Department of Energy
Review Committee Report

on the
review of

TEVATRON OPERATIONS AT FERMI NATIONAL ACCELERATOR LABORATORY

March 2006

EXECUTIVE SUMMARY

The Department of Energy review of Tevatron Operations at Fermi National Accelerator Laboratory (Fermilab) was conducted on March 21-22, 2006 at the request of Robin Staffin, Associate Director for the Office of High Energy Physics. The purpose of the review was to evaluate Fermilab's performance in operating the Tevatron complex, the planned completion of the luminosity upgrades, and the expected performance of the Tevatron through FY 2009.

Performance of the Tevatron in FY 2005 was impressive. The peak luminosity has been increased as a result of successfully completing several Run II Luminosity Upgrades. In addition, in FY 2006 the weekly integrated luminosity is at an all-time high and is meeting the design goal. However, the total integrated luminosity has fallen behind the goal due to three failures of Tevatron magnets and the resulting downtime needed for repairs. Fermilab is aggressively addressing the recent failures of Tevatron magnets, and other reliability concerns, with an extensive remediation program.

The Committee felt that the FY 2006 base luminosity goal is likely to be met, but the FY 2006 integrated luminosity achieved may fall short of the design goal. With regard to the outyear program, achieving the base integrated luminosity seems very likely assuming the reliability of the complex is no worse than experienced over the past couple of years. Achieving the design luminosity will depend crucially on how much improvement can be made to the average antiproton-stacking rate. Improvements to the antiproton-stacking rate will not be known until May 2007 when the upgrades have been completed and operational experience gained.

The Run II Luminosity Upgrades are on schedule and nearing completion (86 percent complete). The Recycler and Electron Cooling have been successfully commissioned and are now in routine operation. Machine studies appear to be appropriately managed to support ongoing operations, commissioning of new equipment, and development of new operating procedures. Adequate resources have been devoted to both operations and the upgrades. The proton plan is now defined and reviewed, and some of the key components of the plan are being implemented.

Overall, Fermilab's safety performance has been excellent and key safety metrics demonstrate continual improvement.

While Fermilab actions related to tritium contamination are prudent and appropriate, this issue will require continued and focused efforts to establish an atmosphere of openness; ensure communications are in context; and take care in making future commitments.

CONTENTS

Appendices

1. INTRODUCTION

The Office of High Energy Physics (OHEP) supports the operation of the Tevatron program at Fermi National Accelerator Laboratory (Fermilab). Run II of the Tevatron is planned to continue through FY 2009, and the neutrino program will continue beyond that time.

OHEP requested that the Office of Project Assessment perform an independent review of the accelerator operations and luminosity upgrades of the Tevatron complex at the Fermilab to determine that they are efficient and effective. The review was conducted on March 21-22, 2006, at Fermilab, and was chaired by Daniel R. Lehman, Director of the Office of Project Assessment. To address the charge, the Committee was divided into subcommittees that examined accelerator operations and integration, the antiproton source, and management. The Committee members were drawn from other Office of Science laboratories. The Department of Energy (DOE) Fermi Site Office observed the proceedings.

The review was based on formal presentations given by Fermilab staff, detailed discussions with Fermilab employees, and the Committee members' extensive experience. A half-day was devoted to presentations given by Fermilab. These presentations provided an overview and response to the charge letter. For the remainder of the day, members of each subcommittee met with Fermilab counterparts in working sessions to further discuss details in the functional area for their respective subcommittees. The remaining time was spent on subcommittee working sessions, Committee deliberations, and report writing. The Committee discussed the results of the review with Fermilab management in a closeout briefing on March 22, 2006.

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2. TEVATRON

2.1 Findings

The Tevatron had an impressive year. The peak luminosity was increased as a result of several upgrades (discussed below). The weekly integrated luminosity is also at all-time high and is meeting the design goal. However, the total integrated luminosity has fallen behind the baseline goal due to three failures of Tevatron magnets and the resulting downtime needed for repairs.

The peak luminosity increased from 1.1×10^{32} cm^{-2} sec^{-1} in spring 2005 to $1.7 \times 10^{32} cm^{-2}$ sec^{-1} in spring 2006, which is less than a factor of two below the ultimate Run II peak luminosity. The peak weekly integrated luminosity of 24.4 pb-1 is a factor of two away from the ultimate Run II design projection. In FY 2005, 600 pb^{-1} was delivered, in excess of the design goal, and 280 pb^{-1} has been delivered thus far in FY 2006.

Impressive progress was made in understanding the Tevatron lattice and methods to improve it. The recently commissioned Beam Position Monitor (BPM) system has been used to measure the lattice functions via the Orbit Response Matrix method, and together with colleagues at Argonne National Laboratory, correct the beta-beating. A new lattice with lower vertical beta-star was commissioned. The lattice is now well-corrected, with lattice functions agreeing with design to within five percent. The chromatic beta-functions have been measured and agree remarkably well with simulations.

The improvement in Tevatron luminosity is due in large part to electron-cooling in the Recycler, and the integration of the Recycler into routine operation. The complex now makes use of Recycler-only operations that provides faster stacking and smaller P-bar emittances to the Tevatron, as well as simplifies the operations sequence. Additional improvements to the luminosity are due to a reduction in vertical beta-star from 36 cm to 28 cm, stabilization of the P-bar tunes that result in better lifetimes, and active orbit stabilization.

A program of separator and helix improvements is nearing completion. The remaining new separators are being installed during the present down period. This will complete the scope for the separator portion of the Run II Luminosity Upgrades. Commissioning of a new, improved, helix scheme will commence upon machine recovery following the scheduled down period.

Detailed optics studies and simulations were performed and have provided valuable input for planning hardware modifications. Octupoles will be used for differential chromaticity control in order to allow the proton chromaticity to remain high, with lowered P-bar chromaticity. The two-family sextupole configuration is being split into more families for better chromatic lattice properties.

Detailed simulations using the LIFETRAC code including primary and head-on collisions have been developed. For the first time, this simulation reproduces the observed bunch-by-bunch "scallops" in the antiproton vertical emittance. Additional simulations were completed to evaluate the performance of three working points and different chromaticities.

2.2 Comments

The Committee was impressed with the use of the improved diagnostics to measure and correct the lattice. This also led to a model that accurately predicts the machine.

Fermilab is aggressively addressing the recent failures of Tevatron magnets with an extensive remediation program. Other reliability concerns are being aggressively addressed. The Committee was impressed with the extent of Fermilab's efforts to address identified reliability concerns.

In order to meet the integrated design luminosity design curve in FY 2006 the Tevatron will need to average 130 hours of operation per week. The Committee felt this is a very challenging goal. The base goal will be met if there are no further significant faults.

The beam-beam interaction will become a serious limitation to Tevatron performance at some current. Calculations and simulations are not precise enough for a quantitative prediction of that current, and this could be a significant consideration. Therefore, it is important that there be multiple ways to optimize the integrated luminosity. There is appears to be sufficient flexibility in the operating scenarios to accomplish this.

Beam-beam effects are influencing the beam dynamics in the Tevatron, from injection through the ramp and into collisions. Variations in bunch-by-bunch tunes and emittances are observed, indicating the influence of parasitic beam-beam effects. Total P-bar tuneshifts are in the range 0.020-0.025. As the P-bar intensity continues to increase, (the intention is to increase the P-bar intensity per bunch by more than a factor of two) beam-beam effects will become a more important component governing the beam dynamics in the Tevatron. Experience in other

machines for which beam-beam effects influence the dynamics suggest that operation will become more complicated at higher P-bar intensities. It is particularly important that a major theme of the work is the comparison of data with theory and simulation.

While beam-beam simulations in a variety of scenarios have been performed, those for the ultimate Tevatron intensities have not yet been accomplished. These studies should be performed in order to help plan future operating parameters. Such simulations, coupled with measurements obtained in machine studies, may further guide the operating beam parameters in the years to come. The Committee applauded the efforts to apply state-of-the-art strong-strong beam-beam codes to the Tevatron beam-beam problem.

Fermilab adequately addressed the recommendations from the March 2005 DOE review.

2.3 Recommendation

1. Continue to investigate beam-beam effects in the Tevatron, both theoretically and experimentally, in order to ensure that the Tevatron is not limited by P-bar intensity at ultimate Run II parameters.

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3. ACCELERATOR OPERATIONS and INTEGRATION

3.1 Findings

The Run II Luminosity Upgrades, scheduled to be 87 percent complete, are currently 86 percent complete. Some components of the plan, such as the stacktail upgrade, may be descoped.

Protons delivered to MiniBoone thus far in FY 2006 exceed the design projection. Protons delivered to Neutrinos at the Main Injector (NuMI) are lagging somewhat behind the base projection at this point due to hardware problems. The slope for NuMI protons-on-target (i.e., integrated protons per week) exceeds the design slope.

The proton plan has been developed and refined over the past year. It has been internally reviewed. As the Run II Luminosity Upgrades wind down, the effort going into the proton plan has increased. During the present shutdown, a number of "proton plan" upgrades are being made in the booster and Main Injector (MI), benefiting both the neutrino programs and antiproton production.

3.2 Comments

The operations and integration teams have functioned effectively in support of Run II.

At present, adequate resources are being allocated to the Run II Luminosity Upgrades Plan. The various Run II hardware improvements are holding to the plan and are being incorporated into operations in a timely manner.

The Committee noted that a number of important Tevatron machine studies tasks were completed during the past year. Studies ranging from investigating beam-beam effects and limitations to the commissioning of diagnostics systems were completed.

Although the Run II Luminosity Upgrades is nearing completion, the Committee expected that the upgrade plan can be considered complete only when the goals of the plan are met. To that end, the Committee noted that it will be essential to ensure that key personnel remain committed to operations to make sure that the many improvements are fully exploited and turned into integrated luminosity.

The Committee noted that there is no reference in this review to instabilities in the MI in

spite of much higher currents.

Fermilab adequately addressed the recommendations from the March 2005 DOE review.

3.3 Recommendation

1. Evaluate high intensity limitations of the proton plan.

4. ANTIPROTON SOURCE

4.1 Findings and Comments

The past year saw very good progress with the antiproton source. The electron cooling in the Recycler was commissioned and put into operation, and a new peak stacking rate of 20 mA/hr was reached.

Protons on Target

As recommended at the March 2005 DOE review, significant effort was devoted to improvement of the longitudinal emittance in the Booster from 2 eVs to 0.8 eVs. This significantly improved the slip-stacking operation in the MI. The protons for the antiproton production target now have a bunch intensity of 7.6e12 and a bunch length of 1.8 ns. This performance is close to the goal of 8e12 and 1.5 ns. Reaching the goal performance or even exceeding it should continue to be a priority as it will directly improve the antiproton-stacking rate.

Significant temperature and cycle-length-dependent variations of the proton beam parameters were identified using the improved diagnostics. This was addressed with automatic steering programs. Although this was successful and improved the performance significantly, the actual cause of these variations should be further explored and quantified and possibly remedied directly.

Recycler and Electron Cooling

The Recycler Ring (RR) is working very reliably. A stash of 400e10 P-bars was reached, which is close to the goal of 510e10 P-bars. The lifetime of the P-bars in the RR is good. A newly installed transverse damper was necessary for this high intensity operation.

The successful commissioning and start of operation of the electron cooling of the 8 GeV antiprotons in the RR is a great achievement. The successful operation of electron cooling was the main risk factor for achieving the Run II design performance and this is now removed. There is now a much increased probability that an integrated Run II luminosity of 8 inv-fb can in fact be reached.

The electron cooling rate actually exceeded the design indicating that the angular spread of the electron beam is less than the design of 200 micro-rad. The electron cooling can also be

used successfully together with stochastic cooling. A new record peak in Tevatron luminosity electron cooling was reached. Full exploitation of electron cooling to increase the integrated luminosity by about a factor of two awaits the upgrade of the antiproton-stacking rate.

A reduced lifetime was observed when the antiprotons were electron-cooled aggressively. This needs more investigation.

Transfer Lines, Debuncher, and Accumulator Apertures

The "running wave method" was used to identify obstacles in the debuncher and has led to visible improvements. The combined aperture of the AP2 and Debuncher has reached 90 percent of design. Further improvements await moving magnets.

The aperture of the Debuncher to Accumulator (D/A) transfer line is limited by the injection kicker to the Accumulator. Some improvements were achieved. The aperture in the Accumulator has deteriorated since 1999 for unknown reasons and was only, just recently, partly restored. Further progress is required.

With the new instrumentation it was possible to monitor to stability. It was found that there are serious fluctuations and drifts believed to be related to temperature variations and changes of the operating cycles. These were addressed by automatic beam steering systems.

Rapid Transfers

Rapid transfers from the Accumulator to the Recycler can improve the P-bar production rate by 15 percent. This is ready for implementation but was not deemed high priority right now. The production rate improvement from rapid transfers should be realized as soon as possible.

Stochastic Cooling Upgrades

A new peak stacking rate of about 20 mA/hr and an average stacking rate of 15 mA/hr was reached. This is a 25 percent improvement.

The overall design goal is to reach an average stacking rate of 30 mA/hr. This is roughly twice the value presently obtained. The achievement of this goal is a major challenge to the project and requires careful development and operation of all stochastic cooling systems at optimal gain unless power limited, in particular the stacktail system. A clear understanding of

any other gain limitations would be very desirable. Significant progress has been achieved, but the pursuit of all possible upgrades and improvement, including aperture, orbit corrections, and transfer efficiencies is required to have a realistic chance to reach the ambitious design goal.

Machine Studies

Adequate machine study time was allocated to the antiproton source development effort and advantage was taken of the prolonged Tevatron down time.

The Run II Luminosity Upgrades are progressing well with most components to be completed during FY 2007, and so far, adequate resources have been assigned. However, it is imperative that the project is fully completed to assure success in achieving design average stacking rate and design integrated luminosity in a timely fashion. Moving resources to other projects prematurely can endanger the success of Run II.

Fermilab was responsive to the recommendations of the antiproton source section from the March 2005 DOE review.

4.2 Recommendations

1. Continue to allocate adequate machine study time for the development of the design average stacking rate of at least 30 mA/hr.

2. Pursue all stacking rate upgrade paths aggressively with the goal to achieve stable and consistent average P-bar production rates of at least 25mA/hr by September 2006 and at least 30 mA/hr by February 2007.

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5. MANAGEMENT

5.1 Findings

The goals of the short-term and future physics program are properly aligned with DOE guidance. The highest priority is to run the collider program for CDF and D-Zero. In parallel there is a neutrino program for MINOS and MiniBoone. There are additional 120 GeV fixed target experiments being supported at the Meson Area.

The Run II Luminosity Upgrades are 86 percent complete and will be completed in FY 2007. Of note is the successful operation of electron cooling in the Recycler, Recycler-only operations, and increased antiproton stacking.

Peak luminosity continues to increase but there has been some stumbling to provide integrated luminosity in FY 2006. There have been three magnet failures associated with quenches. Reliability of the Tevatron systems is being addressed. The beam availability at store is yet to achieve an average of 105 hours per week to reach the FY 2006 design goal of 0.8 fb^{-1}. The FY 2005 average was 124 hours per week but the present FY 2006 average has dropped to 85 hours per week. The base goal for FY 2006 is 0.6 fb^{-1}. This will require an average of about 85 hours per week. The expectation is to achieve the base design integrated luminosity.

Antiproton rate is one of the major luminosity performance objectives. Significant performance gain has been achieved. There is about a factor of two performance yet to be realized by improving the average antiproton-stacking rate. Management formed a dedicated team to address the objective since the March 2005 DOE review. This has been a successful move. The team took advantage of the 3 Tevatron failures to do an extensive series of studies.

Management is aware of the primary issue of managing the transition at the end of Tevatron operations in FY 2009. It was decided to integrate the International Linear Collider (ILC) efforts into the existing laboratory structure and not isolate it as a standalone effort. This will prevent the “us-them” situation and the loss of attention of key personnel to provide quality Tevatron operations. Substantial changes have been made during the past year in the Accelerator Division to optimize Run II and neutrino operations and other accelerator efforts.

The management organization is undergoing several significant changes. The Laboratory organization will be re-aligned on April 1, 2006. Three new positions of COO, CFO, and ES&H will report directly to the Director. A new Deputy Director will be in place on July 1, 2006. A re-competition of Fermilab's M&O contract that expires December 31, 2006 will commence.

A good-faith effort was made to address the 2005 accelerator aspects of the scorecard.

The response to potential savings in the areas of cryogenic operations and machine shop services was complete and well done.

The resource needs after FY 2009, at the end of collider operations, is starting to be addressed. The order of 50 percent of the accelerator operations manpower and purchases goes towards Tevatron support.

Management is concerned with an aging workforce and retirements of key personnel. The uncertain future is causing significant anxiety in the staff about their future employment. Bureaucratic paperwork was voiced as a concern that hinders productive time. People do not want to be left out. Flowing technical workforce between operations and projects helps ameliorate some of the personnel problem. Losing leadership of Collider scientists to other projects is a concern.

A vulnerability analysis of critical components was completed. The costs are dominated by Booster components in need of replacement. In addition, the linac, 7835 power tubes, and 345 kv transformers and switchgear are other high cost items. Upgrades and replacements are in progress for many key items.

The tritium contamination issue is beginning to occupy more of management's attention. The Illinois Environmental Protection Agency has issued a Notice of Violation that included the request to cease offsite un-permitted tritium discharges. Fermilab identified two sources of tritium to date; a leaking pipe between two ponds that allowed tritiated water to be released off-site and the condensate from the NuMI target station. The NuMI experiment is presently expected to start operations when the permit is obtained.

The safety record, as measured by DART and TRC statistics is good and continues to improve.

In general, the user community expressed happiness with the support that Fermilab

provides and the communication with management and the operations staff on scheduling and operations issues. They emphasized that the continuing support of various staff services for the user community was essential and should not be impacted. They expressed the need that DOE High Energy Physics program support some number of compelling, small, fixed-target experiments in addition to the Collider and ultimately the ILC.

Management continues to effectively set priorities between the present Collider program, Run II Luminosity Upgrades, ILC, and proton upgrade plans. The major priority is to insure that the FY 2009 Run II luminosity goal is met and that the transition to the FY 2010 era is planned and properly executed.

5.2 Comments

The Accelerator Division is to be commended for successfully managing challenging Run II Luminosity Upgrades to meet cost and schedule targets and achieving an excellent FY 2005 delivered luminosity performance.

Good vertical and horizontal communications will continue to be critical to address the distractions caused by considerable organizational flux: new senior managers, contract re-compete, and ongoing in-division program and project transitions.

Machine studies appear to be appropriately managed to be supportive of ongoing research and machine operations.

While Laboratory actions related to tritium contamination are prudent and appropriate, this issue will require continued and focused efforts to establish an atmosphere of openness, ensure communications are in context, and take care in making future commitments.

The Committee was concerned that the Run II effort may be significantly impacted by other projects and operations that were not within the scope of this review. Management should be sensitive to this.

The resources being applied to the various programs are adequate. There is a concern with the impending increased power rate costs in FY 2007 and beyond and the need for resources for the support of laboratory infrastructure. The Committee is concerned that descoping of upgrade items such as the stack-tail system may adversely affect the required performance and margin to aggressively achieve the luminosity goal.

The FY 2005 Scorecard was not completed—the detector aspects are still open.

The Committee felt that the FY 2006 base goal is likely to be met, but the FY 2006 integrated luminosity may fall short of the design goal.

With regard to the outyear program, achieving the base integrated luminosity seems to be safe, assuming the reliability of the complex is no worse than experienced over the past couple of years. Achieving the design luminosity will depend crucially on how much improvement can be made to the average antiproton-stacking rate. This will be very well known by May 2007 after the upgrades have been completed and operational experience gained. At that time a reliable estimate can be made for what the integrated luminosity will be at the end of the running in 2009.

5.3 Recommendations

1. Continue to take a flexible approach in providing the necessary Run II resources to optimize success.

2. Focus future DOE High Energy Physics reviews of Fermilab operations on workforce transition and resource issues from the present to the post-Run II period.

3. Continue the open and proactive approach with the regulators and the community to ameliorate the tritium contamination issue.

APPENDIX A

CHARGE MEMORANDUM

DOE F 1325.8
(08-93)

United States Government Department of Energy

memorandum

DATE: January 24, 2006

REPLY TO ATTN OF: SC-25

SUBJECT: Request to Conduct a CD-1 Review of the Tevatron Operations

TO: Mr. Daniel R. Lehman, Director, Office of Project Assessment, SC-1.3

The High Energy Physics program supports the Tevatron program at Fermi National Accelerator Laboratory (FNAL), carrying out a world-class research program at the energy frontier. The Tevatron program includes the operation and performance improvement of the Tevatron accelerator complex and the operation of both the collider detectors and the neutrino experiments.

The memorandum is to request that you organize and conduct a review of the Tevatron Operations on March 21-22, 2006 at Fermilab. The purpose of this review is to evaluate the past performance, and the resource requirements and management practices needed to effectively support its research missions for FY 2006 – FY 2009.

In FY 2005 the Tevatron exceeded the design goal for integrated luminosity and electron cooling was successfully commissioned with all performance specifications having been met except for maximum antiproton intensity. This should allow the committee to concentrate on the following specific areas:

1. Evaluate the technical scope, new operating procedure, and program of machine studies planned to increase the **antiproton production**.
2. Evaluate the technical scope, new operating procedures, and program of machine studies planned to allow **high intensity running in the Tevatron** needed to meet the goals of Run II.
3. Assess whether the lab has identified and allocated the appropriate **resources needed** to complete Run II luminosity improvement plan.
4. Assess the laboratory's **responses to the comments and recommendations** from the March 2005 Tevatron Operations review.

Michael Procario is the program manager for Fermilab in this office and will serve as the OHEP contact person for the review.

We appreciate your assistance in this matter. As you know, these reviews plan an important role in our program. I look forward to receiving your Committee's report. You are asked to submit a formal report to OHEP within in 60 days of the review.

/signed/

Robin Staffin
Associate Director
Office of High Energy Physics

cc: R. Orbach, SC-1
J. Decker, SC-2
M. Procario, SC-25
A. Byon-Wagner, SC-25
P. Oddone, Fermilab
J. Livengood, FSO

APPENDIX B

REVIEW PARTICIPANTS

Department of Energy Review of
Tevatron Operations at Fermilab

REVIEW COMMITTEE PARTICIPANTS

Daniel R. Lehman, Chairman (DOE)

SC 1 Tevatron, Accelerator Operations, and Integration	SC 2 Antiproton Source	SC 3 Management
* Rod Gerig, ANL	* Thomas Roser, BNL	* Derek Lowenstein, BNL
Stuart Henderson, ORNL	Fritz Caspers, CERN	Stephen Meador, DOE/SC
Bob Siemann, SLAC		Jim Siegrist, LBNL

Observers

Robin Staffin, SC-25
Aesook Byon-Wagner, SC-25
Michael Procario, SC-25
Ronald Lutha, DOE/FSO
Joanna Livengood, DOE/FSO

LEGEND

SC Subcommittee
* Chairperson
[ ] Part-time Subcom. Member

Count: 9 (excluding observers)

APPENDIX C

REVIEW AGENDA

Department of Energy Review of
Tevatron Operations at Fermilab

AGENDA

Tuesday. March 21, 2006—Wilson Hall, Comitium

8:00 am	DOE Executive Session	D. Lehman
9:00 am	Welcome and Laboratory Overview—**One West**	P. Oddone
9:15 am	Overview of Accelerator Operations	S. Holmes
9:30 am	Run II Operations: Current Status and FY06 Plan	D. McGinnis
10:15 am	BREAK	
10:30 am	Run II Luminosity Upgrade Plan	B. Baller
11:00 am	Summary of Neutrino Operations and the Proton Improvement Plan	E. Prebys
11:45 am	Resource Planning for Accelerator Operations and Development	R. Dixon
12:00 pm	LUNCH	
1:30 pm	Breakout Sessions	
5:00 pm	DOE Executive Session—**Comitium**	
6:30 pm	Adjourn	

Wednesday. March 22, 2006

8:00 am	Subcommittee Working Sessions—**Comitium**
9:30 am	DOE Full Committee Executive Session Dry Run
1:30 pm	DOE Closeout with Laboratory Management—**One West**
2:30 pm	Adjourn