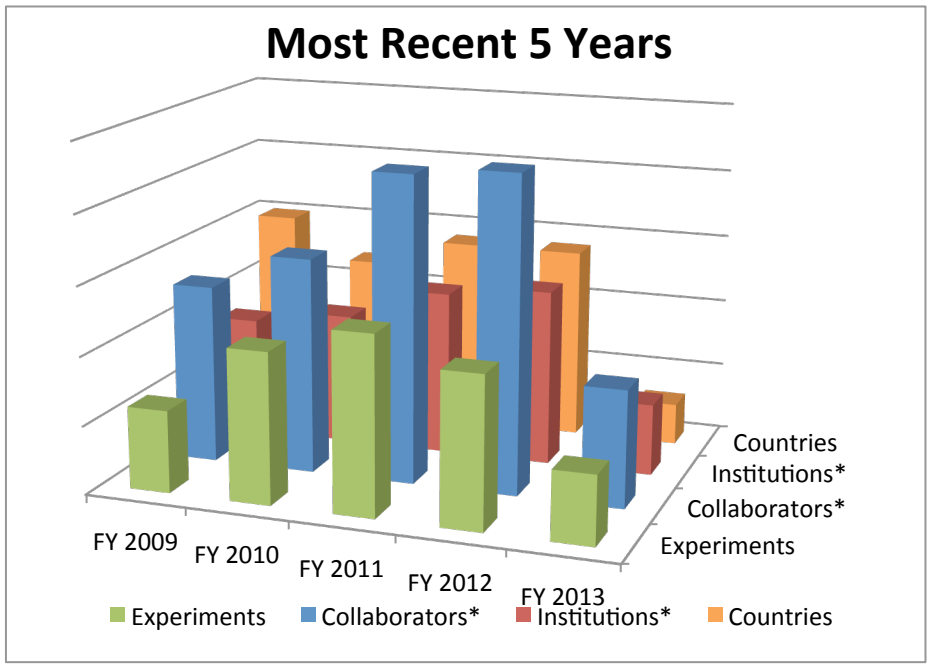

Figure 18: Growth in number of experiments, collaborators, institutions and countries served by the FTBF over the past 5 years. *Number of *Collaborators* has been scaled to fit on plot. *Number of *Institutuions* has been scaled to fit on plot. Note that FY12 consited of only 7 months of beam and FY13 consisted of only 1 month of beam.

Table I: Test Beam experiments performed in FY 2011.

Test	**Description**
T992	Radiation-hard Sensors for the SLHC
T1038	PHENIX
T1043	Mu2e CRV Scintillation Counters
T1045	Mu2e FEM Cherenkov Light from Quartz Cells
T1047	CLAS12 Si Vertex Tracker

The experiments used the facility for data taking purposes 100% of the time, for a total of 4 weeks, out of the 4 weeks with beam available during the year, including 2 weeks of multiple occupancy (four experiments taking data at once). Weekly facility usage since 2005 (when the facility started taking beam) is shown in Fig. 19.

During the 4 weeks of data taking, a total of 25,304 Fixed Target beam cycles occurred, 9173 of which had beam, for a total beam sum of 2.60×10^{13} protons, but many of the experiments requested very low intensity running. Until 2012, the Director's guideline for test beam users effect on antiproton production and neutrino beams is 5%, this usually results in one 6 second event in the 60 second timeline for 12 hours a day. However, in 2012 the SeaQuest Experiment started running which was allowed a 10% impact on neutrino beam (one 6 second event /60 seconds for 24 hours a day), and test beam user effects became transparent. The chart in Fig. 20 shows the numbers of beam cycles per year over the last 7 years, and depicts how FTBF operations have been well below the 5% impact limit set by the Director.

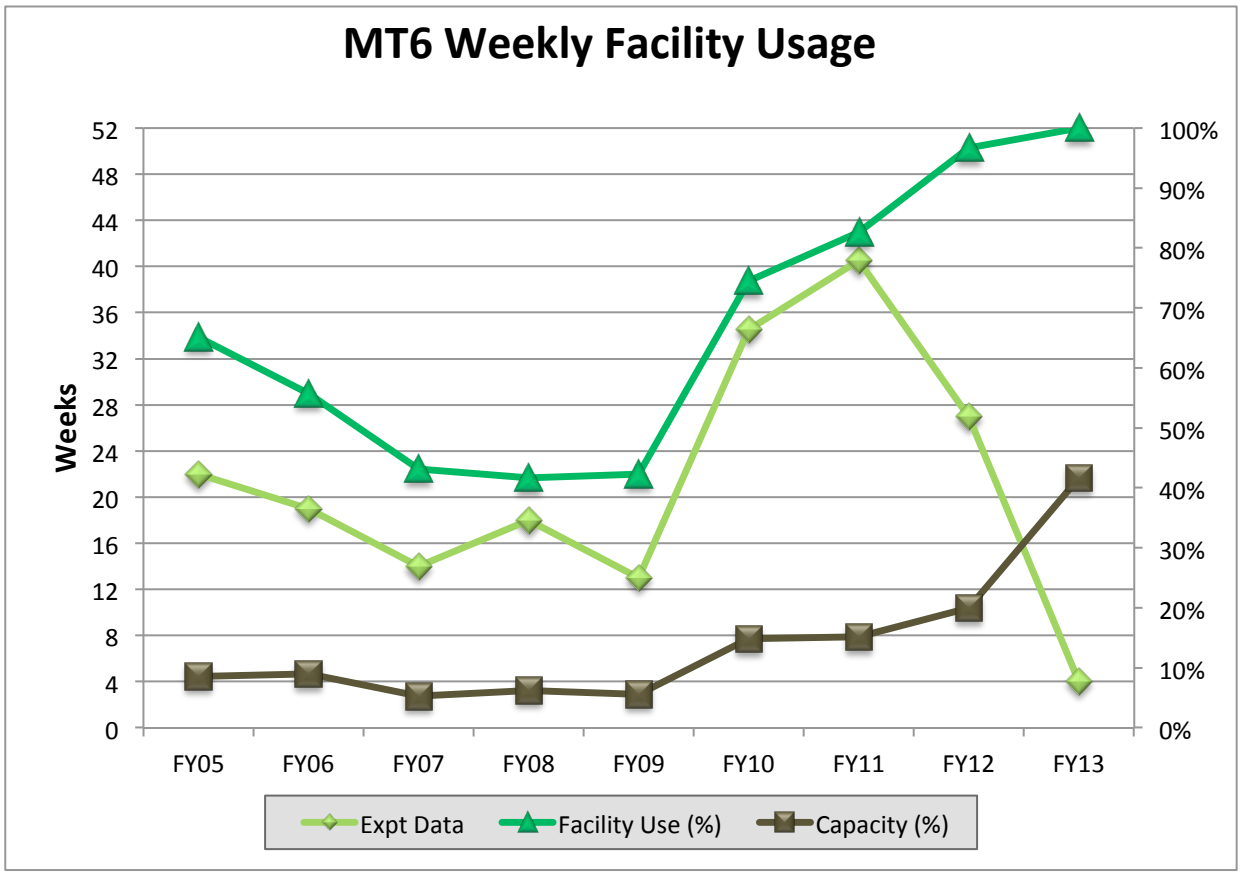

Figure 19: The **Green Line** is a percentage which includes the number of weeks the facility was being used for data taking by an experiment, and installation of an experiment (some large experiments need several days without beam to install), and beam used for facility tests or outreach. This total is then normalized to the total number of weeks the beam was available, (*less than 52*). The **Lime Green Line** is the number of weeks a year (out of 52) the facility was being used by an experiment to take data. The **Black Line** is a percentage which sums the total number of experiments (possibly more than1) taking data a week against the number of weeks a year the facility had beam available, (less than 52), divided by the total number of experiments the facility is capable of supporting (6).

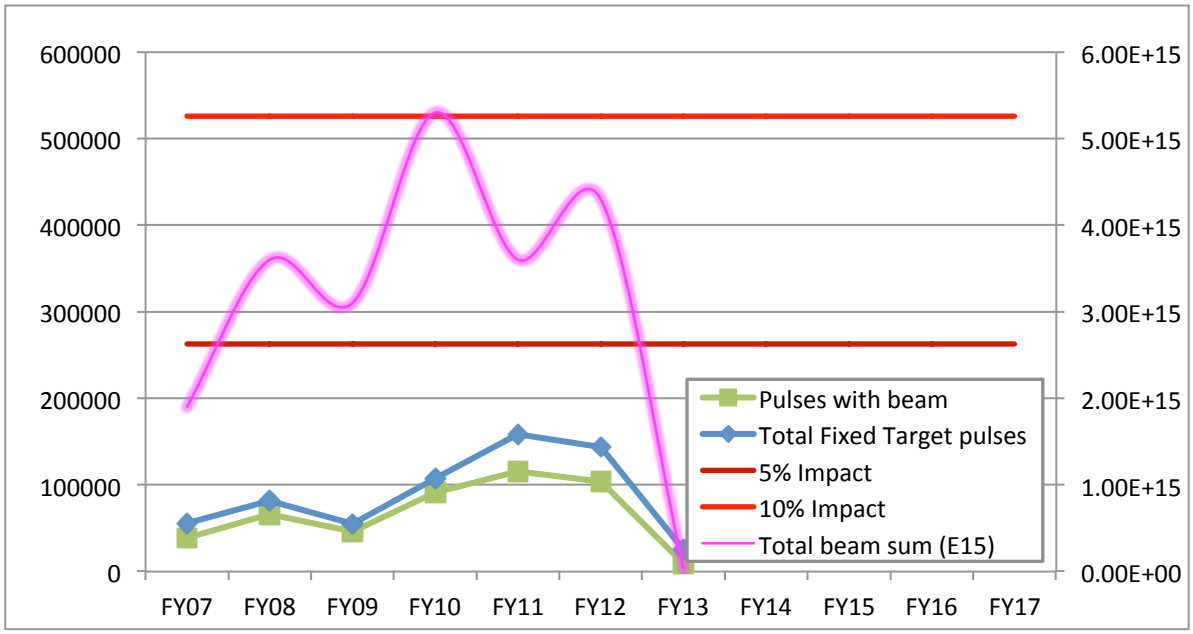

Figure 20: Fixed target pulses, to FTBF with and without.