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Accelerator/Experiment Operations - FY 2005

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This Technical Memorandum (TM) summarizes the Fermilab accelerator and experiment operations for FY 2005. It is one of a series of annual publications intended to gather information in one place. In this case, the information concerns the FY 2005 Run II at the Tevatron Collider, the MiniBooNE neutrino experiment using the Booster neutrino beam, MINOS using the Main Injector neutrino beam, and SY 120 activities.

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

Collider (S. Holmes)

FY 2005 began with the accelerator complex in the midst of a long scheduled shutdown. The shutdown was officially completed on November 26, 2004 coincident with the commencement of Tevatron beam commissioning activities. Summarized below is the final status of the major shutdown activities aimed at improved performance.

Machine/Activity	Goal	Status
Linac		
Drift tube replacement, tank 5	Reduce losses.	Complete
Booster		
BRF19 (new rf station)	Reduce losses during acceleration and provide added redundancy	Complete
L13 area reconfiguration	Reduce losses during Booster acceleration cycle	Complete
Antiproton Source		
Debuncher motorized stands	Increase antiproton production yield	Complete
Debuncher injection area rework.	Increase antiproton production yield	Complete
AP1/AP2 Survey	Increase antiproton production yield	Complete
AP30 SO cord remediation	Correct OSHA violation	Complete
Main Injector		
NuMI kicker installation	Enable NuMI operations	Complete
Beamloading compensation	Enable slip-stacking at 8E12 ppp	Complete
Recycler		
Stochastic cooling tank repairs	Fix water leaks	Complete
Magnetic shielding in NuMI area	Protect Recycler from NuMI beamline stray fields.	Complete
Electron cooling installation	Enable another factor of >2 increase in luminosity	Complete

Machine/Activity	Goal	Status
Tevatron		
Install two new separators at D17	Improved helix flexibility	Complete
Cold mass (dumb bolt) shimming	Re-center cold masses (reduce global coupling)	Complete
Measure rolls on all magnets	Update knowledge of Tevatron alignment	Complete
Unroll misaligned magnets	Reduce global coupling	Complete
Vacuum upgrades at A0 and D0	Improve operability	Complete
NuMI		
MI extraction kickers	NuMI extraction	Complete (See MI)
Extraction line magnets shielding	Protect Recycler from NuMI stray fields	Complete (See Recycler)
NuMI target hall installation	NuMI operations	Complete
MiniBooNE		
Horn replacement	Replace failed horn	Complete
Infrastructure Maintenance		
Electrical distribution	Preventive maintenance	Complete

Tevatron Collider operations for FY 2005 were initiated on December 7, 2004. While the FY 2005 plan entering the year showed cessation of operations on August 8, operations continued through the end of FY 2005, to accommodate preparations for DZero detector upgrade installations, and are being extended into the winter to allow for completion of studies aimed at addressing the shortfall, relative to the design goal, in the antiproton stacking rate. As of the scheduled end of running on August 8, total integrated luminosity (average of CDF and DZero) stood at 467.8 pb^{-1}, 98% of the design goal, delivered over a total of 3678 store hours, 105% of the design goal. As of 00:00 on October 3, the end of the last weekly accounting period in FY 2005, integrated luminosity stood at 598.2 pb^{-1} and store hours at 4621. Total integrated luminosity for Run II now stands at 1.275 fb^{-1}.

Highlights for the year include:

- A record luminosity (average of CDF and DZero) of 13.1×10^{31} on September 25—a 27% increase over the record at the end of FY 2004.
- Delivery of 598.2 pb^{-1} of integrated luminosity over 43 weeks of operations, an increase of 75% over FY 2004 (39 weeks of operations). This includes a best seven-day-period (March 20-26, 2005) integrated luminosity of 21.2 pb^{-1}.
- Establishment of “combination shots” as the standard operational mode. This mode utilizes antiprotons stored in both the Accumulator and the Recycler to create luminosity in the Tevatron. All stores above 10×10^{31} utilized this mode of operation.
- Improvements in the transfers of antiprotons between the Accumulator and Recycler. These transfers are now handled routinely: by the end of the year transfer efficiencies of 93%, accompanied by interruptions to stacking of 45 minutes, had become the norm.
- Installation (in the fall 2004 shutdown) and successful commissioning of electron cooling in the Recycler. This represents the first operation of an electron cooling system in the relativistic regime. By the end of the year electron cooling was being used routinely to

prepare (i.e. reduce the longitudinal emittance of) antiprotons in the Recycler prior to shots.

- Modification of the Tevatron optics (spurred by the successful implementation of the new Tevatron Beam Position Monitor [BPM] system). The interaction optics has been modified to provide a β^* of 28 cm at the B0 (CDF) and D0 (DZero) interaction points. The improvement in luminosity was roughly 15%.
- Improvements to the antiproton stacking rate. These were driven largely by the implementation of slip-stacking in the Main Injector early in the year, initiation of gain ramping in the Debuncher, and better understanding of limitations within the Antiproton Source toward the end of the year. The antiproton stacking rate rose to approximately 17×10^{10}/hour (zero stack stack rate), an improvement of roughly 30% over 2004, but short of the FY 2005 design goal of 25×10^{10}/hour.
- Successful commissioning and initiation of NuMI beam operations. By the end of the year, the Main Injector was delivering typically 2.3×10^{13} protons per pulse onto the NuMI target, with a total of 6.8×10^{19} delivered for the year (which started on May 1) — approximately 13% above the design goal for the year.
- An increase in the number of protons delivered to the MiniBooNE target, despite competition from NuMI. A total of 2.6×10^{20} protons were delivered to the MiniBooNE target in FY 2005—an increase of 20% over FY 2004.
- Operation of the 120 GeV fixed target program in parallel with antiproton stacking and neutrino operations.
- Significant improvements in operational reliability. The total of 4621 hours of stored beam represents 107 store hours/scheduled week of operations, a 12% improvement over the 95 store hours/scheduled week achieved in FY 2004.

The stage was set for these improvements during the very successful fall 2004 shutdown. We expect to embark on the FY 2006 shutdown on March 1, 2006, with luminosity operations in the Tevatron scheduled to recommence 16 weeks later.

Commentary on FY 2005 Performance

The median Collider luminosity over the final five weeks of FY 2005 was 10.3×10^{31}, exceeding the design goal of 9.6×10^{31} by about 7%. The improved performance over the course of the year was derived from a number of sources, some anticipated and some not. The most significant factors include:

- Implementation of Recycler/Accumulator "combination shots." This became the standard operational mode in 2005 and has produced performance benefits in two ways: First, by implementing frequent transfers from the Accumulator to the Recycler the average stack size in the Accumulator is kept down, allowing the average stacking rate to go up; and second, because of the lattice characteristics of the Recycler, the (transverse) emittances are nearly half as big in the Recycler as in the Accumulator, meaning Recycler antiprotons produce more luminosity than do Accumulator antiprotons.

- Initiation of slip-stacking in the Main Injector. The successful implementation of slip-stacking last December has increased the number of protons delivered to the antiproton target by nearly 40% (from 5×10^{12} to 7×10^{12}). This has provided a significant boost to the antiproton production rate.
- Commissioning and integration of electron cooling into operations. This has allowed us to provide lower (longitudinal) emittance antiproton bunches, and to accommodate more usable antiprotons within the Recycler (up to 250×10^{10} by the end of the year).
- Implementation of transverse dampers in the Recycler. The dampers have allowed us to store large, electron-cooled, antiproton stashes within the Recycler without suffering from beam instabilities.
- Implementation of the Booster quadrupole damper. This damper has reduced the longitudinal emittance delivered from the Booster by nearly a factor of two. Accrued benefits include better slip-stacking efficiency, which has lowered losses on the mixed stacking/NuMI cycles, and shorter bunches on the antiproton target, which increases the stacking rate.
- Installation of motorized quadrupole stands in the Debuncher. This has allowed implementation of a beam-based alignment system that has resulted in an increase in the Debuncher aperture to close to the Run II goal.
- Implementation of new Tevatron optics starting on Store 4395 (Sept. 20, 2005). We have lowered the β^* in the two interaction regions to 28 cm. This has increased luminosity by ~15%. This was made possible because of the improved resolution of the new Tevatron BPM system.

The above improvements translated into more antiprotons in collision, accompanied by lower transverse beam sizes, i.e. higher luminosities.

The primary shortfall in FY 2005 was in the antiproton stacking rate. The design goal was 25×10^{10}/hour (zero stack stacking rate) and we have achieved close to 17×10^{10}/hour. Gains this year have been driven primarily by the implementation of slip stacking in the Main Injector. As a reference, to achieve the 25×10^{10}/hour goal requires: 1) delivery of 8×10^{12} protons onto the antiproton production target every 2.0 seconds; and 2) maintaining a production efficiency of 17×10^{-6} in the antiproton source with the 2.0 second repetition rate. Efforts to achieve this are being undertaken by a dedicated task force formed in June and significant study time has been invested. Primary targets of the studies include improvements in proton intensity and beam size on the antiproton target, characterization and improvement of the AP-2 and Debuncher apertures, and exploration of limitations in the Debuncher to Accumulator transfers.

Antiproton availability remains the most important variable determining the luminosity of any particular store, and is expected to remain so for the balance of Run II. Experience to date is that combined shot operations are sustainable on every shot as long as stores remain in the Tevatron for ~24 hours. Under these conditions we are able to sustain luminosities in the 10-13×10^{31} range. This mode of operation puts considerable stress on the stacking rate and on reliability. A stacking rate at the FY 2005 goal would support combined source shots with much more flexibility in the face of 30% of stores terminating prematurely (as is typical). The FY 2005 stacking rate goal will be required to support FY 2006 goals.

Current Vulnerability/Reliability Issues:

- Linac tubes: This remains a long-term vulnerability but the short-term risk has been greatly reduced over the last year. We have been aggressively working with the vendor with the goal of building up inventory to a two year level (~12 tubes). We currently have eight spare tubes in inventory with a delivery schedule of roughly two/month.

Status Relative to the FY 2005 Plan

Planned and actual performance for FY 2005:

	Base Profile	Design Profile	Actual	
Median Initial Luminosity	8.1×10^{31}	9.6×10^{31}	10.3×10^{31}	*
Protons/bunch	260×10^{9}	260×10^{9}	251×10^{9}	*
Pbars/bunch	34×10^{9}	42×10^{9}	41×10^{9}	*
Effective Emittance (πmm-mr)	17	18	16	*
Beta at the IP (cm)	35	35	35/28	*
Hourglass Factor	0.65	0.65	0.67	*
Zero Stack Stacking Rate	17	25	16	*
FY 2005 integrated luminosity	368.1	476.6	598.2	pb^{-1} **
FY 2005 integrated store hours	3200	3500	4621	hours **

* Base and Design correspond to end-of-year goals. Actual corresponds to simultaneous performance on the median store of the last four weeks of FY 2005.

** Base and Design curves stop integrating FY 2005 luminosity on August 8, 2005. Total integrated luminosity was 467.8 pb^{-1} on that date; total hours were 3678. See Figure 1.

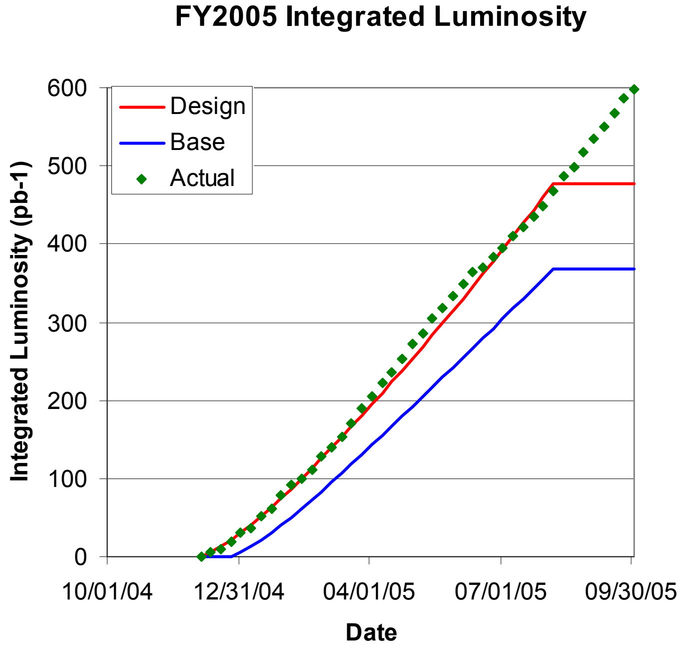

Figure 1. FY 2005 integrated luminosity.

E-830/Collider Detector at Fermilab (CDF) (P. Lukens, W. Sakumoto)

CDF began FY 2005 with a shutdown of Tevatron operations, and a maintenance period for the experiment. The major shutdown activities in fall 2004 involved installation of upgraded components of the electromagnetic calorimeter. These upgrades were parts of the Run IIb Detector Upgrade Project. The systems installed included the following:

- Upgraded Central Preshower Detector. This system replaced the existing preshower system, which was a gas chamber system, with a scintillator based detector. The upgraded detector is more appropriate for the Run II bunch-crossing time and less vulnerable to high occupancy events. The installation was completed well within the time allotted for the shutdown, and the detector has been incorporated into CDF data since.
- Electromagnetic Calorimeter Timing. This installation involved cable and electronics work on the central electromagnetic calorimeter. This installation is also complete, and the upgrade provides high resolution timing on electromagnetic energy. This will be used primarily for background reduction in photon reconstruction.

Tevatron operations resumed in December, 2004, and CDF resumed data collection. No major system failures occurred during the remainder of the year, and operation proceeded smoothly. A total luminosity of 621 pb^{-1} was delivered during FY 2005, and 509 pb^{-1} was collected (Figure 2). The total efficiency of 82% includes dead time associated with trigger acceptance and data collection. By the end of FY 2005, the experiment had collected just over 1 fb^{-1} in Run II.

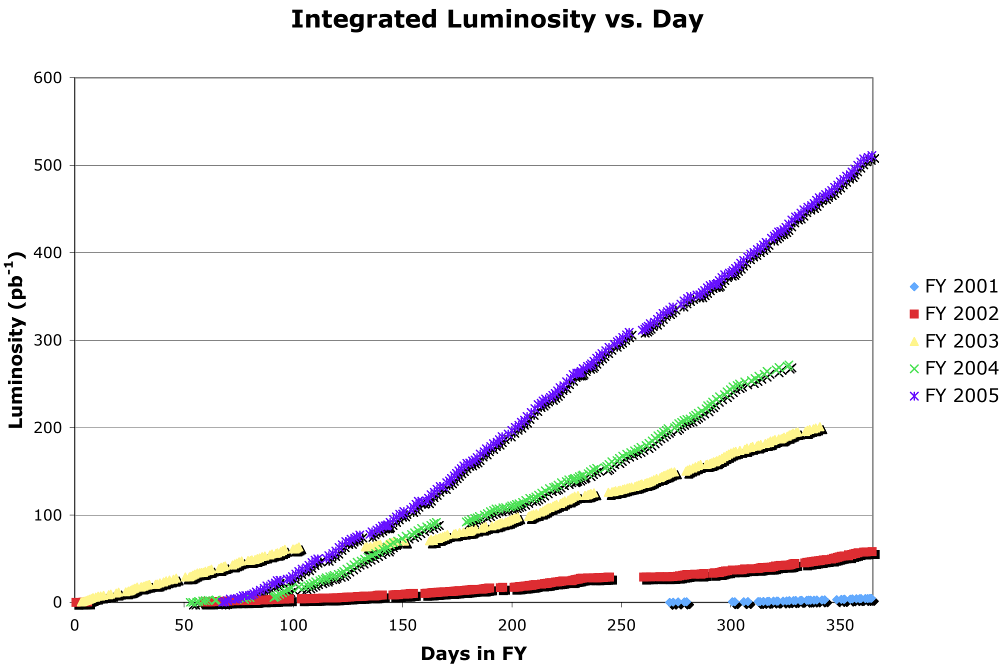

Figure 2. Luminosity acquired by CDF in fiscal years 2001-05.

One of the main issues for operations during FY 2005 concerned the installation and commissioning of additional upgrades to the experiment. These were all components of the Run IIb Upgrade Project. As various components were delivered, the operations group worked to incorporate them into daily operations as soon as was practical, so as to maximize the benefit to the experiment.

The first of the upgrades to be commissioned was the replacement of the Level 2 trigger decision crate. The replacement device is based on newer technology, and high-speed processors. This system replaces one with obsolete computing and difficult maintenance. Test runs of the upgraded system were made in the winter of 2005, and the system was declared fully installed by April, 2005. The older system was removed a month later.

Installation of the second upgraded system is in small batches, over a period of several months. This upgrade involves removing time-to-digital converters (TDCs) for the drift chamber, modifying them for higher-speed readout, and replacing them. The limited supply of these devices forces this small-batch installation strategy. By the end of FY 2005, twelve out of twenty crates were populated with modified TDCs. Simultaneous with the installation of modified boards, CDF is installing new front-end trigger cards for the upgraded track trigger. The full installation of this system requires some down time, and is planned for FY 2006.

A major effort went into the commissioning of the upgrades to the silicon vertex trigger (SVT) this year, as well. New and higher-capacity front-end memory cards were installed. These cards allow for a larger number of track patterns and finer segmentation at the trigger level. The trigger-level track-fitting hardware was also installed, leaving only a buffer memory upgrade remaining.

The final upgrade to the experiment was the replacement of the event builder system. As with the Level 2 trigger, the existing event builder was based on obsolete hardware with a difficult maintenance record. The new system, based on fairly common network and processing technology, was installed in August, 2005, and is now fully included in data collection. This system doubles the bandwidth of the experiment into the Level 3 computing farm.

E-823/DZero (D0) (B. Casey, H. Evans, G. Ginther, W. Lee, R. Lipton, T. Yasuda)

When FY 2005 began, the Tevatron complex was in a shutdown period. DZero used the shutdown time to improve detector performance and reliability, and to make detailed measurements of the available clearance for the Layer 0 silicon detector upgrade, which is scheduled to be installed during the next shutdown. Noise studies were performed and the detector ground was improved to reduce coupling between outside noise sources and the sensitive electronics of the detector. Power supplies and power supply controls were upgraded to improve stability and reliability. The online computer cluster was upgraded to enable larger bandwidth. Safety system tests, minor repairs, routine maintenance and individual channel recoveries were performed in anticipation of a long operating period without substantial downtimes.

The Layer 0 clearance measurements were performed optically, and the results were consistent with expectations based upon analysis of records from Coordinate Measuring Machine results performed during the construction of the Silicon Microstrip Tracker. The radial clearance is about 1 mm. The operations necessary to perform the clearance measurement provided insights and experience that are valuable in planning for the scheduled installation of the Layer 0 detector.

The superconducting solenoid was warmed to room temperature during the shutdown to fix a leak in a vapor-cooled current lead. Upon completion of the maintenance activities, during attempts to raise the solenoid current to its nominal operating value of 4750 amps, the solenoid quenched. A new operating point of 4550 amps was established. Detailed analyses of the behavior of the solenoid and the cryogenic system, combined with review of the historical records, indicate that a solder joint on the inner coil of the solenoid has likely been resistive, and that the resistance of that joint apparently increases when the coil experiences large thermal cycles. Figure 3 shows the temperature change in a coil support located in the vicinity of the coil joint when the magnet is charged (relative to zero current) as a function of time. Significant changes in the temperature in the coil support are correlated with warm-ups of the solenoid coil above 90K, and there is no evidence of additional degradation of the joint during stable operations. Preparations have been made to allow for implementation of additional cryogenic headroom (should that become necessary to maintain the new operating current). To minimize the risk of additional degradation of the coil joint, controlled access procedures have been revised to allow entry to the Collision Hall without ramping down the solenoid in order to minimize the frequency of charging and discharging cycles of the solenoid. In addition DZero intends to maintain the solenoid coils below 30K in the future.

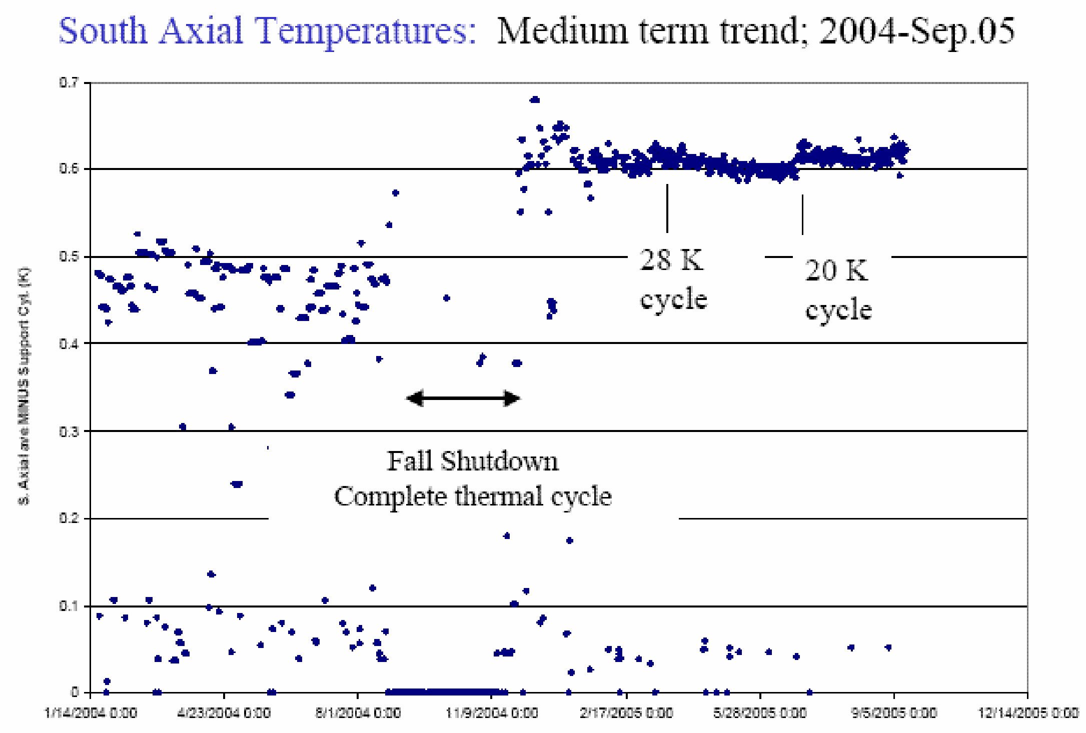

Figure 3. Temperature at south axial support (solenoid at full current relative to zero current) as a function of time.

Startup after the long shutdown was very smooth for the DZero detector, and the detector has been operating relatively smoothly and efficiently during the remainder of the fiscal year (as illustrated in Figure 4, which shows the detector efficiency as a function of time). Peak luminosities have been growing throughout the year, and DZero has developed a new trigger list to effectively handle the increased instantaneous luminosity. In addition, DZero continues efforts to streamline operations and improve monitoring tools and firmware to enhance reliability and operating efficiency. The upgrades to the VME Readout Buffer (VRB), the VRB controller (VRBC) firmware and the Sequencer have resulted in a much more stable readout of the Silicon Microstrip Tracker system and reduced the operating inefficiency significantly.

At the start of the year, the luminosity readout electronics were a Run I legacy system based on custom NIM modules. During the year, DZero commissioned a new custom VME system, which fully instruments each individual counter. The new system is much less sensitive to the backgrounds and deadtime that led to significant nonlinearities in the original system. The new electronics are also less prone to saturation effects, allowing DZero to increase the gain on the detector photomultiplier tubes and adopt a more efficient operating point. The new electronics are also fully integrated into the DZero readout which allows detailed information on system performance to be studied offline, providing for enhanced monitoring and calibration.

The silicon tracking detector has been exposed to 1 fb^{-1}, and studies of the change in depletion voltage of the various individual detectors as a function of integrated luminosity indicate that radiation damage is unlikely to seriously compromise the overall performance of the detector once the upgrades are installed.

During FY 2005, the DZero detector has recorded 494 pb^{-1} of the 569 pb^{-1} delivered integrated luminosity, which represents an average efficiency of 86.8%. Note that during FY 2005, the recorded Run II data sample has doubled (as illustrated in Figure 5).

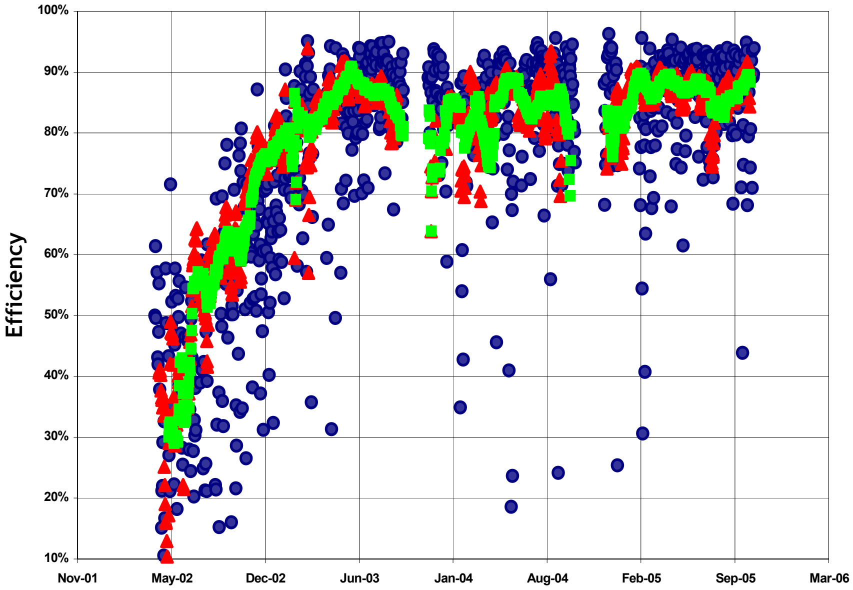

Figure 4. DZero data-taking efficiency as a function of time during Run II. The blue dots represent a daily average, the red triangles represent a 10-day average, and the green squares represent a 30-day average.

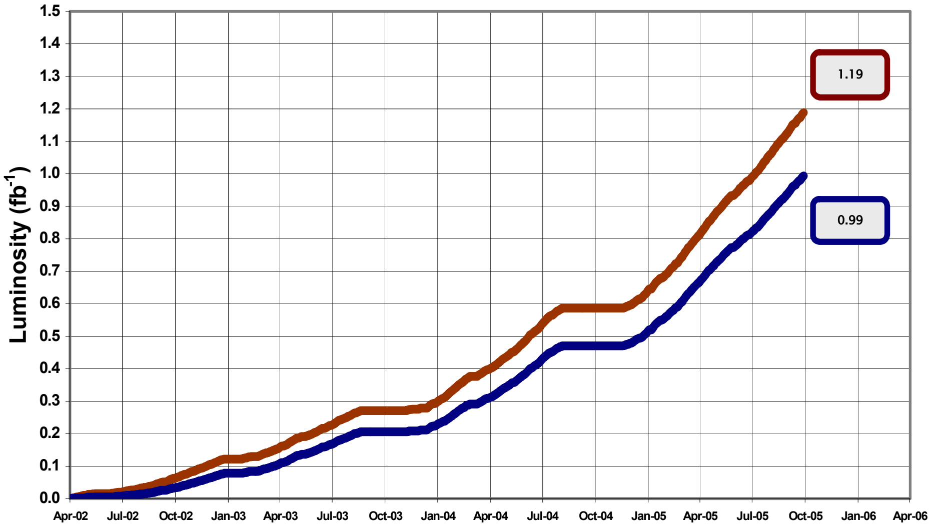

Figure 5. Delivered (upper line) and recorded (lower line) luminosity as a function of time at DZero during Run II.

In parallel with efficient operation of the detector, DZero has successfully completed design, fabrication and production of upgrades to the trigger and the detector that will improve detector performance and insure that the detector is capable of handling the instantaneous luminosities anticipated in the coming years. Parts of these upgrades were installed during the shutdown at the start of this fiscal year, but the majority of the upgrades are scheduled for installation during the next shutdown.

A new "Layer 0" silicon detector has been built and tested for installation during the next shutdown. The detector consists of 48 silicon strip detector modules assembled on a carbon fiber support structure that will be located inside the inner radius of the current Silicon Microstrip Tracker. Each detector module is built of a 256 channel 300 micron thick sensor of either 71 or 81 micron pitch attached by Kapton analog cables to a pair of SVX4 readout chips mounted on a ceramic hybrid. Module construction and testing was completed in June of 2005 and installation onto the support structure was completed on August 1. Extensive system testing was performed in July and August for the 1/2 system and fully assembled detector, respectively. Mockup tests of installation techniques and tooling were performed at DZero, Lab 3 and SiDet. The detector is of very high quality with 99.9% good strips and assembly alignment reproducible to 2-3 microns.

The current Level-1 Calorimeter Trigger (L1Cal), which is one of the few DZero subsystems remaining from Run I, will be completely replaced for high luminosity running. The newly designed trigger (L1CalIIb) takes advantage of advances in electronic technology to implement sophisticated clustering algorithms, currently only possible in the 2nd Level trigger. It has been shown, using both data and simulation, that the L1CalIIb trigger will give a reduction in Jet and EM trigger rates that should be large enough to allow DZero to run at the highest luminosities foreseen at the Tevatron, while still retaining current levels of efficiency for interesting physics processes.

FY 2005 was a particularly productive period for the L1CalIIb effort. Production of all active custom electronics for the L1CalIIb was completed, and commissioning of the entire system at Fermilab began in earnest. Especially useful in the commissioning process is a "shadow system" set up outside of the DZero Movable Counting House, which will soon comprise the entire L1CalIIb system. This Test Area allows the L1CalIIb to be run in parallel with the current L1Cal during DZero data-taking, receiving several channels worth of real data split off from the normal trigger data path. Tests of system operations have been very successful and comparisons between actual calorimeter data processed by L1CalIIb during DZero data-taking show excellent agreement with the standard readout of calorimeter energy. Current plans, scrutinized in a successful DZero Technical Readiness Review in late August, have the system ready for installation in the late fall of 2005.

E-898/MiniBooNE (J. Conrad, W. Louis)

The MiniBooNE experiment began taking data at Fermilab in late August, 2002, and has collected over 680K total neutrino events during the first three years of operation. This report summarizes the MiniBooNE data collection and analysis progress during the 2005 fiscal year.

As shown in Figure 6, the Booster has delivered about 6.5×10^{20} protons to the MiniBooNE target during the first three years of MiniBooNE operation and about 2.8×10^{20} protons in FY 2005 alone. The year began with the replacement of the focusing horn, which performed admirably during almost two years of operation and pulsed a record number of 84.8M pulses (96M including the test pulses). The new focusing horn has, so far, recorded 71.8M pulses and has performed flawlessly.

Due to the short duty factor of the Booster beam, it is very easy to identify genuine neutrino events. Figure 7 shows the time distribution of events (in a 19 micro-second time interval around the Booster beam spill) that satisfy the criteria of more than 200 tank phototube hits and less than six veto phototube hits. As can be seen in the figure, nearly all of the events are neutrino events produced during the 1.6 micro-second beam spill and there are very few cosmic-ray induced events outside the beam spill window. The ratio of neutrino events to cosmic-ray induced events during the beam spill is about 5000 to 1. Using the above criteria to identify neutrino events, MiniBooNE has collected over 680K neutrino events during the first three years of data-taking and approximately 300K neutrino events in FY 2004 alone.

The MiniBooNE detector and beamline have also performed extremely well. In FY 2005 about 99% of the phototube channels worked well, and the data acquisition livetime averaged ~99%. Furthermore, the reconstructed time, position, energy, and angular resolutions are all in agreement with expectations, and the experiment is clearly observing charged-current quasi-elastic events, charged-current pion-production events, neutral-current pion-production events, and neutral-current elastic-scattering events. As an example, Figure 8 shows the preliminary MiniBooNE charged-current pion-production ($CC\pi^+$) cross section as a function of neutrino energy. The MiniBooNE data (points with error bars) are compared to the predictions of the NUANCE and NEUGEN cross section programs. In addition, MiniBooNE is observing events produced by the NuMI beamline. Whereas the MiniBooNE neutrino event rate from the 8 GeV beamline is about 1.1×10^{-15} events per proton on target (POT), the event rate from the NuMI beamline is about 0.51×10^{-15} events per POT.

Based on the data analysis progress to date, Figure 9 shows the updated MiniBooNE oscillation sensitivity for a total of 1×10^{21} protons on target (MiniBooNE is now about 65% of the way toward this goal). As can be seen in the figure, MiniBooNE should be able to cover almost the entire LSND region at 5 sigma. If MiniBooNE confirms the LSND signal, Figure 10 shows how well the oscillation parameters can be measured at two different points in the Δm^2 - $\sin^2(2\theta)$ parameter space.

Overall, 2005 was another outstanding year of data-taking for the MiniBooNE experiment. The detector and beamline performed well, and the Booster delivered 2.8 ×10^{20} protons on target (56% of the experiment's desired yearly goal), despite the fact that the NuMI beamline began operating midway through the year.

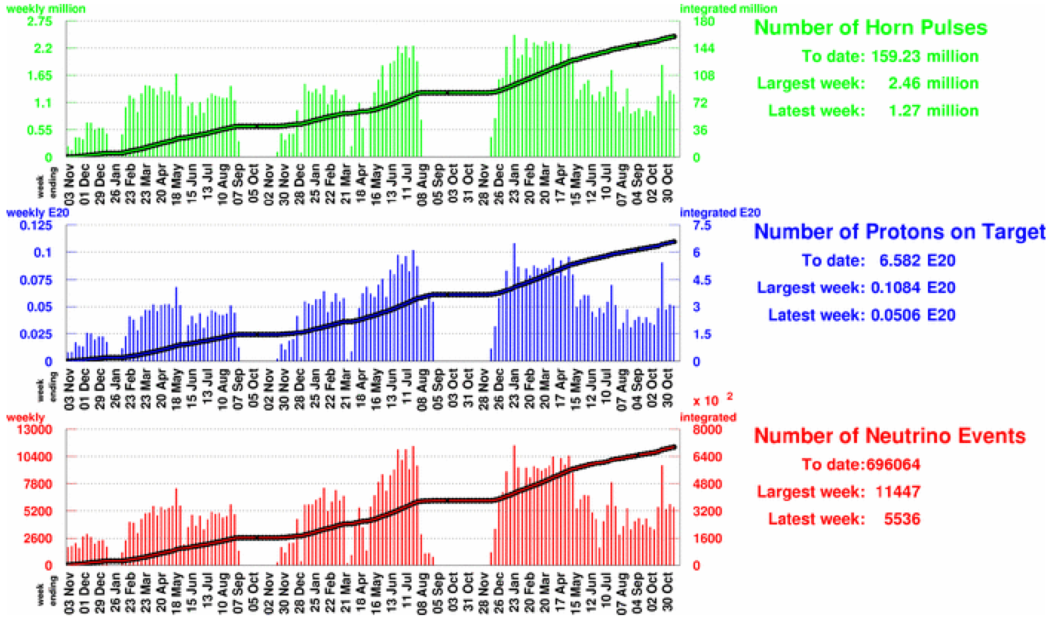

Figure 6. The progress in delivering beam to MiniBooNE during the first three years of operation.

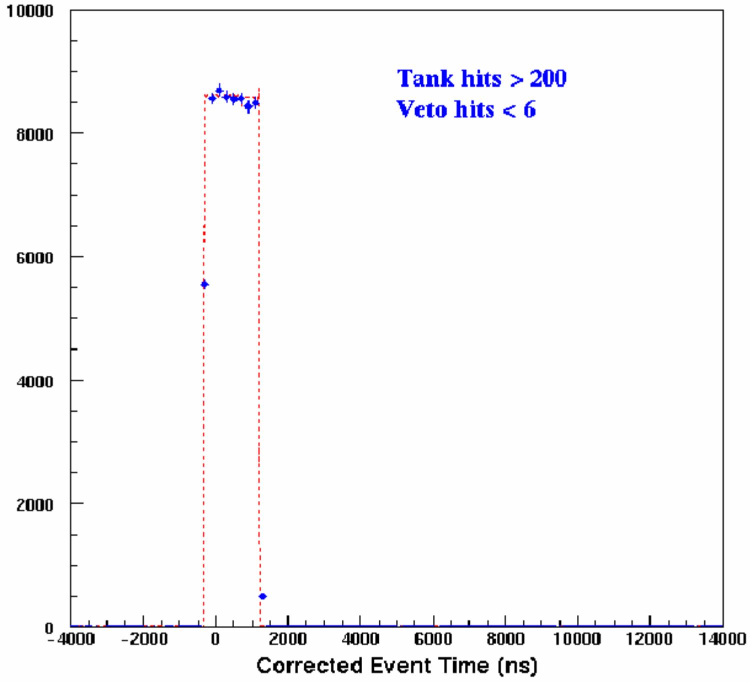

Figure 7. The time distribution of events (in a 19 micro-second time interval around the Booster beam spill) that satisfy the criteria of more than 200 tank phototube hits and less than six veto phototube hits.

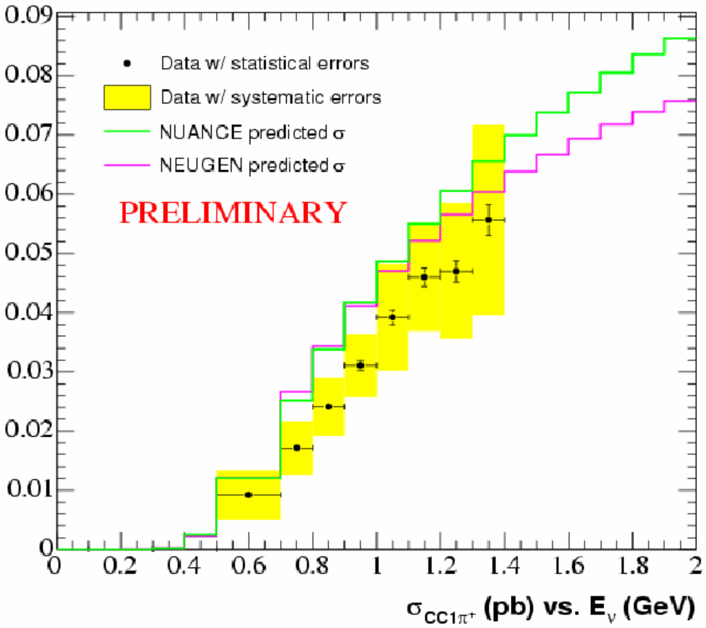

Figure 8. The preliminary MiniBooNE CCπ^+ cross section as a function of neutrino energy. The MiniBooNE data (points with error bars) are compared to the predictions of the NUANCE and NEUGEN cross section programs.

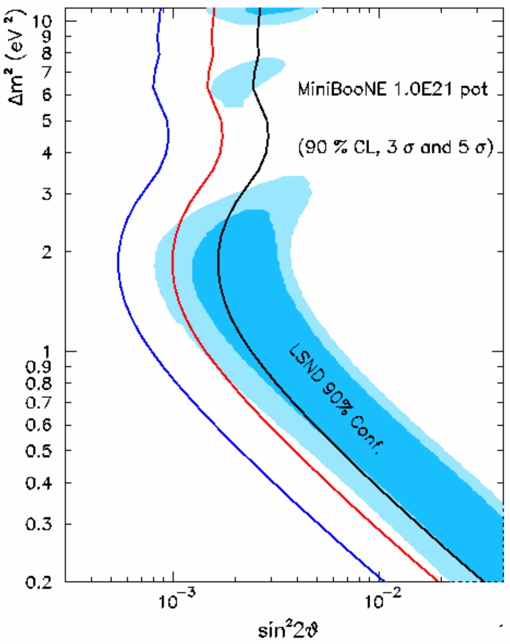

Figure 9. The updated MiniBooNE oscillation sensitivity for a total of 1×10^{21} protons on target.

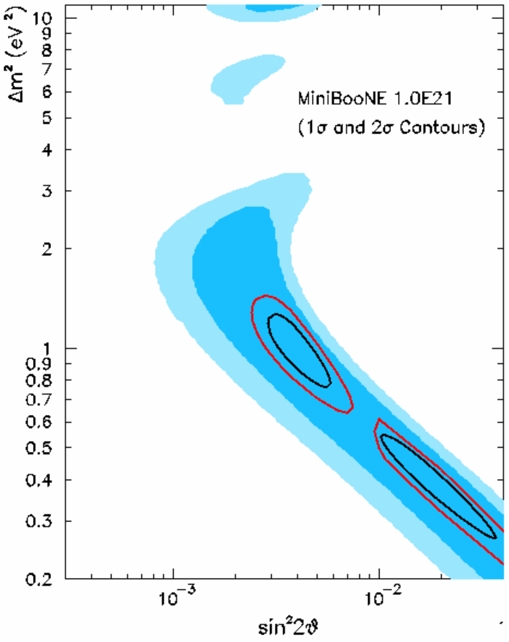

Figure 10. This figure shows how well the oscillation parameters can be measured at two different points in the Δm^2-$\sin^2(2\theta)$ parameter space.

Fixed-Target Switchyard 120 GeV (SY120) (C. Moore)

SY120 120 GeV proton beam was reestablished in early December 2004 to MTest and MCenter. Tuning of the 0.6-second slow spill beam continued in early 2005 in parallel with the delivery of single-turn 120 GeV beam to T-926. A significant accomplishment was the establishment of many different momentum tunes in the secondary beam portions of both beamlines: from 4 GeV/c to 66 GeV/c in MTest, and from 5 GeV/c to 80 GeV/c in MCenter. Both beamlines can also be run independently in a pinhole-collimator-attenuated mode which allows the delivery of low-intensity 120 GeV/c protons through the secondary beam regions of the beamline down to the two experimental areas.

In order to maximize the data-taking rate for E-907 (Main Injector Particle Production - MIPP), a 4.1 second spill was instituted in early March. This involved a retuning of the entire P1, P2 and P3 beam lines, the rest of Switchyard, and the Meson beamlines. Also, the safety requirements needed to deliver very low intensity 120 GeV/c protons to the MIPP experiment were resolved, and this beam was used for measurements with the NuMI target during the August, 2005 MIPP run period.

Number of Beam Pulses delivered to SY120

	Total SY120 Pulses	MCenter*	MTest*
June 2005	15,023	7,411	3,560
July 2005	22,847	21,724	4,349
August 2005	16,711	16,253	3,853
September 2005	16,416	16,079	77
October 2005	17,974	16,863	515

Number of beam pulses since stable 4 second spill achieved in June.
* = Pulses with beam.
Note: the 18K pulses in October (at 6 seconds per SY120 cycle) represent 4.0% of the total time line for the month.

NuMI / E-875 MINOS – Main Injector Neutrino Oscillation Search

(S. Childress, R. Plunkett, R. Rameika)

NuMI

Component installation for the NuMI project, which provided the facility and a high-flux beamline for delivering neutrinos from Fermilab to Soudan MN for the MINOS experiment, was completed in the early part of FY 2005. Figure 11 below shows a schematic of the NuMI facility at Fermilab.

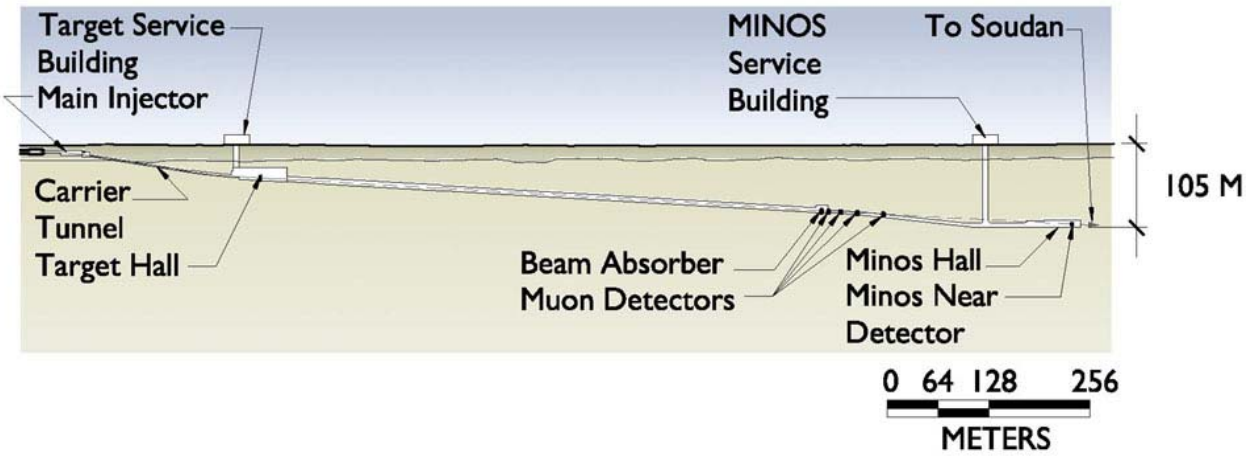

Figure 11. Schematic of the NuMI Facility.

Beam commissioning followed installation completion, with a rapid progression to high-intensity neutrino production. Three very successful beam commissioning periods were scheduled around final installation of target hall support systems:

i) December 3-4, 2004: Initial low intensity 3.0×10^{11} protons per pulse (ppp) 120 GeV beam extraction from the Main Injector, and transmission to the hadron absorber 1 km away from the extraction point, with no target in the beam.

ii) January 21-23, 2005: Commissioning of the neutrino beam with single batch extraction of 2.6×10^{12} ppp. First beam running with the graphite target and a two-magnetic-horn focusing system and observation of neutrinos in the near detector. The beam requirements for NuMI CD-4 project completion were accomplished.

iii) February 18-22, 2005: Commissioning of high intensity multi-batch NuMI beam. While operating with a dedicated NuMI cycle, 2.5×10^{13} ppp was delivered to the NuMI target with 6-batch operation.

Following completion of the target shielding chase cooling system, mixed-mode beam operation for NuMI was begun on March 16, 2005. In this mode NuMI receives five batches of beam during each Main Injector stacking cycle for antiproton production. A major problem with the NuMI target occurred on March 21, with the development of a cooling water leak within the target vacuum chamber. A period of one month was required for diagnostics and development of a successful procedure to allow continued running with the existing target. In late April, the target was reinstalled and returned to operation using He backpressure to prevent water flow through the small hole in the cooling tube. The effectiveness of this approach has been regularly checked with low-intensity beam scans across the target, using secondary beam monitors to determine the target integrity.

Following the target re-installation, NuMI beam operation resumed, with a very successful running period from May 1 through September 30. Figure 12 shows the average protons per hour to NuMI during this time period. A steady increase may be seen, along with a rapid progression above the base and design expectations for beam capability to NuMI during FY 2005.

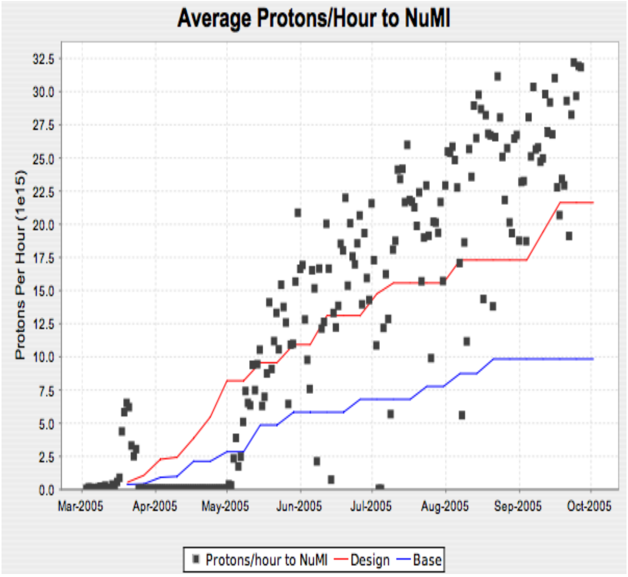

Figure 12. Average protons per hour to NuMI in FY 2005.

Primary beam intensity and beam power delivered to NuMI during the week of September 21-28 are shown in Figures 13a and 13b. During this week, NuMI received 210k beam pulses, with an average intensity of 2.3×10^{13} ppp and an average beam power of 165kW. The two distinct intensity peaks are for mixed-mode five-batch and NuMI-only six-batch operation. The broader spread in beam power is due to an operational spread of cycle times for the antiproton stacking.

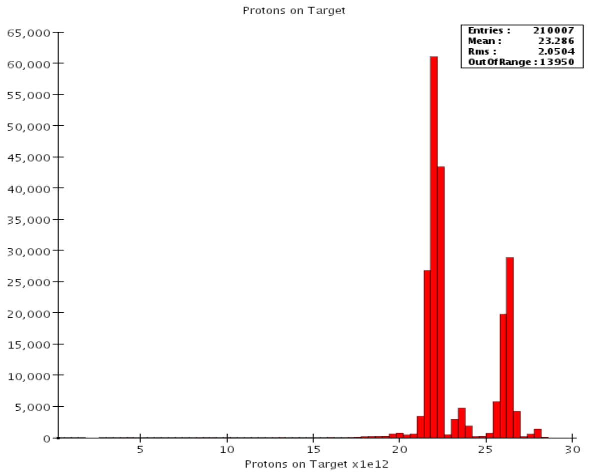

Figure 13a. NuMI Primary Beam Intensity.

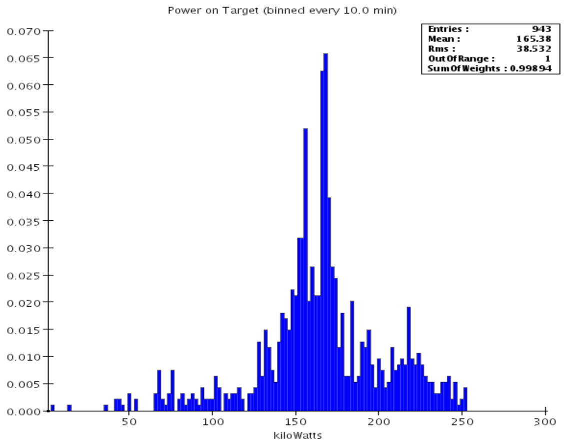

Figure 13b. NuMI Primary Beam Power.

Extraction and primary beam operation for NuMI have been very robust, even with the very high beam intensity and severe constraints on allowable beam loss. The combination of a comprehensive beam permit system, which inhibits beam if conditions are not appropriate for extraction to NuMI, as well as a fully automated beam position control for transport to the target, have been key factors in this accomplishment.

The position of the beam centroid is maintained at the desired position on target to within 100 µm. This is shown for NuMI-only operation in Figure 14 for each of the six batches composing a NuMI beam spill. The width of the target is 6.4 mm, equal to the full horizontal extent of the plot.

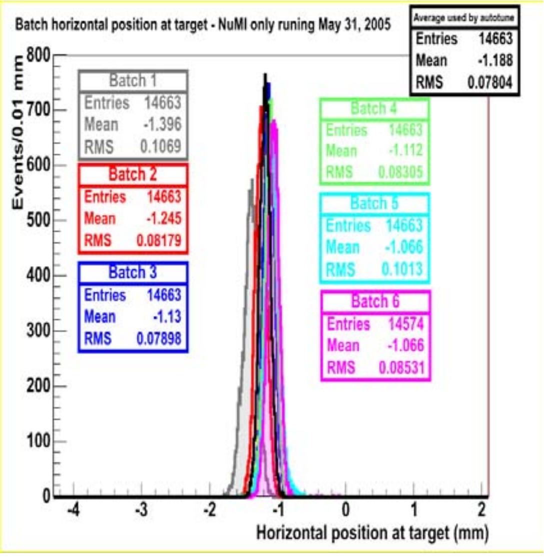

Figure 14. Rms beam stability on the target (NuMI-only mode).

MINOS

The MINOS experiment studies the interactions of the NuMI neutrino beam in two locations: the MINOS Near Detector Hall at Fermilab and the MINOS Far Detector Hall at the Soudan Underground Laboratory in Soudan, Minnesota, 735 km away. The two MINOS detectors are of similar design. The basic configuration is a series of steel planes aligned perpendicular to the direction of the beam, most of the steel planes bearing a layer of scintillator strips. The steel provides a target for neutrino interactions and the scintillator counters provide a means of detecting the charged particles produced in the interactions. Each detector comprises several hundred planes, which allows for muon identification, energy deposition measurements, and event reconstruction. The steel is toroidally magnetized by a high-current coil running longitudinally through each supermodule of the detectors. This enables the MINOS detectors to distinguish neutrinos from antineutrinos. The far detector has two super modules; the near detector is a single unit.

The MINOS near detector was completed in fall 2005 and commissioned as part of the commissioning phase of the NuMI project, which achieved CD4 on February 28, 2005. The first neutrino events were observed in the near detector on January 21, 2005. Since then, the beam intensity has steadily increased. MINOS has taken data with the NuMI beam in three target positions, providing a range of beam energies for systematic studies, but the bulk of the data-taking has been with neutrinos of the relatively low energies needed to optimize the signal of neutrino oscillations. Figure 15 shows the total delivered protons to the NuMI target since May 1, 2005.

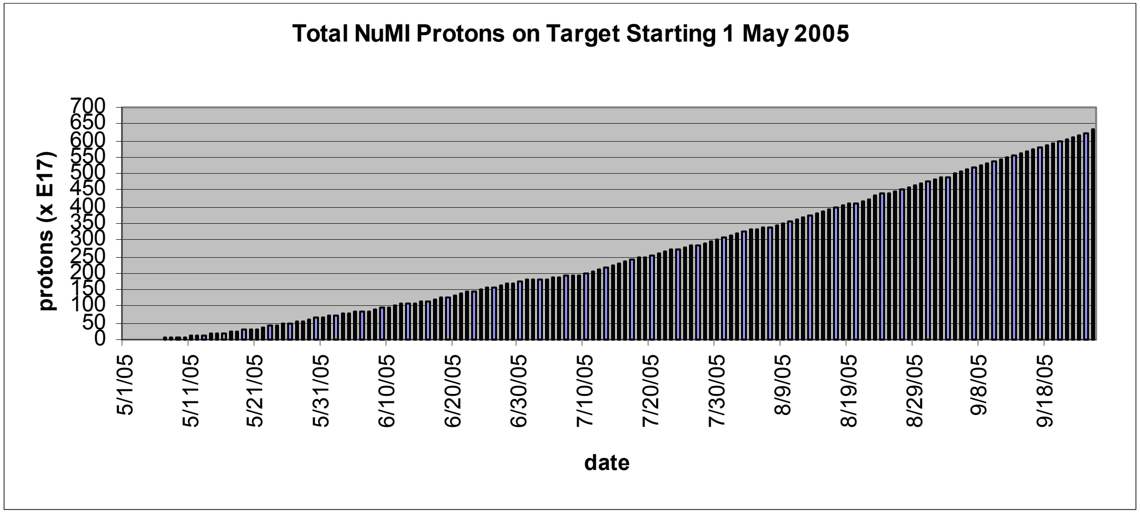

Figure 15. NuMI protons on target since May 1, 2005.

The near detector is operated from the MINOS twelfth-floor control room in the Fermilab highrise. Operational efficiencies are high, routinely exceeding 98% during beam-on conditions. Maintenance largely consists of repairing single channels of front-end electronics boards which occurs at a rate of two to four per week. Several cabling errors in the detector were found and corrected by inspection of analysed data, which is available soon after data-taking. A small number of ongoing studies led to improved detector performance by replacement of PMT's, associated cable harnesses, etc.

The MINOS far detector has been in steady operation throughout FY 2005. Atmospheric neutrino running was accomplished before the commissioning of the NuMI beam. Since beam commissioning, both atmospheric and beam data have been taken. The far detector is also usually operated from the MINOS twelfth-floor control room, with additional monitoring from the Soudan Underground Laboratory during daily working hours. Personnel are available for call-in at Soudan on a 24-hour basis. The detector can be operated from Soudan if there is an interruption of network service, providing a robust data-taking configuration. The far detector runs with high operational efficiency, routinely exceeding 95% for weekly averages and 98% during beam-on conditions. Figure 16 shows protons delivered since May 1, 2005 with the detectors on and off, whose ratio gives the beam-on livetime for this period.

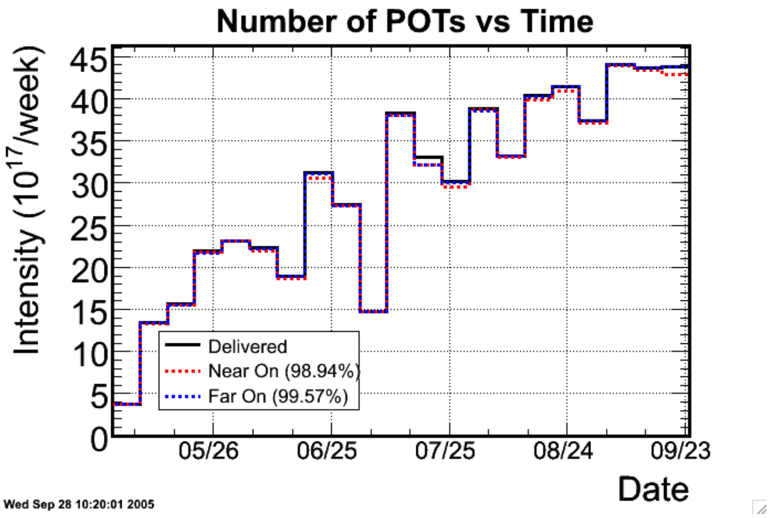

Figure 16. Weekly protons delivered to the MINOS detectors, and the number delivered while the detectors were active, beginning on May 1, 2005.

Problems were experienced at the far detector during 2005 with the chilled water system which supplies water for the MINOS magnet. Chiller trips were usually resettable before the magnet coil sensors would trip off the coil, so only two trips were experienced, one of which caused the loss of a negligible amount of beam data. The origin of the problem was traced to the input voltage into the laboratory, which exceeded the default trip-point variations for the chiller. Manual tuning of these set points has corrected the problem. Other maintenance consisted of replacement of small numbers of electronics channels and photomultiplier tube assemblies, and debugging of minor problems with the high-voltage distribution system.

E-907/MIPP – Main Injector Particle Production (R. Raja)

The MIPP experiment (Fermilab E-907) is designed to measure particle production using Main Injector secondary beams ($\pi^{\pm}$, $K^{\pm}$, $p^{\pm}$ with beam momenta ranging from 5 GeV/c to 90 GeV/c) over a variety of targets ranging from hydrogen to beryllium, carbon and heavy nuclei. The centerpiece of the experiment apparatus (Figure 17) is a time projection chamber capable of detecting particles over nearly 4π acceptance. Using a combination of dE/dx, time of flight, Cerenkov and RICH detectors, MIPP identifies the charged particles in the final state. With this data, MIPP hopes to restart the study of non-perturbative QCD interactions with unprecedented accuracy as well as to measure cross sections in nuclei for the purpose of proton radiography and nuclear physics. A critical measurement MIPP will make is of particle production from the NuMI target, which will be beneficial to all neutrino experiments using the NuMI beam.

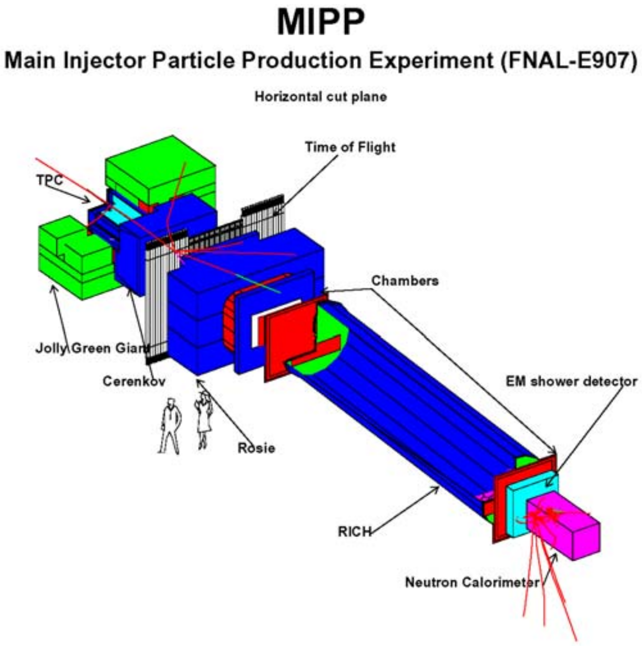

Figure 17. The MIPP apparatus.

A Director's Review of MIPP was held on 10th November 2004, which assessed the readiness of the experiment. The review of the state of the experiment was extremely positive and the prioritized run plan MIPP presented received approval. The proposed and approved physics for MIPP is prioritized as follows. In the priority 1 data, completed in FY 2005, MIPP acquired 9 million events, in priority 2 mode MIPP is acquiring an additional 18 million events, and in priority 3 mode MIPP would obtain an additional 45 million events for a grand total of 72 million events. The data acquired are of unprecedented quality in acceptance and particle identification and span various nuclei.

The MIPP physics run started in earnest in January 2005. During the early part of the running, the cryogenic liquid hydrogen target was successfully commissioned. Before the startup of MINOS, MIPP was able to take data at the rate of a minimum of six spills per minute (3.6 seconds spill time) that increased to ~12 spills per minute (7.2 seconds spill time) as the antiproton stack size grew. With the MINOS turn-on, MIPP received one 4-second spill every two minutes (two seconds of spill per minute). The experiment is fully functional and the low spill rate is impeding MIPP’s ability to acquire all of its proposed data (72 million events). In July 2005, MIPP switched to 120 GeV/c protons on the NuMI target (Figure 18) and acquired 1.5 million events. The complex beam manipulations that required the installation of a pinhole collimator went smoothly.

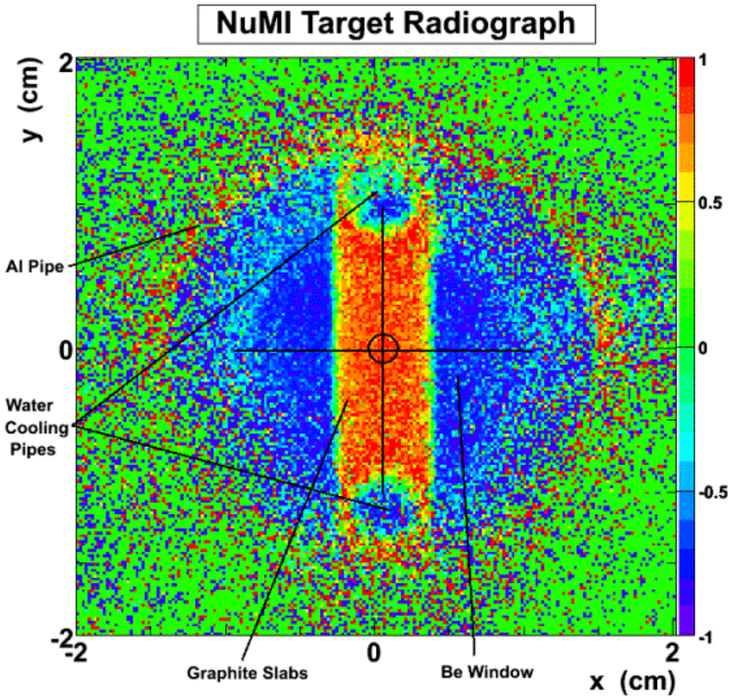

Figure 18. NuMI Target Radiograph.

By the end of FY 2005, MIPP had completed their priority 1 running and was in the middle of priority 2 running. MIPP will run till the March 2006 shutdown, by which time, with the current spill rate, MIPP hopes to complete a significant portion of the priority 2 data (~50%) for a total of ~18 million events.

Meson Test Beam Facility (E. Ramberg)

The Meson Test Beam Facility (MTBF) saw regular operation during FY 2005. Potential test beam users request time at the facility by creating a Memorandum of Understanding (MOU) with the Laboratory such that the beam and other requirements are spelled out in detail. The list of test beam MOU documents can be found at

http://www-ppd.fnal.gov/MTBF-w/mtbf_mou.htm.

There have been 14 experiment MOU's over the two-year lifetime of this test facility. Four of these are new MOU's that were proposed during FY 2005. During FY 2005, seven of the tests completed data-taking, three are taking data now, and three have not taken data yet. (One test beam effort was completed in FY 2004.) Table 1 summarizes the test beam usage so far.

Table 1. A description of test beam experiments.

Experiment	Description	Status
T-926	Radio Ice Cerenkov Experiment	Completed
T-927	BTeV Pixel Detector	Completed
T-930	BTeV Straw Detector	Completed
T-931	BTeV Muon Detector	Completed
T-932	Diamond Detector	Approved
T-933	BTeV E.M. Calorimeter	Completed
T-935	BTeV RICH Detector	Completed
T-936	US/CMS Forward Pixel Detector	Taking data
T-941	U.Iowa PPAC Test	Completed
T-943	U.Hawaii Monolithic Active Pixel	Completed
T-950	Vacuum Straw Tracker	Taking data
T-951	ALICE EMCAL Prototype	Taking data
T-953	U.Iowa Cerenkov Light Tests	Approved
T-955	RPC Detector Tests	In review

During FY 2005 the duty cycle of the SY120 extracted beam was changed from 0.6 seconds of slow spill per minute to 4 seconds of slow spill every two minutes. This beam supports the MIPP experiment as well as MTBF. The maximum beam intensity in the Main Injector that has been extracted to the test beam target has been approximately 2.4×10^{12} per spill. When sending primary protons to users (120 GeV), a pinhole collimator is used to reduce rates for safety. This translates into 800,000 protons per spill at 120 GeV. When tuned to the lowest secondary-beam momentum achieved so far (4 GeV), the maximum particle rate is 500 particles per spill with no collimation. About half of these particles are electrons. Table 2 gives a summary of the rates and electron content of various test beam tunes.

Table 2. Rate of beam in the MTBF user area (MT6) and fractional flux of electrons. All rates are normalized to 2.4×10^{12} protons in the Main Injector.

Tune (GeV)	Total rate/spill	e-fraction
120	800,000	0
66	90,000	0
33	40,000	0.7%
16	15,000	10%
8	5,000	30%
4	500	60%

The beam has an approximately 1% momentum spread, as measured in the BTeV electromagnetic calorimeter test. It can be focused to a 7 mm rms spot size for 120 GeV protons and approximately 2-3 cm rms spot for the lower momenta.

During the current run, a tracking DAQ was implemented. It consists of three MWPC chambers, two single-wire drift chambers, and the signals from the two beamline Cerenkov detectors. It can take data at the rate of about 3000 events per spill, and the tracking reconstruction currently achieves approximately 1-2 mm spatial resolution.