Accelerator/Experiment Operations - FY 2015


Introduction
This Technical Memorandum summarizes the Fermilab accelerator and experiment operations for FY 2015. It is one of a series of annual publications intended to gather information in one place. In this case, the information concerns the FY 2015 NOvA, MINOS+ and MINERvA experiments using the Main Injector Neutrino Beam (NuMI), the activities in the SciBooNE Hall using the Booster Neutrino Beam (BNB), and the SeaQuest experiment and 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 (S. Nagaitsev, P. C. Czarapata)

FY 2015 Accelerator Operations

The low-energy and high-energy neutrino beams, the SeaQuest beam, and the LArIAT and Test Beams in the Meson area were brought into operation after the accelerator shutdown. The high-energy neutrino beam was scheduled for beam delivery for 36 weeks. The startup occurred on October 24th and ran until the present shutdown which began July 4th for Muon Campus, PIP, and Recycler work. The NuMI horn failed on June 13th with a stripline fracture, so the last few weeks of running were with the horn off. The total hours of high-energy operation were 4865 hours, delivering 3E20 protons on the NuMI target.

Booster Neutrino Beam was not needed for most of the year. The BNB horn needed to be replaced, which was done along with a redesigned extraction mechanism. About 264 hours of Booster Neutrino Beam was delivered to the SciBath experiment starting on June 22nd. Work on the PIP program continues on pace. The number of Booster cavities refurbished and installed prior to the shutdown was 17, which allowed us to begin 12 Hz beam operation with several periods of 15 Hz running.

SeaQuest was scheduled for beam delivery for ~30 weeks. The starting date of initial beam delivery was the first week in November. Beam delivery time was 4341.2 hours with 4.1E18 protons delivered. The slow spill beam had the desired intensity and very good extraction efficiency. The 53 MHz duty factor was improved from 30% to 45%.

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1 Editor
2 Administrative support

Operated by Fermi Research Alliance, LLC under Contract No. De-AC02-07CH11359 with the United States Department of Energy.
The Fermilab Test Beam Facility was scheduled for beam for ~30 weeks of the 52 week period. Beam delivery started on November 7th and continued until July 4th. A total of 5.97E15 protons were delivered. The facility operated for 2050.2 hours driven by user requests.

The LArIAT experiment located in the MCenter beam began initial operation in March. Beam operated to the experiment for 1559 hours as requested.

The following plots show the beam delivery over the period:
MINOS and MINOS+ Progress in FY 2015 (K. Lang, R. Nichol, R. Plunkett, J. Thomas, and D. Torretta,)

In FY 2015 the MINOS Collaboration continued analyses of data collected in the low energy (LE) NuMI beam setting whilst operating the MINOS+ experiment, which is a continuation of MINOS using the NOvA optimized medium energy (ME) beam setting.

The main focus of the collaboration during this year has been improving our analysis techniques in the sterile neutrino sector. Our analysis is now sensitive to a wider range of sterile neutrino masses including those that distort the observed neutrino energy spectra at the Near Detector. The latest constraints from the MINOS-era data have excluded a wide region of previously unexplored phase-space, particularly in the disappearance channel, shown in Figure M-1 (left). It is not possible to have sterile-driven $\nu_\mu \leftrightarrow \nu_e$ transitions without having both $\nu_\mu$-disappearance and $\nu_e$-disappearance. Therefore it is possible to combine results from the MINOS long-baseline $\nu_\mu$-disappearance and reactor $\nu_e$-disappearance for comparison with the anomalous results from $\nu_\mu \leftrightarrow \nu_e$ experiments. Using the Bugey results this is shown in Figure M-1 (right).

Figure M-1: (Left) MINOS searches for light sterile neutrinos that mix with the active neutrino flavors using charged-current and neutral-current neutrino interactions. No evidence for sterile neutrinos is found in the MINOS data. This figure shows the 90% C.L. excluded regions on the parameter space $\Delta m^2_{43}$ vs. $\sin^2(2\theta_{24})$ obtained from the MINOS analysis compared to CDHS, CCFR, SciBooNE and MiniBooNE experiments. (Right) In this figure, the $\nu_\mu$ disappearance results from MINOS are combined with $\nu_e$ disappearance results from the Bugey reactor experiment to yield 90% C.L. limits on the sterile mixing parameter $\sin^2(2\theta_{\mu e}) = 4|U_{e4}|^2|U_{\mu 4}|^2$ relevant to $\nu_\mu \leftrightarrow \nu_e$ transition experiments also shown. Regions of parameter space to the right of the red contour are excluded at 90% C.L.

The MINOS+ experiment will contribute to the improving of the measurement of “standard” 3-flavour oscillation parameters. Figure M-2 shows that the measured Far Detector energy spectrum from the first full-year of MINOS+ data has a clear oscillation signature. An updated analysis is expected during FY16 using three years of MINOS+ data.
Figure M-2: (Left) The spectrum of $\nu_\mu$ and $\nu_\mu$ charged-current interactions in the first year of MINOS+ Far Detector, summed with the existing low-energy data from MINOS. The hatched histograms show the predicted spectra for MINOS and MINOS+, calculated using the best-fit oscillation parameters from MINOS. The two predictions are summed to give a combined spectrum, which is shown by the blue histogram. In addition, the red histogram shows the combined spectrum for the case of no oscillations. The observed data, indicated by the points with errors, are well described by the oscillation model. The MINOS+ data significantly increase the event yield in the medium-energy region, enabling precision measurements of the $\nu_\mu$ survival probability curve.

The collaboration is continuing to investigate how the unprecedented MINOS+ data sample can be used to explore new areas of exotic neutrino physics. In the past year, there has been significant progress with several analyses including those sensitive to: large-extra dimensions, non-standard interactions and anomalous $\nu_e$-appearance. As an example of one of these analyses, Figure M-3 shows the MINOS limits on large-extra dimensions.

Figure M-3: (Left) An illustration of how the $\nu_\mu$ survival probability can be distorted by the presence of large extra dimensions. (Right) The MINOS limits on the size of the large extra dimension assuming that a massive sterile neutrino could propagate through the extra dimensions.

There are many challenges for the first MINOS+ analyses, specifically understanding the performance of the beam and Near Detector as they run at record intensities. Two examples of the exciting potential of the MINOS+ data set are shown in Figure M-4, illustrating the sensitivity of the MINOS+ experiment to two regimes of sterile neutrino mixing.
Figure M-4: (Left) The sensitivity of the MINOS+ experiment to anomalous $\nu_e$-appearance driven by sterile neutrino mixing.  (Right) The sensitivity to sterile neutrinos from one year of running MINOS+ with a beam configured for anti-neutrinos.

Figure M-5: MINOS Near Detector live time during FY2015.
MINOS+ operations in FY 2015 were smooth and highly automated, which is reflected in live times consistently greater than 96% often as high as 99%, at both near and far detectors (figures M-6 and M-7 show the live time for each of the detectors).

Figure M-6: MINOS Far Detector live time during FY2015.

Figure M-7: MINOS+ NuMI beam delivered to MINOS+ during FY 2014-2015.
During the ME data taking period, MINOS+ collected $3.26 \times 10^{20}$ POT in FY 2014 and $3.12 \times 10^{20}$ POT in FY 2015 for a total of $6.38 \times 10^{20}$ combined, as shown in figure M-8.

During the 2014 summer shutdown, which began in September 2014, MINOS+ commissioned new timing readout computers at both FD and ND, to replace the old (2000-2001) computers, which are obsolete. The timing electronics remained unchanged. The work was completed before beam returned on October 31, 2015. The new system has been working reliably since. At the same time a crew of very dedicated people started and completed the cleaning of all the ND electronics racks (30) and front-end electronics boards (~1000), which should reduce electronics failures due to accumulated dust on the circuits. Racks were vacuumed and boards were cleaned by blowing out the accumulated dust in a cleaning area upstream of the detector. The job was completed in about 3 weeks and only two boards were damaged in the process – these were repaired at ANL. The racks’ filters were replaced with new ones. All this resulted in a very clean detector.

Automated alarms in case of DAQ or electronics failures and proactive intervention were crucially important (in fact, mandatory) in reaching the very high livetime shown above. No obstacles are seen in maintaining this performance.

**NOvA Progress in FY 2015** (M.D. Messier and P. Shanahan)

The NOvA project was completed in July of 2014 and responsibility for daily operations of the experiment transferred to the collaboration. During FY 2015 the experiment operated at very high efficiency (>99% channels active, >96% uptime) and reported first results in the muon neutrino disappearance channel and electron neutrino appearance channel based on an equivalent of 2.74E20 protons on target exposure recorded between February 2014 and May 2015.

Detector operations for physics data began when the first four kilotons of the experiment were commissioned. The collaboration has been running 24/7 shifts since February of 2014 so the transition from project to collaboration was quite smooth. The operations plan was reviewed on October 28-29 ([http://nova-docdb.fnal.gov/cgi-bin/ShowDocument?docid=12339](http://nova-docdb.fnal.gov/cgi-bin/ShowDocument?docid=12339)). The review generated several recommendations and the collaboration has responded to each one ([https://nova-docdb.fnal.gov:440/cgi-bin/ShowDocument?docid=13171](https://nova-docdb.fnal.gov:440/cgi-bin/ShowDocument?docid=13171)). The plan for detector operations is documented in the Experiment Operations Plan ([http://nova-docdb.fnal.gov/cgi-bin/ShowDocument?docid=12225](http://nova-docdb.fnal.gov/cgi-bin/ShowDocument?docid=12225)).

Figures N-1, N-2, and N-3 summarize the detector uptime and efficiency for recording protons-on-target (POT) delivered to the experiment. Overall the NOvA far detector operated >90% of the time including scheduled downtimes during beam-off periods. In FY15, the far detector recorded 2.985E20 of the 3.125E20 POT delivered, 95.5%. Likewise the NOvA near detector operated >95% of the time including scheduled downtimes during beam-off periods and recorded 96.8% (3.023E20 of 3.125E20) of the POT delivered in FY2015.
Figure N-1: The NOvA far detector uptime since start of operations (FY15 = 1.10.2014). This shows the daily (points), 7-day (green line), and 28-day (red line) average uptime of the NOvA detector systems including planned downtimes for maintenance during beam-off times. Overall the detector operated >90% of the time during FY15.

Figure N-2: The total protons on target accumulated by the NOvA far detector since the start of operations. In FY15 (1.10.2014) the far detector recorded 2.985E20 of 3.125E20 (95.5%) of the protons delivered.
Figure N-3: The total NOvA near detector uptime. This shows the daily (points), 7-day (green line), and 28-day (red line) average uptime of the NOvA near detector systems including planned downtimes for maintenance during beam-off times. Overall the detector operated >95% of the time during FY15.

During July 2014 through November 2014 a series of detector retrofits was undertaken to replace a set of brass fittings on hoses in the APD chilled water system which were installed early in the project and had an unacceptably short time to failure. Failures of these hoses resulted in frequent water leaks which resulted in detector down time and put equipment at risk. The retrofit work was supervised by our Operations Manager, Robert Plunkett and completed according to schedule on November 19, 2014. Other long-term infrastructure improvements includes work on the air handling system for the far detector buffer farm computer room. This room houses a large number of computer nodes which hold detector data waiting for a network packet of beam trigger information to arrive from Fermilab. Overheating in this room during warm weather has required load shedding and resulted in detector down time. Maintenance of the HVAC system on July 5th has stabilized the situation, but we continue to explore options to improve the reliability of this system.

Using this data, and the data recorded in FY14, NOvA released its first results for muon neutrino disappearance and electron neutrino appearance. These results were presented by Ryan Patterson at a Fermilab Wine & Cheese seminar on August 6th, by Mark Messier at the APS DPF Conference on August 7th, and by Peter Shanahan at Lepton-Photon on August 18th.

Figure N-4 shows the reconstructed muon neutrino event spectrum recorded at the NOvA far detector. While 201 events are expected based on the extrapolation from the spectrum recorded at the NOvA near detector, only 33 events were seen. This major depletion results from the location of the NOvA far detector at the oscillation maximum and enables measurements (Figure N-4) of the mass splitting and neutrino mixing in the 2-3 sector with precision which is rapidly approaching that of experiments with much larger data sets.
NOνA has also released its first data on electron neutrino appearance. The experiment uses two particle ID algorithms to select electron neutrino events. The Likelihood Identifier (LID) uses many variables from the overall event shape and the topology of the leading shower in the event in an artificial neutral net; the Library Event Matching (LEM) algorithm compares the overall event topology to a large library of simulated events to extract signals. These algorithms have nearly equal physics performance and have roughly 60% overlap. In this first sample, the LID technique selected 6 events on a background of 1 (3.3σ significance) and the LEM technique selected 11 events on a background of 1 (5.5σ significance). Figure N-5 shows the locations of these events in the particle ID and energy spectrum at the far detector and the comparison of the oscillation parameters these rates imply compared to reactor measurements.

The electron neutrino signals recorded at the far detector require somewhat higher oscillation rates than would be predicted without enhancement to the oscillation probability from the neutrino mass ordering and CP violating effects, and 23 mixing in the >45° octant. Hence the results favor the normal mass ordering and CP phases between π and 2π. In the case of the LID results (Figure N-6, left) the preference is only slight with some space between 0 and π ruled out at 90% for the inverted mass ordering. In the LEM case, the inverted ordering is disfavored everywhere at 2σ. These are intriguing first results, but clearly much more data is required.
Figure N-5: The location of the 11 events selected by the NOvA particle ID algorithms in the particle ID spectrum (top left) and in energy (bottom left). The plots to the right compare the measured rates for the LID (top) and LEM (bottom) to the expectations from reactor experiments. The observed excesses are somewhat more consistent with the normal neutrino mass ordering (top right) than the inverted mass ordering (bottom right).

Figure N-6: Significance of the NOvA result combined with the reactor data as a function of mass ordering and choice of CP phase. Left is results for the LID identifier. Right is for the LEM identifier.
The MINERvA experiment began taking physics quality data in November 2009 while the last components were being built and commissioned. By mid-March 2010 the installation was completed and the experiment 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 added a water target. The experiment took data throughout FY 2012 in the NuMI Low Energy beam. During the FY13 shutdown the MINERvA experiment upgraded its Data Acquisition system and upgraded the roof over the detector to protect it from water damage. In FY14 and FY15 the MINERvA experiment took data in the NuMI Medium Energy beam. Two additional sites qualified to take remote shifts since the last Operations Summary: Otterbein College and PUCP in Lima. During the FY15 run the experiment ran approximately 40% of its shifts remotely.

Over the course of FY15 MINERvA collaborators together with PPD’s EED group continued to upgrade the data acquisition firmware so that the experiment would have a reduced dead time associated with each time a readout cycle was initiated, at the expense of recording the lowest gain channels. In the new scheme the low gain channels, which are used only rarely, are read out only one time after the spill, instead of being read out for each event inside a spill. The firmware that was written in FY14 to improve the number of events stored per spill was tested successfully during the FY15 testbeam run. The FY14 firmware upgrade version (v95) is being installed in the underground neutrino detector during the FY15 shutdown, and once the new readout design is finished then it will also be installed, potentially during the FY15 shutdown. Both of these new features will be important for the medium energy neutrino run as the accelerator provides higher intensity beam.

The MINERvA collaboration also took Medium Energy test beam data, which is described in a different chapter of this report. The collaboration together with the FTBF group was able to take data in two different detector configurations, and by changing the trigger configuration was able to take data in both a pure electron and a predominantly hadron beam.

Work continued at SciDet to help MINERvA diagnose problems with (older) PMT alignment that was leading to high crosstalk values between neighboring pixels.

**Physics Goals for MINERvA in Low Energy Beam**

The goal during the low-energy neutrino running was 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 MINERvA detector to identify single particles and the exclusive channels important for current and future oscillation experiments. MINERvA’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. MINERvA 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).
MINERvA achieved the first of its physics goals in FY13 by publishing a high statistics measurement of the quasi-elastic neutrino interaction, for both neutrinos and antineutrinos (Physical Review Letters (2013, volume 111, 022501, and 00022502). In the beginning of FY14 MINERvA reached another milestone when it released its measurements of cross section ratios between iron and scintillator, and lead and scintillator (Physical Review Letters (2014, volume 112, 231801).

MINERvA produced results in FY14 on the scintillator target, which is primarily hydrocarbon. A measurement of the cross section for inclusive pion production in charged current neutrino interactions was submitted for publication in June 2014 [arXiv:1406.6415]. MINERvA also published results on quasi-elastic scattering on carbon as measured by the final state proton arm (Phys Rev D. 91.071301 (2015)). MINERvA’s charged current coherent pion production measurement was also published in FY14 (Phys. Rev. Lett. 113, 261802 (2014)).

In FY15 MINERvA continued its study of pion production by releasing results on neutral pion production by antineutrinos, a process very similar to the charged pion production by neutrinos which is a new probe of final state interactions. The result, shown in Fig. MV-1 (left) shows that the current neutrino interaction models predict the level reasonably well but do not precisely predict the neutral pion momentum spectrum. By looking at this process as well as the charged pion process one can infer that there is more inelastic final state interactions in nature than in the event generator GENIE, currently used by NOvA, MINERvA, and the T2K Near Detector.

An extension of MINERvA’s earlier nuclear target cross section ratio analysis was released in FY15. This analysis focuses on the Deep Inelastic Scattering process by including neutrino energies up to 50GeV and removing events at the elastic peak using reconstructed kinematic variables like the invariant mass of the hadronic system and the momentum transfer. The ratios as a function of neutrino energy are again in agreement with prediction, similar to the inclusive analysis, but there is a deficit in the ratio in the data that grows with the size of the nucleus, compared to the theory, indicating a larger shadowing effect than expected from charged lepton scattering.

At the end of FY15 MINERvA released its first measurement of electron neutrino charged current quasi-elastic scattering, which is an important signal process for both the T2K and NOvA oscillation experiments. This is one a very small number of cross section measurements for electron neutrinos and the first one of this specific process. The ratio of cross sections between electron and muon neutrinos as a function of momentum transfer (Q2) is shown in Fig. MV-1 (right). The cross section ratio is within uncertainties of the predicted ratio. If the predicted electron to muon neutrino flux ratio was incorrect that would also show up in this ratio.
Figure MV-1: (left) shows the cross section for antineutrino charged current neutral pion as a function of the neutral pion momentum, and the predicted contributions to neutral pion production from GENIE, which is an event generator used by most US-based neutrino experiments. (Right) shows the cross section ratio between electron neutrino and muon neutrino charged current quasi-elastic scattering as a function of the momentum transferred to the nucleus.

**Time Line of MINERvA Operations**

MINERvA started taking antineutrino 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. After January the remaining 45% of the detector was installed. 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. 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, but was used for the first time in a publication of the antineutrino coherent scattering result that was produced this year.

On March 22, 2010 the detector installation and checkout was completed and neutrino running began. This run includes all of the solid nuclear targets that are planned for the experiment. The live times 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 live time of MINERvA was 97.1%, and the experiment integrated $3.04 \times 10^{20}$ POT when both MINERvA and MINOS Near Detectors were collecting data. The data taken in FY 2014 was all Medium Energy neutrino data, and MINERvA accumulated $3.08 \times 10^{20}$ POT over all running modes with an integrated livetime of 97.5%.

The data taken in FY 2015 was all Medium Energy neutrino data with roughly two weeks of horn off data taken just before the Summer 2015 shutdown. Between October 24, 2014 and September 30, 2015, the experiment received $3.02 \times 10^{20}$ POT over all running modes. The MINERvA detector was live for 97.7% of the protons delivered on target. During this running period the experiment was able to calibrate the detector, monitor the detector light levels, and check the reconstruction performance of both the MINERvA and MINOS detectors continuously, and much more quickly after the data were taken than in the Low Energy run.
**Fixed - Target Switchyard 120 GeV (SY120) and MTest** (D. Geesaman, C. D. Moore, P. E. Reimer, M. Rominsky, J.J. Schmidt)

The general operation of SY120 was relatively smooth. The MCenter Beamline with a final tertiary beam capability for the LArIAT experiment continued to operate as needed. The beam losses for Meson and SeaQuest were manageable and the intensity to SeaQuest continued to increase along with improvement to the duty factor. Instrumentation improvements continued to be developed with the main emphasis on improving the BPM system. During the FY15 shutdown the main effort was on cable remediation.

**E906/ SeaQuestDrell-Yan** (D. Geesaman, P. E. Reimer)

The SeaQuest experiment (E906) is determining the ratio of the d-antiquarks to u-antiquarks in the proton and the nuclear dependence of antiquark distributions in the $x_{\text{Bj}}$ range of 0.1-0.5 by measuring relative rates of Drell-Yan production on liquid $^1\text{H}$ and $^2\text{H}$ targets. Complementary measurement using nuclear targets (C, Fe and W) will allow SeaQuest to determine the EMC effect in sea quarks over the same range of $x_{\text{Bj}}$. Additional measurements from the same data set will include the energy loss of fast quarks in cold nuclear matter and the nuclear dependence of $J/\psi$ production.

This has been an exciting year for SeaQuest. We have been accumulating “production” data since spring, 2014. As of July 2015, production data has been accumulated with $8.3\times10^{17}$ live protons. Approximately 70% of these protons were used for the dbar/ubar measurement on liquid hydrogen and deuterium targets. The remainder of the beam was used to study nuclear dependences and to place limits on the nuclear correction for the deuterium yields using solid carbon, iron and tungsten targets.

A subset of the collected data has been completely analyzed and was presented as a “preview” at the April APS meeting. Assuming that there is no increase in efficiency, these data represent less than 10% of the data we expected to record by July 2016. The dbar/ubar preview is shown in Fig. SQ-1 and the EMC effect is shown in Fig. SQ-2. These results demonstrate that the complete spectrometer-analysis chain is working. The results are consistent with earlier Drell-Yan measurements.

The Accelerator Division has made great improvements in the instantaneous duty factor of the extracted beam. Most notably, an improvement in December 2014 led to a jump from approximately 25% to 40% in duty factor. Not only did this increase the number of “live protons” at a given intensity seen by SeaQuest, it allowed the proton intensity to be increased, creating a double win. Nevertheless, the duty factor is less than expected in the proposal. The high intensity buckets during poor duty factor periods of a spill lead to unacceptable random trigger rates as well as significant additional track noise in the spectrometer that together have a strong impact on readout dead time, number of events that must be reconstructed and overall reconstruction efficiency. To prevent a flood of events in the DAQ during “super-bucket” beam pulses, SeaQuest uses a beam Cherenkov counter to veto for a period of 190 ns around beam buckets that have greater than ten times the average intensity. This rejects approximately 45% of
the protons seen by G2SEM in the beamline. A comparison of the curves in Fig. SQ-3 shows the effect of this veto.

During the shutdown in summer 2015, the experiment installed a new tracking chamber to replace the temporary Station 1 chamber. The new chamber will have better rate capabilities, allowing for higher luminosity and the wider acceptance needed to improve the efficiency for high-\(x_{\text{Target}}\) events. In addition, routine maintenance was performed on the cryo-target systems and some of the DAQ front-end systems were upgraded to more modern, Linux-based CPU’s.

Figure SQ-1 (Left): The ratio of deuterium to twice hydrogen Drell-Yan dimuon yields as a function of the \(x_{\text{Target}}\). The red points indicate the new SeaQuest data while the black points are earlier E866 data. (Right) The ratio of dbar to ubar extracted from the cross section ratio data. The blue line indicates the parameterization from the CTEQ group. The shaded band indicates the systematic uncertainties (which are expected to decrease significantly with additional study).

Figure SQ-2: These plots show ratio of the Drell-Yan dimuon yield per nucleon for carbon (left), iron (middle) and tungsten (right) to deuterium as a function of \(x_{\text{Target}}\). The red circles show the new SeaQuest data while the black squares show the earlier E772 measurements. The shaded band indicates the systematic uncertainties (which are expected to decrease significantly with additional study). Note that for the carbon data, an additional systematic has been discovered, and will be corrected.
Figure SQ-3: This graph shows integrated protons delivered to SeaQuest. The black line represents the protons seen by G2SEM. In red are the protons that are delivered to the experiment with an acceptable duty factor and in blue are the protons with both an acceptable duty factor and the DAQ live. Note that in December 2014, there was a significant improvement in the duty factor.

The experiment currently has twelve graduate students whose Ph.D. thesis data will be collected in E-906/SeaQuest. There are also eleven undergraduate students and seven postdoctoral research associates working on the experiment. Recent studies have shown that the apparatus, as a classic beam stop experiment, also has sensitivity to dark photons (a possible form of dark matter) in a unique regime of mass and coupling constant. This physics is also being pursued.

**The Fermilab Test Beam Facility** (M. Rominsky, J.J. Schmidt)

The Fermilab Test Beam Facility (FTBF) gives users from around the world an opportunity to set up their particle detectors in a variety of beams conditions. A plan view of the facility is shown in Fig. TB-1. The website URL for the facility is ppd.fnal.gov/ftbf. Since it began operation in 2005 the facility has served 73 experiments, consisting of 835 individual experimenters from 177 institutions in 30 countries.

Research Performed at the FTBF in FY 2015

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. Three new TSWs were approved in FY2015, and eight new experiments took data during FY 2015. An additional seven experiments returned from previous years to take more data in FY 2015. These 15 experiments are listed in Table TB-I and represent 233 collaborators from 67 institutions in 13 countries. The chart in Fig. TB-2 shows the trend in these numbers over the last 5 years.
Figure TB-1: View of the Fermilab Test Beam Facility.

Figure TB-2: Number of experiments, collaborators, institutions and countries served by the FTBF over the past 5 years. *Number of Users has been scaled to fit on plot. *Number of Institutions has been scaled to fit on plot. Note that FY12 consisted of only 7 months of beam and FY13 consisted of only 1 month of beam.
Figure TB-3: Weekly Usage of MTest and MCenter beamlines, nominalized to number of beam-weeks available.
Table TB-I: Test Beam experiments performed in FY 2015.

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The experiments used the MTest beamline for data taking purposes 160% of the time, for a total of 43 experiment-weeks, out of the 35 weeks with beam available during the year. Weekly facility usage since 2005 (when the facility started taking beam) is shown in Fig. TB-3.

The MCenter beamline was used for commissioning and data taking for the LArIAT experiment (T1034) and for T1059. LArIAT installed for 18 weeks, commissioned for 13 weeks and took
five weeks of data. During the commissioning weeks, experiment T1059 took data for four weeks in the secondary beam.

During the 35 weeks of available beam, a total of 618,383 Fixed Target beam cycles occurred, 113,659 of which went to beam for the MTest beamline, for a total beam sum of $5.7 \times 10^{15}$ protons. The MCenter beamline had 88,659 pulses with beam for a total beam sum of $2.4 \times 10^{15}$ protons.

Until 2012, the Director’s guideline for test beam users effect on antiproton production and neutrino beams was 5%. This 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 per 60 seconds for 24 hours a day), and testbeam user effects became transparent. The chart in Fig. TB-4 shows the number of beam cycles per year over the last 7 years. The impact of FTBF operations has been well below the 5% (now 10%) limit set by the Director.

SciBooNE Hall (W. M. Lee)

The SciBooNE Hall hosted its first experiment in many years if FY15. Test experiment, T-1025, operated from 22 June 2015 to the end of beam in preparation of the summer shutdown on 3 July 2015. The goal of T-1025 in the SciBooNE Hall was to measure the flux of fast and thermal beam-induced neutrons in the enclosure using the SciBath-768 detector (shown below). These measurements will be valuable to the Fermilab short-baseline program and to future experiments using the SciBooNE Hall. The analysis of this data is in progress.

T-1025 requested 1.0E19 protons on target (POT) from the Booster Neutrino Beamline for their run in the SciBooNE Hall. The Accelerator Division was instrumental in achieving this goal, for replacing their horn and providing beam for the last 12 days before the shutdown. As can be seen in the plots below, the goal was met with a total of 1.25E19 POT of data collected.
Acknowledgement

This report gives a brief summary of the performance and output of the accelerator complex and associated accelerator-based experiments during FY15. It therefore summarizes the work of many people from Fermilab and from the collaborating institutions. The credit for the successful outcome of the FY15 running is shared amongst many.