Department of Energy

Review Committee Report

on the

Run II Luminosity Performance

of the

Fermilab Tevatron

October 28 – 31, 2002

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Executive Summary

A review was held on October 28 – 31, 2002, to examine the progress made by Fermi National Accelerator Laboratory (Fermilab) in improving the luminosity performance of its Tevatron accelerator-storage ring complex toward the goals necessary to support the planned physics research program. The review was conducted at the request of Dr. John R. O'Fallon, Director of the Department of Energy (DOE), Office of Science's Division of High Energy Physics. The review was chaired by Dr. David F. Sutter, Senior Program Officer for Technology R&D in the Division of High Energy Physics. The 15-person review committee (Appendix A) had an international composition, including technical consultants from U.S., European, and Canadian particle physics research laboratories and from U.S. universities. It also included DOE Division of High Energy Physics staff persons with experience in the relevant technical and management areas.

Luminosity is one of two numbers that express the capability of colliding charged particle beams to produce new particles, and thus new physics. The other number is the effective center-of-mass energy. Luminosity is a performance measure of colliding beams that is independent of any specific fundamental particle interaction. It contains the information of the incoming particle flux, the number of incoming particles per second, and the number of target particles per unit area, which is the colliding, or target, beam. The information on a specific charged particle interaction, or event, is contained in a number called the "cross section." Cross sections can be either measured or calculated from first principles and embody the information on the quantum mechanical probability that a particular fundamental interaction will occur (the physics) when a projectile particle gets within an effective transverse area centered on the target particle. When the luminosity of a colliding beam machine is multiplied by the cross section that a particular fundamental particle event will occur, the result is the number of events of that kind that can be expected to occur per second.

Of more utility to the study of elementary particle physics is the integrated luminosity. This number is the sum (in the sense of the integral calculus) of the products of luminosities seen for short periods of time multiplied by the associated time intervals. Thus the Tevatron, when looking for rare events like the production of the Higgs boson, must produce these particles at the highest possible rate (highest luminosity) for long periods of time (largest integrated luminosity). It was concern about progress in raising the Tevatron luminosity and integrated luminosity when measured against the planned increases that was the reason for convening the review reported here.

The Charge to the review committee (Appendix B) asks for an evaluation of the technical status of the Tevatron, the management that Fermilab has put in place to address the luminosity performance, the planning in place, or projected, for raising luminosity performance, and the related scheduling. The committee was also asked to be sensitive to infrastructure issues that could impact the machine reliability or availability of the Tevatron operation.

In order to respond to the Charge, the review committee sifted through a large amount of technical information, and this is reported in some detail in the report. Three important conclusions resulted from this part of the review:

- First, significantly greater attention must be paid to the maintenance and upgrading of the instrumentation needed to measure machine performance.

- Second, the 8 GeV Booster synchrotron, which is operating very well at this time, will need significant work if it is to meet reliably the future needs for proton production necessary to carry out the full Fermilab physics program as presented to the committee.

- Third, while machine availability is currently at greater than 75 percent, high priority must be given to providing the resources and manpower to address the infrastructure issues raised in recent Fermilab studies and to carry out the additional studies and work recommended in Section 10, Reliability, by the committee. The committee notes that the Fermilab staff is already spending considerable effort to systematically improve the Tevatron reliability, aiming toward an availability of 90%.

In the first question of the Charge, the committee is asked to review and comment on "the current status of the Run IIA luminosity performance and the effectiveness of the current technical and management activities to improve that performance." The committee found that great progress had been made in increasing luminosity performance in the six months prior to the review. New world record peak and average luminosities had been achieved and sustained, and the "integrated luminosity" was also at record levels. The detectors are operating reliably and physics data is being taken with low backgrounds and with several hundred inverse picobarns (1000 inverse picobarns equals 1 inverse femtobarn) of integrated luminosity expected to be logged by the coming summer, giving promise that the year 2003 integrated luminosity goals will likely be met.

The committee found that the Fermilab directorate and the Laboratory as a whole have increased their focus and priority on achieving the long-term luminosity goals of the Tevatron. The Fermilab Beams Division has the overall responsibility for making this happen. In early summer the Fermilab Associate Director for Accelerators took over the leadership of the Beams Division in an acting capacity. Additional staff persons have been brought from other parts of the Laboratory to assist in high priority tasks, and a program of enlisting help from expertise outside of Fermilab has been established. The present Beams Division management team is very experienced, has identified the technical problems to be addressed, particularly in the short term, and appears to have developed a solid platform for future success.

Prior to the review Fermilab had broken planning for the luminosity performance upgrades into two parts, Run IIA and Run IIB. At the review, this distinction was dropped, the two parts were merged, and a revised set of goals and plans was presented. The detailed list of revised luminosity goals is presented in Table 2 of the Introduction (Section 1.0) to this report. In summary, the long standing goal of achieving an integrated luminosity of 15 inverse femtobarns by the end of the year 2008 has been replaced by a "base goal" of 6.5 inverse femtobarns, considered by Fermilab to have a high probability of success, and a "stretch goal" of 11 inverse femtobarns, considered by the laboratory to be of high risk. Both goals apply to the period from now through the end of Fiscal Year 2008.

Question two of the Charge asks for an evaluation of the planning with respect to these revised goals. It has three parts.

First, the committee was asked if the technical scopes of work proposed for each major Tevatron subsystem were adequate to support the revised Run II goals and are they reasonable and achievable. The list of scopes of technical work required to raise the Run II luminosity was presented as part of a draft Run II luminosity upgrade plan proposed in December 2001. The committee found the list of technical tasks, the "scopes," to be adequate, reasonable, and in principle achievable with the caveat that some of the technical goals, such as electron cooling, may represent a significant challenge and will certainly require intense R&D to be successful.

The second part of question two asks if the plans to achieve the proposed goals are adequate in terms of manpower, costs, and resource loaded scheduling. The committee found that the planning for work to be carried out in Fiscal Year 2003 was reasonably complete and adequate to carry out the work proposed. Other than the detailed list of technical tasks mentioned in the preceding paragraph, no plans beyond Fiscal Year 2003 were presented. The committee considers that such planning is essential and strongly recommends that preparation of a plan covering the Fiscal Years 2004 through 2008 be given high priority and should be completed by June 2003.

The third part of question two asks the committee to determine if Fermilab has a strong management team and appropriate structure in place to successfully execute the plans. While there remain issues of manpower and resources that can only be addressed by detailed long range planning, the committee believes that the Beams Division has a management team and structure which can develop the required long range plan and execute it. A major concern is that Fermilab needs to quickly find a permanent Director of the Beams Division with the necessary leadership, management and technical skills. [Editors Note: Since the review, Fermilab has appointed a new Beams Division Head, who will assume the position January 15, 2003]

The third question of the Charge asks the review committee to judge whether the proposed plans and processes give reasonable assurance that the Tevatron will meet the luminosity goals set for Run II. This proved to be a difficult task because the planning beyond Fiscal Year 2003 remains to be completed. Section 2.0 of the report, "Meeting the Luminosity Goals," gives a detailed response to question three and the bases for the conclusions reached. In summary, the committee believes:

1. Reaching the base luminosity goal of 6.5 inverse femtobarns delivered by the end of the year 2008 will be a *significant challenge*. The committee found that a well thought out plan exists for luminosity improvement in FY 2003, but comparatively little detailed scheduling and resource planning beyond FY 2003. It is the lack of out year detailed planning that prevents the committee from making a more affirmative response to this goal.

2. At this time, reaching the stretch luminosity goal of delivering 11 inverse femtobarns by the year 2008 is *very uncertain* because it requires full and timely success of all elements of the luminosity scenario, including electron cooling. The lack of detailed planning, concerns about certain accelerator physics issues, and concerns about some high risk technical goals influence this conclusion.

In response to the committee's findings, comments, and recommendations, three Action Items were drafted at the end of the review and agreed to by Fermilab and the Department of Energy (Appendix F). These require that (1) Fermilab prepare and deliver by June 2003 a detailed, resource loaded plan for completing the Run II luminosity upgrade by the end of the Fiscal Year 2006; (2) the Department of Energy conduct a follow-up review of the Run II luminosity upgrade no later than two months after receiving the upgrade plan. This review should evaluate the status of the technical and accelerator physics uncertainties related to the long-term goals as well as the detailed and comprehensive long-term plan for the balance of the Tevatron complex luminosity upgrade; and, (3) Fermilab provide the Department of Energy with level 1 and level 2 milestones for the Fiscal Year 2003 Run II luminosity plan by November 27, 2002, as these were not made available at the time of the review. [Editor's note: This has been done]

1.0 Introduction

This report presents the results of a Department of Energy (DOE) review of the Fermi National Accelerator Laboratory (Fermilab) Tevatron accelerator storage ring complex luminosity performance. The review was conducted at the request of Dr. John R. O'Fallon, Director of the DOE Division of High energy Physics, Office of Science (Appendix A). The review was held at Fermilab on October 28-31, 2002. The review committee was charged by Dr. O'Fallon (Appendix B, Charge to Committee) with examining the technical, management, schedule and resource issues associated with increasing the luminosity performance of the Tevatron in accord with plans developed by Fermilab. The Chairman of the review was Dr. David F. Sutter, Senior Program Officer for Technology R&D. Division of High Energy Physics, Office of Science, DOE. Dr. Michael Procario, Program Officer, Division of High Energy Physics, Office of Science, served as Executive Secretary. The fifteen person review committee had an international composition with technical and management consultants drawn from U.S., Canadian, and European national laboratories and from U.S. universities (Appendix C, Review Committee Members).

The Fermilab Tevatron complex consists of five major accelerators and storage rings linked together by a complex set of charged particle beam transport lines. The major pieces are the Proton Source, consisting of the hydrogen ion source, the 750 keV Cockroft-Walton voltage multiplier, the 400 MeV Linac and the 8 GeV Booster Synchrotron; the 120/150 GeV Main Injector Synchrotron; the 1 TeV Tevatron; and the Antiproton Source, consisting of the antiproton production target, Debuncher storage ring, Accumulator storage ring and Recycler storage ring, all operating at 8 GeV energy. The Proton Source functions as the sole supplier of all 8 GeV protons for all operating modes of the Tevatron complex. The Main Injector and Recycler are the newest part of the complex having been completed in 1999. They are physically located in the same tunnel enclosure and each has a two mile circumference, one half that of the four mile circumference of the Tevatron's superconducting magnet ring. The Tevatron complex has the design capability to operate in several modes for physics research, including 1 TeV $\times$ 1 TeV colliding protons and antiprotons, 1 TeV proton beam on a fixed target, 120 GeV protons (from the Main Injector) on a fixed target, and 8 GeV protons on a fixed target.

A major function is the production of antiprotons, cooled to the required 6-dimensional phase space. This process starts with the Main Injector sending 120 GeV protons to the production target. The antiprotons are then focused in a lithium lens, collected, and transferred to the Debuncher ring which changes the bunched beam from the production target (the bunch structure on the target is set in the Main Injector) into a continuous or direct current (dc) beam with no longitudinal structure. This beam is precooled slightly and then transferred to the Accumulator ring which further cools and accumulates, or “stacks,” antiprotons from the Debuncher until a sufficient number is stored for transfer to the Main Injector. They are then accelerated to 150 GeV and injected into the Tevatron ring.

In the current Run II operating configuration, protons and antiprotons at 8 GeV are accelerated in the Main Injector to either 120 GeV or 150 GeV and distributed as follows: 120 GeV protons to the antiproton production target and 150 GeV protons and antiprotons to the Tevatron, with the bunches structured so that there are 36 equally spaced antiproton bunches circulating in the Tevatron against 36 equally spaced counter-circulating proton bunches. In addition, the proton source is supplying 8 GeV protons to the MiniBooNE experiment as a parasitic operation.

Luminosity is one of two numbers that express the capability of colliding charged particle beams to produce new particles, and thus new physics. The other number is the effective center-of-mass energy, which for the Tevatron is currently .980 TeV + .980 TeV or 1.96 TeV. Luminosity is a performance measure of colliding beams that is independent of any specific fundamental particle interaction. It contains the information of the incoming particle flux, the number of incoming particles per second, and the number of target particles per unit area, which is the colliding, or target, beam. The Tevatron luminosity is proportional to the number of particles in a proton bunch, N_{p+}, multiplied by the number of particles in an antiproton bunch, N_{p-} divided by the effective beam overlap area of the two bunches when they collide, all multiplied by the number of times these collisions occur per second, or

$$\mathcal{L} \sim \frac{N_{p+} \times N_{p-}}{\text{Bunch Overlap Area}} \times \text{Collision Frequency},$$

where the bunch collision frequency is the product of the bunch revolution frequency (the number of times a bunch goes around the ring per second) multiplied by the number of proton or antiproton bunches.

The information on a specific charged particle interaction, or event, that can take place when particle beams collide, is contained in a number called the “cross section.” Cross sections can be either measured or calculated from first principles and embody the information on the quantum mechanical probability that a particular fundamental interaction will occur (the physics) when a projectile particle gets within an effective transverse area centered on the target particle.

When the luminosity of a colliding beam machine is multiplied by the cross section that a particular fundamental particle event will occur, the result is the number of events of that kind that can be expected to occur per second, or

$$\text{Number of events per second} = \mathcal{L} \times \sigma.$$

A big luminosity is, therefore, essential for looking for rare fundamental particle interactions.

A number of great utility is the integrated luminosity. This number is the sum (in the sense of the integral calculus) of the products of luminosities seen for short periods of time, $\mathcal{L}_n$, multiplied by the associated time intervals, Δt_n, or in the format of the calculus:

$$\text{Integrated luminosity} = \sum \mathcal{L}_n \Delta t_n \rightarrow \int \mathcal{L}\, dt.$$

The utility is that the integrated luminosity over the total time a high energy particle physics experiment has run when multiplied by the cross section, containing information on the probability that a fundamental particle event will take place, gives the number of events of that kind that the experiment should have seen. Consequently, to maximize physics productivity, Fermilab must do two things, achieve the maximum luminosity and run at that luminosity for as much time as possible.

The Tevatron was operated as a 900 GeV on 900 GeV proton-antiproton collider in Run IB from December 1993 until February 1996. The typical luminosity at the beginning of stores in Run IB eventually reached 1.6×10^{31} $cm^{-2}s^{-1}$, and the total luminosity integral for the run was approximately 140 pb^{-1} [Editor's note: 10^{-24} cm^2 = 1 barn, so 1 picobarn = 10^{-36} cm^2]. Fermilab has carried out a major upgrade of the accelerator complex to increase the luminosity for Run II. The centerpiece was the construction from 1992 through 1999 of a new 150 GeV synchrotron, the Main Injector. The Main Injector was designed to replace and improve on the performance of the old Main Ring synchrotron for delivering a proton beam to the Antiproton Source and for injecting protons and antiprotons into the Tevatron. A new 8 GeV antiproton storage ring, the Recycler, was also constructed and installed in the Main Injector enclosure to increase the antiproton storage capacity of the complex and to create the capability of recovering antiprotons remaining at the end of Tevatron stores. The upgrade also included additional stochastic cooling in the Antiproton Source, various beam-mode dampers, and a six-fold increase in the number of both proton and antiproton bunches in the Tevatron (from 6 to 36) to limit the number of interactions per proton-antiproton bunch collision by reducing the charge per bunch, while at the same time keeping constant or raising the total number of protons and antiprotons in the Tevatron, and therefore the luminosity.

Before Run IB began it was envisioned that the typical luminosity for that run would reach 1×10^{31} cm^{-2}s^{-1}, and that the upgrade program would subsequently provide a five-fold increase to 5×10^{31} cm^{-2}s^{-1} for Run II. The goal for Run II was moved to 8×10^{31} cm^{-2}s^{-1} after 1.6×10^{31} cm^{-2}s^{-1} was reached in Run IB, and then the goal was increased to 2×10^{32} cm^{-2}s^{-1} when the Recycler was added to the Main Injector project in 1997.

Run II of the Tevatron (without the Recycler) began in March 2001 with the beam energy increased to 980 GeV. The commissioning of the accelerator did not proceed smoothly. By the end of 2001, the seriousness of the problem was widely recognized, and the lab formulated a plan of improvement. An outline of this plan was presented at the January 2002 HEPAP meeting by Associate Director for Accelerators, Stephen Holmes. This plan called for achieving a peak luminosity of 8.6×10^{31} cm^{-2}s^{-1} by the end of 2002, and to integrate 300 pb^{-1} for Run II by then, and ultimately to accumulate a total of 15 fb^{-1} by the end of 2007. The highest peak luminosity achieved in Run II as of October 20, 2002 is 3.6×10^{31} cm^{-2}s^{-1}, and the corresponding luminosity integral for the run is approximately 110 pb^{-1}. This is a new world record performance, although only 50% of the January 2002 goals.

The shortfall relative to the January plan was obvious by late summer and the lab responded by developing a new plan with detailed specification of the technical goals and the needed resources to implement those goals during fiscal year 2003. This new plan specifies the manpower, resources and schedules in more detail than the previous plan. It has been reviewed within the lab and by an external director's review committee.

The primary goals revised for the FY 2003 plan are expressed in terms of "base" goals that Fermilab believes have a high degree of certainty of being achieved and "stretch" goals that represent the laboratory's "best estimate" of the limit of performance to which the facility can be pushed, with the most likely outcome somewhere in between. The goals of the FY 2003 plan are shown below.

	Integrated Luminosity pb^{-1}	**Best Peak Luminosity $\times10^{31}$ cm^{-2}s^{-1}**	**Best Weekly Integrated Luminosity pb^{-1}**
Base	200	5.0	10
Stretch	320	8.0	15

Table 1: Goals of the FY 2003 plan submitted to the DOE in October 2002

The planning for years beyond FY 2003 is less developed. The principal technical changes needed to continue to improve the luminosity have been identified:

- slip stacking in the Main Injector,

- antiproton yield improvements,
- antiproton target lithium lens gradient upgrade,
- AP2-Debuncher aperture upgrade,
- antiproton stochastic cooling improvements,
- electron cooling in the Recycler,
- rapid antiproton transfers between the Accumulator and the Recycler,
- deceleration and transfer of antiprotons from the Main Injector into the Recycler,
- Tevatron beam-beam compensation.

The resource scheduling for this long range plan has just begun. A project manager has been appointed and a completed plan is expected in spring of 2003. The current understanding of these improvements is that they should produce integrated luminosities between 6.5 and 11.0 fb^{-1} by the end of fiscal year 2008. In the fiscal years 2007 and 2008, the stretch goals call for an integrated luminosity of 3.0 fb^{-1} per year, approximately 90 pb^{-1} per week, and peak luminosity of 4×10^{32} $cm^{-2}s^{-1}$. A comparison of the year-by-year breakdown of the integrated luminosity from the December 2001 Run IIB Handbook and the plan presented at the review is given below in Table 2.

	Run IIB handbook (fb^{-1})	**Review Base goal (fb^{-1})**	**Review Stretch goal (fb^{-1})**
FY 2002	0.32	0.08*	0.08
FY 2003	0.83	0.20	0.32
FY 2004	1.30	0.40	0.60
FY 2005	1.80	1.00	1.50
FY 2006	3.40	1.50	2.50
FY 2007	3.90	1.50	3.00
FY 2008	3.90	1.80	3.00
Total	15.00	6.50	11.00

*Already achieved.

Table 2: Longer term goals presented at the review compared to the Run IIb Handbook.

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2.0 Meeting the Luminosity Goals

In order to carry out long range strategic program planning, the DOE needed a best estimate of the degree of luminosity performance that could be expected from the Tevatron. This is a difficult estimate to make. Nevertheless, question 3 of the charge asked the committee to make such a judgment. The following is the committee's response citing information developed in answering the questions 1 and 2 of the charge as necessary to provide the context of the reasoning and conclusions.

Question 3 of the Charge asks,

"In the Review Committee's judgment, do the proposed plans and processes give a reasonable assurance of meeting Fermilab's luminosity goals set for the Tevatron complex for run II? How might these plans and process be improved?"

The Committee's response is:

The overriding impression of the review committee is that Fermilab has embraced the challenge of meeting the luminosity goals for the Tevatron complex, and that the laboratory realizes the significant level of challenges ahead.

There has been excellent progress in the past year that serves as a solid platform for future progress and the increased focus of the laboratory on this effort is a crucial factor.

The laboratory's technical approach for increasing luminosity over the next six years is sound and well motivated and, if successfully implemented, will maximize the integrated luminosity over this time period.

At the present time the Beams Division is focused primarily on FY 2003. The technical approach being taken is appropriate with most of the important tasks recognized and receiving sufficient priority. A particular area that requires significantly increased emphasis in this period is diagnostic instrumentation.

There is a reasonably detailed plan for FY 2003 that is adequately matched to existing resources. The committee judges that there is a good likelihood that the base luminosity goal set for FY 2003 will be met or even exceeded.

In the longer term there are large uncertainties ranging from technical and basic accelerator physics challenges (long range beam-beam effects, high energy electron cooling, the Booster, "near-end-of-life" infrastructure, etc.) to funding issues.

The committee believes that reaching the base luminosity goal of 6.5 fb^{-1} delivered by 2008 will be a *significant challenge*. Careful planning, appropriate investments in diagnostic instrumentation, maintenance and upgrading infrastructure, and sustained focus on key machine R&D topics will be essential. Much depends on the success of the ambitious electron cooling effort for the Recycler. Without successful electron cooling, most other components of the luminosity upgrade scenario must be successful for the base luminosity goals to be reached.

The committee believes at this time that reaching the stretch luminosity goal of delivering 11 fb^{-1} by 2008 is *very uncertain* because it requires full and timely success of all elements of the luminosity upgrade scenario including electron cooling.

Finally, adequate funding throughout the luminosity upgrade period is not assured and so constitutes a substantial risk to reaching the goals.

Although there have been detailed studies of the significant technical issues that need to be addressed in FY 2004 and beyond, there is comparatively little detailed schedule and resource planning for the period beyond FY 2003. This lack of detailed planning prevents the committee from making a more affirmative response at this time concerning the 6.5 fb^{-1} base goal. Consequently, it is the committee's position that the laboratory must develop such detailed and comprehensive plans with well-defined tasks and resource loading.

The committee recommends a follow-up review in about 8 months to evaluate the status of the technical and accelerator physics uncertainties related to the long-term goals as well as the detailed and comprehensive long-term plan for the balance of the Tevatron complex luminosity upgrade.

3.0 Accelerator Physics

3.1 Findings

Excellent progress has been made, and continues to be made, in pursuit of Run II luminosity goals. Luminosity records in the Tevatron are especially notable as is the progress that has been made in the development of stochastic cooling and the implementation of the dual lattice scheme in the Antiproton Accumulator, in enhanced performance of the Main Injector, and in the commissioning of the Recycler. It is now possible to be confident of the Recycler's success.

The Beam Physics Department has been active in support of many of these advances, in particular in the areas of Tevatron optics development, energy deposition issues, and beam-beam simulation and studies.

There are approximately 25 people in Beam Physics Department, of whom about 20 are involved at least peripherally in Run II activities. About five Beam Physics Department members are directly involved as active participants during machine studies shifts in the control room. The department is currently housed on the 12th floor of Wilson Hall, but soon the majority of the department will relocate to offices in the Cross Gallery, much closer to the Main Control Room.

Although several members of the Beam Physics Department contribute to machine studies and simulations, their role seems to be insufficiently recognized and/or organized. Full participation of the Beam Physics Department will be crucial to achieve Tevatron Run II luminosity goals.

Control room activities and (especially) machine studies in each machine of the Tevatron accelerator complex seem to be somewhat disconnected: for example, several independent logbooks are kept for the Main Injector, and the Tevatron, et cetera. This may lead to a lack of coordination and of overview of the different contributions and/or limitations from each sub-system to the final Tevatron luminosity performance.

The "dancing bunches" instability seen in the Tevatron seems to originate in the injectors, and could be cured there, but has been independently investigated only in the Tevatron.

Several "ad hoc working groups" have formed, more or less spontaneously, to study important aspects of the Tevatron Run II performance. These include:

- Optics (Tevatron only),
- Beam-Beam studies,
- Energy Deposition (Booster, Tevatron, experiments),
- Shot Data Analysis (SDA).

All of these efforts integrate Beam Physics Department activities with those of other machine departments, and with the headquarters group, in the Beams Division.

On the one hand, the current "Run II crisis" climate in Fermilab has resulted in a reduction of effort in projects that are essential in meeting Tevatron long-term luminosity goals. On the other hand, day-to-day problems and medium-term problems, such as intrabeam scattering (IBS) in the Accumulator, are solved with impressive speed.

There are many outstanding beam dynamics problems in the Tevatron, such as the origin of the unwanted direct current (coasting) beam, and the fact that the first and last antiproton bunches adjacent to each of the abort gaps have longer lifetime than the other ones. The Tevatron group is addressing these problems, but feels that it will make little progress with the current allotment of shifts devoted to machine development studies.

3.1 Comments

The Beam Physics Department should preserve, and possibly increase, the knowledge base required by a challenging project such as the Tevatron Run II luminosity upgrade. This requires a sustained and recognized effort over several years, with the possibility of attracting and keeping at Fermilab a cadre of excellent machine physicists. The "knowledge profile" in beam physics has somewhat deteriorated over the past 5-10 years, although several outstanding physicists are still present. The situation can be improved by the Beam Physics Department "re-inventing" itself, with the support of Beams Division management, and by reinforcing the existing collaborations with universities and with other accelerator laboratories, both in the US and abroad.

The review committee fully supports the re-location of the Beam Physics Department members active in Run II from the 12th floor of Wilson Hall to the Cross Gallery.

The ultimate Tevatron luminosity depends in part on the proton beam brightness, which is set in the Booster. There may be fundamental reasons for the Booster to have a relatively low space charge limit, in comparison with other machines in this energy range, but they have yet to be identified. It is clearly important to investigate the space charge limit in the Booster, not only empirically, but also from simulation and theoretical perspectives.

Currently, the Booster transition jump system is not in use, and longitudinal beam instabilities are not actively damped. However, now that the beam position monitor (BPM) system in the Booster can measure the closed orbit through transition, there are plans to turn the jump system back on. Ideally, beam would go cleanly through transition, and longitudinal instabilities would be actively damped.

Enhanced Beam Physics Department staff activity in the study of space charge effects and transition crossing in the Booster would be very useful; the former has the potential of improving transverse brightness, and the latter, the longitudinal. Besides potentially improving Tevatron peak luminosity, improved Booster brightness would result in a reduction of beam loss for a given intensity, thus reducing Booster machine activation, enhancing maintainability, and extending machine lifetime.

The Radio Frequency and Instrumentation Department is currently limited in its ability to perform non-empirical (longitudinal) beam dynamics studies. Here, too, there is a need to either inject one or more beam physicists into the team, or to reinforce a longitudinal beam dynamics "culture" in the Beam Physics Department itself.

The Beam Physics Department should continue to evaluate the potential use of pulsed wires for compensation of long-range beam-beam effects in the Tevatron, as proposed and studied at CERN for use in the LHC. Pulsed wires may be a cost effective complement to the electron lens compensation system.

The review committee recommends upgrading the “ad hoc working groups" to "task forces", each with a formally charged scope. The committee also strongly supports the construction of two additional "task forces", with active Beam Physics Department staff involvement integrated with other Beams Division departments:

- Space charge and transition crossing issues in the Booster (see comments above).

- Longitudinal (and transverse) emittance budget and preservation, through the injector chain "from cradle to grave".

Beams Division management should consider formally placing the Beam Physics Department in charge of the optics for all of the machines in the Tevatron accelerator complex. The contribution of beam physicists to online and offline optics modeling has not been sufficiently encouraged in the past. We recommend that the Beam Physics Department establish fully realistic and accurate offline models of Run II accelerators, where possible.

The Beams Division’s Beam Physics Department and Headquarters group are the natural places to analyze and plan the more global perspectives of Run II integration, "end-to-end" through the accelerator chain, and on a longer timescale than just FY 2003. For example, it may be that a modest modification of the parameters of one accelerator in the chain could significantly ease tight performance in the next. Thus:

- The committee strongly supports an effort to reinforce and expand the shot data analysis based "operations analysis" working group into a task force, with a clear mandate and responsibilities to oversee beam physics studies for the whole Tevatron accelerator complex, including a centralized and publicly available "logging" system. Systematic long-term archiving of relevant machine configuration data should be implemented for post-mortem or machine development analysis. Systematic planning is essential to make the most efficient use of the limited number of beam studies shifts available.

- Beams Division management should consider assigning formal responsibility to a single person in the Beam Physics Department, to develop and maintain up-to-date lists of consistent beam parameters for baseline, stretched, and several intermediate luminosity scenarios. These intermediate scenarios will be useful in comprehensively assessing intermediate and long-term luminosity goals, in case some of the subsystems do not meet their nominal specifications. For example, what if the electron cooling system can only run with half of the nominal electron current? What if the stored beam lifetime at full intensity is only half of the nominal anticipation? There are similar contingency issues concerning revised antiproton emittances, store turn-around times, optimum store duration, et cetera.

3.3 Recommendations

1) Formalize the scope and role of Beams Division "Task Forces" in assigning the Beam Physics Department appropriate responsibilities for an effective integration with machine departments in Run II.

2) Expand the role of the Shot Data Analysis team effort led by Beam Physics Department and Beams Division Headquarters staff, with the goal of enhancing broad "source-to-collisions" and "short-to-long-timescale" analyses of Run II performance.

3) Enhance the realistic modeling and simulation activities of the Beam Physics Department to support machine development, particularly addressing beam-beam studies in the Tevatron, and space charge and transition crossing effects in the Booster.

4.0 Tevatron

4.1 Findings

The luminosity in the Tevatron has made great progress over the last few months and is now only about a factor of two below the Run IIa design goals. The higher antiproton intensity available from the upgraded antiproton source, a systematic approach to reduce the proton and antiproton beam emittances, and a minimization of the effect of the increased number of parasitic collisions with the 36 on 36 bunch pattern has resulted in a dramatic increase of the peak luminosity, reaching a record value of 3.6 x 10^{31} cm^{-2} s^{-1}.

The proton intensity in the Tevatron appears to be presently limited by the beam-beam effect of the protons on the antiprotons and a transverse instability. Replacement of the C0 Lambertson magnet, which was used for beam abort during slow extraction, with a Main Injector dipole magnet will allow for a larger proton-antiproton beam separation helix and therefore reduced long-range beam-beam effects.

The limiting instability of the proton beam in Tevatron is identified to be the transverse weak head-tail instability. The present limit is reached by artificially introducing large, positive chromaticity. Two means are identified to increase the beam intensity beyond the present limit, namely feedback dampers and octupoles. There are initial indications that a feedback damper together with high chromaticity would indeed suppress the instability.

The importance of the beam-beam effect in the Tevatron Run II was recognized early in the project, and relevant simulations have been performed. One Tevatron electron lens, to be used for suppression of the beam-beam interaction at the proton-antiproton intersection point, was completed, and operated but not for the purpose of beam-beam compensation. At 150 GeV injection energy, it has been observed that the antiproton lifetime depends on the proton intensity and the amplitude of the proton-antiproton separation as set by the helix. Both effects are due to the long-range beam-beam effect. Simulations show that this effect causes the chromaticity to vary significantly with the transverse oscillation amplitudes in each antiproton bunch. There is no sizable influence of the beam-beam effect on the protons at injection, but the large helix amplitude required to reduce the long-range beam-beam effect on the antiprotons leads to a low proton lifetime. With the Tevatron optics set for collisions, it is observed that the antiproton lifetime is different for different positions in the bunch trains (as noted in section 3.0) due to the long-range beam-beam effect. But in optimized conditions, the antiproton lifetime should be dominated by annihilation at the interaction points rather than by beam dynamic effects which could be attributed to the beam-beam effect. For the proton beam the situation is different. Current data has been interpreted as showing that the long-range beam-beam effect dominates the proton lifetime during colliding beams.

A very large emittance growth of 7π mm-mradian was found in the antiproton beam transfer from Main Injector to Tevatron. There is, therefore, a large gain to be made by improving this transfer line and its operation.

The shot setup for the Tevatron takes approximately 3 hours. This time is dominated by magnetic field standardization and injection optimization.

4.2 Comments

The design efforts applied to the helix orbits are reasonable and well motivated. The preparation for C0 Lambertson magnet replacement and the necessary optics changes are sound.

More studies—experiments, simulations, or both—will be needed to assure that the feedback damper is indeed capable of damping the higher order head-tail modes particularly if the chromaticity is lowered. More studies are also encouraged to reduce coupling and find other ways to reduce the artificially introduced high chromaticities. Octupole magnets are also possible cures by providing Landau damping. The disadvantage is that their non-linearities also may affect the single particle beam lifetime. More studies will have to be made before octupole magnets become a viable cure for the proton beam instability.

It is expected that with the installation of the feedback dampers, implemented on the basis of careful studies, the proton beam instability should be controlled up to the Run II target level. The threshold for the fast head-tail instability should be calculated.

The luminosity in the Tevatron is proportional to the proton bunch intensity and the total antiproton intensity but independent of the number of bunches, as is expected in a collider where one beam is production limited. The number of bunches is determined by other issues such as collision rate in the detectors, multi-bunch instabilities of the proton beam, number of parasitic collisions, etc. There is now experience with 6 and 36 bunches that highlights the importance of increased number of parasitic collisions. Based on this experience the optimum number of bunches in the Tevatron should be investigated again.

Going beyond 36 bunches requires that parasitic head-on collisions are avoided using a non-zero crossing angle resulting in an additional penalty on the luminosity. The proposed scenario of going to 103 bunches (132 ns bunch spacing) would have to be very carefully studied if it were to be maintained as a viable option.

The varying chromaticity over the antiproton amplitudes indicates that one should try to increase the helix amplitudes and to decrease the dispersion at parasitic crossings. The importance of the beam-beam effect for the proton beam was not anticipated and is still not understood quantitatively. It could be a potential limit for the allowed antiproton intensity and urgently has to be studied. If the 132 ns option should remain feasible, a study on the influence of the enhanced beam-beam effect should be made to find out the influence of the crossing angle and the stronger forces at parasitic crossings.

While the Tevatron electron lens has proven a very useful device for eliminating the unwanted protons outside the bunches, the so-called dc beam, its usefulness for compensating beam-beam forces has not yet been demonstrated. If the Tevatron electron lens should come to fruition for this task, more manpower has to be invested in the project. Acknowledging the potential limits from the beam-beam effect and the fact that much has yet to be understood, we encourage an increase of accelerator physics studies.

Possible sources of the emittance growth in the antiproton beam transfer from Main Injector to Tevatron include optics mismatches and injection jitters. It remains to be seen if these identified sources explain the entire observed emittance growth and whether the injection dampers (expected to turn on in March 2003) and the optics tuning will reduce the 7π mm-mrad growth to 2π mm-mrad as in the FY 2003 plan. The diagnostics and injection tuning tools need to be improved to gain a quantitative understanding of the emittance growth. It is expected that most of the 7π mm-mrad emittance growth will be removed in FY 2003.

A reduction in the time needed for shot setup can lead to a relevant gain in integrated luminosity. The main issues to investigate are: can the time between dumping the beams and shutting down the detectors be decreased, can the preparations for ejection from the Antiproton Accumulator Ring start earlier, so that the shot setup for protons and antiprotons can start approximately at the same time, can the extraction from the Accumulator be faster, can the time spent for the magnetic field standardization procedure be shorter. Reducing the time spent for field standardization would be aided by the installation of a reference superconducting magnet and the development of a strategy of dealing with the snap back effect due to persistent currents in the superconducting magnets. All these efforts might shorten the 3 hours setup period to approximately 2 hours.

4.3 Recommendations

1) Schedule the C0 Lambertson replacement at the earliest possible date.

2) Allocate sufficient Tevatron study time to sustain the excellent rate of progress in the luminosity development that has been achieved over the last few months and will be required over the next few years.

3) Install the Tevatron feedback dampers as planned. Assure, as soon as possible, that the dampers can indeed damp the higher-order head-tail instability. Investigate

whether octupoles effectively cure higher-order head-tail instability without affecting the single particle lifetime.

4) Install Tevatron injection dampers and test the optics tuning as planned. Implement the necessary beam tuning tools and diagnostics as a high priority.

5) Study in more detail the observed influence of the antiproton bunches on the proton beam and initiate a thorough study effort of the impact on luminosity of a five-fold increase in antiproton intensity in the Tevatron.

6) Define the role of the Tevatron electron lens for Run II.

7) Make a decision, at the earliest possible date, whether a viable option to go to 103 bunches in the Tevatron (132 ns option) should be maintained.

8) Initiate a study to shorten the shot setup procedure; the study should include potential benefits from the installation of a Tevatron reference superconducting magnet.

5.0 Proton Source

5.1 Findings

The proton source has for the most part satisfied the demands of the Tevatron collider program up to now. Credit is to be given to the groups in charge of the machines comprising the proton source (Hydrogen ion source, Cockroft-Walton, Linac, Booster, and main Injector) for an impressive record. Linac/Booster availability is a combined 95%.

These machines are the workhorses of the complex. Proton-beam intensity in the Booster is about 4.5×10^{12}/pulse. This is sufficient, albeit just, to meet the present demand of the collider, with 7-bunch coalescing in the Main Injector. Pulse intensity in the Booster has to be raised to $\approx7\times10^{12}$ by FY 2004, unless efficiency is markedly improved in the following machines and transfer lines. Good diagnostics will be important in reaching this goal, recent progress in this regard (tune meter) is encouraging.

The 8 GeV Booster synchrotron presently operates at an administratively imposed radiation-dose limit for the tunnel consistent with hands-on maintenance. Radiation is becoming a limitation, not so much for collider operation but rather for the fixed-target experiments that are starting to present additional demands, particularly the MiniBoone experiment, at this time. Proton Source Department leadership is aware of the issues and has projects in place to localize the beam loss with beam collimators (installed but not yet shielded and commissioned), to reduce the beam loss by improving orbit steering using the new ramped correctors (thus increasing the aperture available for the beam) and by other measures.

Projects in the Main Injector to reduce the longitudinal emittance of the proton beam include upgrades to the phase-lock (“cogging”) system and the longitudinal bunch-by-bunch feedback system.

The Main Injector performance has essentially reached its design parameters and also has very good availability. Seven bunches from the Booster are routinely coalesced into one with tolerable losses, although with somewhat more emittance growth than desired. The beam-loading compensation is working well and is indispensable for efficient coalescing. The group is presently focusing on beam-emittance preservation.

Damping systems are being constructed for Main Injector horizontal, vertical, and longitudinal dimensions. A unified design, applicable to the other machines as well and based on commercial hardware, is being developed for the electronics; this appears to be a very suitable and efficient approach. Of particular concern are a longitudinal beam instability at injection and vertical emittance growth during acceleration, the latter not yet understood.

5.2 Comments

Beam loss in the Booster at low energy is believed to arise from space charge; loss is also seen to occur at transition. The committee expects the measures outlined above to improve the situation by a factor 3–5, based on information given at the review. This would not be sufficient to fully satisfy future demands. The committee agrees with the desire to "hold the line" with respect to radiation limits; it is very important to preserve the hands-on maintainability of the Booster.

The existing Booster transition-jump system has suffered from orbit distortions and has therefore not been used. It is hoped that reactivation after the orbit has been fixed will reduce the transition losses. The longitudinal dampers should cure possible beam instabilities that may arise after transition.

The ongoing work on damping systems for the Main Injector is expected to markedly improve beam quality and should be brought to timely conclusion. This includes injection dampers as well as instability feedback systems.

The observed transverse proton emittance in the Tevatron is still about 20% larger than expected. The effort on improved beam matching in the transfer lines into the Tevatron should continue vigorously.

There is a strong vertical emittance blowup of the proton beam in the Main Injector during acceleration which needs to be understood.

At present, bunch coalescing in the Main Injector leads to too large a longitudinal emittance (≈3 eVs) and causes beam loss of about 12–15% (7-bunch coalescing). The cause appears to be a longitudinal instability at injection into the Main Injector, forcing the extracted emittance of the Booster to be blown up deliberately (×2). The situation may be improved by the new damping systems and/or by coalescing only 5 bunches, which would also reduce the losses to ≈8%. At present, the Booster does not deliver enough intensity for 5-bunch coalescing.

5.3 Recommendations

1) Increase significantly efforts on Booster machine physics and on hardware to meet anticipated demands on proton throughput and pulse intensity. A vigorous program to commission and understand the collimators should be launched.

2) Monitor the radiation dose received by the Booster ring components, including magnets.

3) Implement a program of beam studies to understand space-charge effects in the Booster and the beam dynamics during transition crossing, with the goal of minimizing losses and allowing for higher beam intensity. Beam Physics Department members should help.

4) Develop a plan to address upgrading of aging and un-maintainable equipment throughout the Proton Source, especially those items that can cause extended downtime like the Booster low level radio frequency system, injection bump power supplies, *etc*.

5) Consider strengthening the Booster team to enable it to vigorously pursue the above tasks.

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6.0 Antiproton Source including Recycler

6.1 Findings

The supply of antiprotons at a high rate and from a sufficiently large antiproton stack is essential to high integrated luminosity in the Tevatron.

The present initial antiproton stacking rate of 12.4×10^{10} per hour (66% of Run IIA goals) is a respectable achievement. However, the present Debuncher cycle time of 2.2 seconds is 50% larger than the design value of 1.5 seconds due to stochastic cooling limitations, which presently are the main causes of the lower initial stacking rate.

The equilibrium stack core emittances for a given stack intensity were initially a factor of two higher than during Run IB. This has been identified as caused by the lattice modifications of the Accumulator necessary to support the higher stack tail stochastic cooling bandwidth, which had the adverse effect of increasing the horizontal emittance growth rate due to intrabeam scattering. A complete rebuild of the stack core cooling system as well as the commissioning of a special lattice to reduce intrabeam scattering while cooling has cured this problem in record time.

The stacking efficiency drops off rapidly with increasing stack size, mainly due to insufficient stack tail gain at higher stack intensities combined with an excessive $\Delta p/p$ from the Debuncher. The main cause in reduction of stacking rate with increasing stack intensity is understood and is due to an instability of the high-gain stack tail cooling system due to an instability involving the beam transfer function of the intense stack core. This instability requires reduction of the stack tail gain as the stack intensity grows.

A number of short term projects have been launched which should improve the Debuncher and stack tail cooling in FY 2003. This should reduce the cycle time such that both the stacking rate and the maximum useful stack intensity can be expected to increase by 50% in FY 2003, thus achieving the Run IIa goals.

In parallel a number of longer-term projects are being pursued. The main items are: an upgrade of the aperture of the Debuncher and antiproton transfer line (AP3), a Li-lens gradient upgrade, and more protons on target per pulse (slip stacking in Main Injector). Beam sweeping on the antiproton target is foreseen to prevent target damage and will be installed in the future.

As these projects progress and increase the antiproton flux, the problems associated with the Accumulator cooling at high stack intensities will require integration of the Recycler into normal operation.

The progress achieved in the commissioning of the Recycler and its stochastic cooling is noteworthy. It has now reached a point where integration into normal operation within a year is being considered.

The R&D on the challenging high-energy electron cooling has also been progressing well. The goals for energy and current through a 180 degree bend have been reached. The Pelletron accelerator high voltage trip frequency due to instabilities is still too high, and the problem is being addressed. The precise cause is still unknown. Tests with a complete electron beam line are being prepared and the Pelletron acceleration gradient will be reduced by the addition of an extra 1 MV acceleration section. Bids for the required civil engineering for installation in the Main Injector have been issued.

6.2 Comments

The prompt manner in which the stack core emittance problem was identified and cured by the antiproton team is noteworthy and laudable. The increased intrabeam scattering caused by the lattice change came as a bit of a surprise, but the antiproton team quickly identified the problem and found a viable solution.

An additional surprise was the coherent stack tail instability involving the longitudinal beam transfer function of the stack coupled with waveguide propagation of high frequency electromagnetic fields in the vacuum chamber caused by the use of a higher stack tail frequency band. This instability is presently the main cause of the decreasing stacking rate with stack intensity. Several cures are being considered. In the long run, the integration of the Recycler in normal operation will reduce or eliminate this problem. However, it is prudent to continue with stacking improvements in parallel in order to improve the margin relative to expected antiproton requirements.

The committee is confident that the short term projects and cures being proposed are effective and will permit reaching an initial stacking rate of 1.8×10^{11} per hour and maintain a reasonably high stacking rate with stacks up to 2×10^{12} before the end of FY 2003.

The R&D activities and projects proposed to further increase the stacking rate over the next few years are well conceived and should be pursued with adequate resources and priority to ensure successful termination in a timely manner. The projects include slip stacking in the Main Injector, target beam sweeping, higher Li-lens gradient, increased acceptance of the AP3 transfer line and the Debuncher ring, and electron cooling in the Recycler. The latter is a high risk, high payoff project worth pursuing if completed in a timely manner.

6.3 Recommendations

1) Verify stack tail cooling rate with protons up to 5×10^{11} per hour (50 mA/h) to verify that the modified Accumulator stack tail system can digest the higher flux of antiprotons resulting from Main Injector slip stacking, Li-Lens, AP3 and Debuncher acceptance upgrade.

2) Continue to support the electron cooling R&D with adequate funding and manpower to ensure completion within a useful timeframe.

3) Integrate the Recycler into normal operation as soon as the performance is adequate for breaking even in integrated luminosity.

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7.0 Instrumentation

7.1 Findings

The Shot Data Analysis system stores and provides easy access to diagnostics and other information recorded during physics production and machine studies runs. The data are accessible through a variety of programs and will allow many people to analyze data and help understand the Run II performance. It complements the data loggers and will be an important tool for realizing the Run II goals.

The Synchrotron Light Monitor is an instrument that allows non-invasive measurements of beam centroids and sizes at the Tevatron collision energy of 980 GeV. At this energy it provides the only beam profile measurements possible without unacceptable detector backgrounds. It can record bunch-by-bunch transverse profiles of both beams with a ~ 30 msec integration time. It provides information on x-y coupling and clear evidence of long-range beam-beam effects. The optical arrangement is relatively rudimentary, and there are unresolved calibration issues. Despite this it is providing valuable information.

The flying wire systems provide clean transverse profiles, and they measure the emittance once the beta- and dispersion-functions at the wire location are known. They are valuable for measuring emittance dilution along the injection chain, but the Tevatron flying wires produce unacceptable backgrounds during collisions.

Schottky detectors operating at 1.7 GHz are under construction for the Recycler and Tevatron. They are general purpose, non-invasive devices that will provide information on proton and antiproton tunes and chromaticity in the Tevatron, and on tune, chromaticity and longitudinal properties in the Recycler. The design is that of the Antiproton Source kickers and pick-ups. Surplus vacuum hardware and electronics from the Antiproton Source will make construction of these pickups an economical project.

The Beam Line Tuners (BLT) measure the transverse beam positions at single locations in the Recycler, Main Injector and Tevatron. They provide essential measurements of injection steering and can measure tunes, chromaticity, and coupling.

Beam position monitors in the Recycler, Main Injector and Tevatron need substantial improvement.

- The Recycler beam position measurements have intensity dependence, are not reproducible and cannot be relied on for steering and lattice diagnostics. These problems are attributed to the signal processing electronics and not the beam position monitors themselves. There is a detailed technical design for new signal processing electronics based on digital receivers.

- The beam must have 53 MHz structure for orbit measurements in the Main Injector. The beam that will be returning from the Recycler will not have this structure. Instead it will be bunched at 2.5 MHz. The signal processing electronics must be replaced in order to measure the orbit of this beam in the Main Injector.

- The Tevatron beam position monitors do not function during stores. There are two issues. First, the signal processing electronics requires 53 MHz structure, and does not work with the coalesced beam. (Orbits measured with test batches with 53 MHz structure do not agree with orbits measured with coalesced beam at the required precision of 0.5 mm.) Second, antiproton orbits cannot be measured. Orbits are measured with test batches every one or two weeks through the entire injection, ramp and squeeze cycle. There is evidence that the beams move by more than the critical limit of 0.5 mm during a store.

7.2 Comments

The Run II plans call for a substantial increase in peak and integrated luminosities, and beam instrumentation will be critical for realizing them.

The Shot Data Analysis system, synchrotron light monitor, wire scanners, Schottky detector, beam line transfer monitors discussed in the findings above will provide important information. They are impressive work.

At the same time there is basic instrumentation that is missing. The Recycler, Main Injector, and Tevatron beam position monitors do not perform at the level needed to sustain and improve the luminosity. The shortcomings are detailed in the findings above. It is essential that the beam position monitor systems be properly funded instead of being targeted for cuts.

We left the breakout sessions with the strong impression that the physicists and engineers working on instrumentation did not feel themselves well-integrated into the team improving the Run II performance. This included not being involved in planning and not having an understanding of whether budgetary or technical considerations dominated decisions. There will be a reorganization of the management and responsibilities for instrumentation starting November 1. Team building should be an early part of the activities.

The recommended efforts on accelerator modeling, simulations and studies will be sterile without adequate beam instrumentation.

7.3 Recommendation

1) There must be significantly increased emphasis and resources devoted to instrumentation.

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8.0 Schedule and Resources

8.1 Findings

A detailed FY 2003 plan with a resource-loaded schedule was presented. It is developed down to level 3 tasks.

An initial plan for Run IIB was developed in December 2001 describing the technical scope of the Tevatron luminosity upgrade. However, an updated plan for Run IIB (beyond FY2003) with a resource-loaded schedule was not presented. The laboratory identified a dedicated project manager for Run IIB reporting to the Beams Division head.

8.2 Comments

The existence of a resource loaded plan for FY 2003 should be very beneficial to the coordination of the luminosity development efforts and the data taking by CDF and D0 during FY 2003.

FY 2003 plan as presented lacks definite milestones. Such milestones would be useful both for clarifying expectations within the laboratory and for DOE's use in tracking progress.

8.3 Recommendations

1) Prepare a formal list of milestones for the FY 2003 plan.

2) Develop a resource loaded plan for all of Run II.

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9.0 Systems Integration

9.1 Findings

Many meetings throughout the Beams Division are held each week to plan coordinated activities for beam operation and project updates. These meetings cover various aspects of the accelerator and operations involving all layers of management, support groups, accelerator physics, and the particle detectors. The spirit of these meetings to work together towards a common goal is very good. The committee feels that these meetings cover the appropriate organizational requirements. It is noted that many of the people out in the field, on site doing the actual work are allowed to make decisions that affect the quality and outcome of their work.

9.2 Comments

The communication between the various accelerator groups is very good in general and is improving with time. However, there are several groups that could work more effectively if they were included more in the planning and development of the technical goals and the operating decisions of the collider. With more communication, these groups would take more ownership of their contributions to the project. The groups are the Diagnostics Group and the Beam Physics Department.

The Antiproton Source Department has always been technically strong, being very autonomous and doing their own diagnostics and theory. Recently, they have been helping other machines, e.g. the Recycler and the Main Injector, to develop needed diagnostics and tune up their beams needed for optimal operation in the Source. The committee encourages this collaborative effort to continue and to expand. The Antiproton Source Department is doing an excellent job.

9.3 Recommendations

1) Improve the communication between the Diagnostics Group and the rest of the Beams Division.

2) Improve the communication between the Beam Physics Department and the rest of the Beams Division.

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10.0 Reliability

10.1 Findings

The Tevatron complex has at present a good reliability with an availability of about 75%. The current time lost to failures in the last eighteen months has been acceptably low. The FNAL staff is spending considerable effort to systematically improve the Tevatron Collider reliability aiming towards an availability of about 90%, typical of other colliders.

10.2 Comments

The Tevatron complex is made up of a number of major subsystems that, with the exception of the Main Injector, are decades old and include technical components that may be approaching obsolescence. In order to achieve the long-term integrated luminosity goal of the Tevatron complex, a long term (>5 year) replacement and upgrade plan for the facility is required to guide the activities needed to assure reliability and to determine the resources needed to support these activities.

A recent "vulnerability study" has identified a list of items which could turn off the Tevatron complex for three or more months. The list contains several substantial items. Management should complete the second half of this study and develop a plan to provide for adequate backup.

The Booster synchrotron is reliable at present (about 95% availability). However, its reliability with increased radiation dose later in the FNAL beam program is uncertain and needs careful investigation.

The electron cooling project is crucial for high luminosity later in the Tevatron program. The reliability of this apparatus is, because of its complexity, potentially relatively low. Although there is considerable effort underway to make this system as reliable as possible, extra effort should be added to achieve that goal.

A study similar to the vulnerability study, but looking for "near end of life" components, should be done with an eye on looking for large-but-one-time failures or small-but-frequent failures. A plan to deal with these potential failures should be developed.

Many subsystems of the Tevatron complex have substantial maintenance items that have been deferred as they do not affect immediate Tevatron operation. Many of these items are dealt with in longer scheduled downs. However, due to personnel overloading, many items do not get accomplished during scheduled downs. A strategy to deal with deferred maintenance should be made.

Many members of the systems group have changed positions recently or left the laboratory, and the Beams Division should be concerned that corporate memory of maintenance issues could easily get lost. A process for retaining this vital memory should be developed.

The Tevatron experimental detectors should reestablish exactly how much dose the silicon trackers can handle before they need replacement. This dose limit when compared with dose rates from projected Tevatron operations of recent times will predict when silicon tracker upgrades are really needed.

10.3 Recommendations

1) Develop a technical and financial plan for providing backups for items in the "three month down" vulnerability study.

2) Make a study to identify "near-end-of-life" components.

3) Determine the vulnerability of the Booster to substantially increased radiation doses expected in coming years and develop a repair plan.

4) Redouble the effort to make the electron cooling system reliable.

5) Develop a strategy for dealing with deferred maintenance.

6) Develop a process to retain "corporate knowledge" of reliability issues as people move from group-to-group or leave the organization.

7) Re-estimate the date when the radiation dose limit of the silicon trackers will be reached using recent beam data so that a more up-to-date replacement schedule can be made.

11.0 Management

11.1 Overall management issues

11.1.1 Findings

There has been great progress during 2002. The team working on the Tevatron complex has increased the luminosity by a factor of 4 since January 2002 and a new record peak luminosity has been achieved. The detectors are operating reliably and physics data is being taken with low backgrounds with several hundred inverse picobarns expected to be logged by the coming summer. This success serves as a solid platform for future progress. All involved are to be congratulated!

This is fundamentally an R&D driven "project." As a result, goals have an inherent uncertainty due to technical and a few accelerator physics considerations that are not completely understood or yet under control. The multi-year nature of the effort also contributes to the inherent uncertainty in establishing a reliable plan to meet the long-term goals.

The laboratory states that it recognized two levels of luminosity goals: a base goal of delivering 6.5 fb^{-1} by 2008, and a stretch goal of delivering 11 fb^{-1} by 2008. The base goal calls for reaching a yearly integrated luminosity of 1.5 fb^{-1} in FY 2007 and 1.8 fb^{-1} in FY 2008 and beyond. The stretch goal calls for 2.5 fb^{-1} in FY 2006 and 3.0 fb^{-1} in FY 2007 and beyond.

The laboratory correctly emphasizes that reaching the long-term luminosity goals assumes the success of several R&D efforts and adequate financial support.

The laboratory directorate and the laboratory as a whole have increased their focus and priority on achieving the long-term integrated luminosity goals of the Tevatron complex. The laboratory has provided significant support to the Run II effort from outside the Beams Division, roughly 50 people (~25 FTEs). This number is expected to remain constant although the names may change.

The present management team is very experienced and is capable of successfully bringing the Tevatron complex to its long-term luminosity goals.

A comprehensive plan has been developed for FY 2003. Although there have been detailed studies of the significant technical issues that need to be addressed in FY 2004 and beyond, there is comparatively little detailed scheduling and resource planning for the period beyond FY 2003.

In order to execute the FY 2003 plan, incremental funding for materials and services and for salaries of approximately $3.5M beyond that needed for routine maintenance is required and is not currently foreseen to be made available. As a result of this shortfall, the current view of management is that a number of important activities required for progress in FY 2004 and beyond would not be supported in FY 2003. These activities include two out of the three BPM upgrades and half of the maintenance initiatives for the proton source. The cancellation of these efforts still leaves a shortfall of about $1.8M.

Beyond FY 2003 it is estimated that an additional $13M would be required to support new activities. This estimate is very preliminary, does not include contingency, and has a high degree of uncertainty.

DOE has encouraged Fermilab to involve experts from other laboratories in the Run II upgrade. Fermilab has been involving outside experts, but only in situations where there is a good expectation of the outsiders being able to make meaningful contributions. Thus far the level has been about 5 FTE.

The committee heard a discussion of the reliability activities. The Tevatron complex is made up of a number of major subsystems that are decades old with technical components that are approaching obsolescence. This is a significant reliability challenge that requires a proactive long-range replacement and upgrade plan if the overall luminosity goals are to be met.

11.1.2 Comments

Reaching the long-term luminosity goals of the Tevatron complex will require sustained effort over a period of years. The success for the long-term effort will depend strongly on the capabilities of whoever is appointed to head the Beams Division (currently, Steve Holmes serves as "acting" head) and on establishing an appropriate balance between activities with short term and long term payoff.

Clearly there is a pressing need for the laboratory to develop a comprehensive plan for achieving the long-term integrated luminosity goals of the Tevatron complex, addressing the period through the time when luminosity will plateau and the Tevatron complex will focus on production running for physics. This plan must integrate project-type activities, R&D efforts, backup scenarios, operations of the complex for experiments, replacement and upgrading technical components and infrastructure, routine maintenance, and installation activities. This plan should be resource loaded and completed by June of 2003.

In addition, it would be wise to extend the plan through FY 2009 using a relatively broad brush so that any downstream deficiencies can be anticipated.

Additional manpower resources are needed to support the planned activities in FY 2003. In the management area, more effort for planning and tracking appears to be needed.

While recognizing the need for Fermilab to produce cutting edge science, the laboratory director and the DOE must assure that the human, fiscal and technical resources needed to reach the long-term luminosity goals are provided. The overall funding level for the nation's high energy physics program and for Fermilab in FY 2004 and beyond is a major concern, one that could severely impact Fermilab's ability to deliver on the luminosity goal for the Tevatron complex.

The Committee is concerned that there is an apparent lack of funding to support the additional tasks, such as routine maintenance and the new BPM systems. We encourage the Fermilab management to look within their extended laboratory budget and make some of the difficult choices.

Involving outside experts is a tricky business and must be done carefully to avoid unproductive efforts and negative impact on morale. Experts who are able to spend considerable time (many weeks) at Fermilab should be able to contribute and the internal staff should be positive about their involvement. There have been a number of positive cases of outsiders being in residence and helping successfully. This has helped increase the comfort level of the inside staff.

In addition, if and when separable projects that are well matched to outside expertise can be identified, outside labs can be utilized. The key to utilizing outside expertise is the Fermilab team identifying a need, there being a capability on the outside that is able to meet the need, there being points of contact on the inside and on the outside to facilitate collaboration and information flow, and there being a willingness on the inside to accept help and on the outside to provide help. Achieving these conditions is subtle and takes time.

In order to achieve the long-term luminosity goal of the Tevatron complex, a long term (greater than 5 year) replacement and upgrade plan for the facility is required to guide the activities needed to assure reliability and to determine the resources needed to support these activities.

11.1.3 Recommendations

1) By June 1, 2003 Fermilab should develop detailed and comprehensive plans for achieving the long-term integrated luminosity goal of the Tevatron complex.

2) The DOE should undertake a follow-up review in about eight months to evaluate the technical and accelerator physics uncertainties related to the long-term goals as

well as the detailed long-term planning for achieving the long-term integrated luminosity goals of the Tevatron complex.

3) DOE and the Fermilab management should verify that the new long-term base luminosity goal is consistent with the physics reach of the Tevatron complex (e.g. discovery potential for the Higgs boson) expected by the users and the rest of the high energy physics community.

4) Fermilab should rapidly appoint a "permanent" (*i.e.* non-acting) head of the Beams Division who has the experience, capability, and commitment needed to successfully lead the effort to achieve the long-term luminosity goals for the Tevatron complex.

11.2 Organization

11.2.1 Findings

The luminosity upgrade effort is headed by the head of the Beams Division who has overall responsibility for achieving the luminosity goals in a timely fashion. The deputy head of the Beams Division has been designated as the Project Leader for Run IIa. The Project Leader is assisted by the run coordinator who is responsible for controlling day-to-day activities. The run coordinator serves for a 4 month term. The Beams Division is a matrix organization, consisting of systems departments (Main Injector, Tevatron, etc.) and support departments (Mechanical Support, Controls, etc.).

All Departments within the Beams Division participate strongly in the luminosity upgrade effort with the exception of the NUMI Department, the External Beams Department, and the Special Projects Department. The systems department heads hold overall responsibility for the performance of their machines. This generally means understanding performance issues and providing the planning and scientific support necessary to meet performance goals. In general, significant technical resources do not exist in the systems departments. As a result they draw significantly on the resources of the support departments for maintenance and hardware improvement activities.

The systems department heads report organizationally to the division head. The support department heads report organizationally to the Associate Division Head for Engineering. The Associate Division Head for Engineering is charged with focusing on reliability issues within the complex.

In addition there is a Beam Physics Department. This department is responsible for accelerator physics support to the division. The group is composed entirely of physicists.

The Operations Department holds responsibility for control room operations. There are five operations crews staffed nominally with five members each. They control operations of the machines 24 hours a day.

Communication within and between the relevant organizations and with the users appears to be good. There are a series of meetings to look at sort term and long term progress, problems and priorities.

The Recycler is a key element to increases in luminosity in the future. The laboratory has assigned an experienced senior manager/physicist to lead the effort, and he is now assembling a team.

11.2.2 Comments

It is not clear that the level of intellectual ownership for identified problems and solutions is yet adequate. Overall responsibility and ownership are clearly vested in the head of the Beams Division and, under him, the Run II project leader and post-FY 2003 project manager. However, it is not so clear that there is the required continuity at the lower levels. For example, the run coordinator is rotated every four months and this leads to a concern that the needed ownership doesn't extend over a sufficient time-scale for such a multi-year effort.

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Appendix A

Letter Requesting Review

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Department of Energy
Washington, DC 20585

Dr. Michael Witherell
Director
Fermi National Accelerator Laboratory
P.O. Box 500
Batavia, Illinois 60510

Dear Dr. Witherell:

I am writing to confirm the arrangements for the Department of Energy (DOE) on-site Tevatron Luminosity Performance Review. The review is scheduled for October 28-31, 2002, and will be chaired by David F. Sutter, Senior Program Officer, Technology R&D, Division of High Energy Physics.

The purpose of the review is to examine the issues relevant to present and future luminosity performance of the Fermilab Tevatron Facility. A more detailed description of the questions to be addressed by the review committee is provided in the enclosed charge. Members of our staffs are in the process of completing the final arrangements and tentative agenda, which will be provided to you shortly.

It is my understanding that relevant background material will be provided directly to the Committee members by Fermilab. We would appreciate committee members being provided with copies of all presentation material at the beginning of the review. If you or your staff have any questions, please do not hesitate to call Dr. Sutter at (301) 903-5228 or Michael Procario, who will serve as Executive Secretary to the review committee, at (301) 903-2890.

Sincerely,

John R. O'Fallon
Director
Division of High Energy Physics

Enclosure:
Charge to Committee

cc:
A. Byon-Wagner, SC-223
M. Procario, SC-221
D. Sutter, SC-224
P. Debenham, SC-224
B. Strauss, SC-224
J. Monhart, CH/FRMI
S. Holmes, Fermilab

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Appendix B

Charge to Committee

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Department of Energy

Fermilab Run II Luminosity

Performance Review

Oct. 28-31, 2002

Charge to the Review Committee

The Fermilab Tevatron facility has been in operation colliding protons and antiprotons since March of 2001, following a five-year hiatus of collider operations to carry out a program of fixed target operations and to complete construction of a new 120 GeV Main Injector synchrotron, upgrades to the rest of the accelerator complex, and to the CDF and D-Zero detectors. In the period of collider operations prior to the hiatus, known as Run IB, the Tevatron performance set world records for peak, average, and integrated luminosity in a proton-antiproton (P-bar) collider. In the present run, Run IIA, the Tevatron has in July, August, and September of this year exceeded its Run IB records and is again operating at world record peak, average, and integrated luminosity, exceeding those of Run IB. However, the start-up of operations for Run IIA has not progressed smoothly and is not consistent with published Fermilab long range planning for this activity. The integrated luminosity is about a factor of two behind its original, planned time line, but also, the progress in improving performance does not at this time provide assurance of achieving the plan presented by the laboratory at the January 2002 meeting of the High Energy Physics Advisory Panel.

The Run II Tevatron collider program is anticipated to be an enormously significant extension of the productive physics program of Run I, which included the discovery of the top quark. With the successful commissioning of the Main Injector and the Recycler, the Tevatron in Run II was projected to run at luminosities an order of magnitude higher than it has in the past, and at the higher center-of-mass energy of 2 TeV. The degree to which the Tevatron can be pushed in performance in Run II will determine the physics reach of the Tevatron beyond that of any previous experiments and could well lead to the discovery of one or more Higgs bosons, super symmetry, technicolor, or other very important new physics. For this reason, it is vital to the U.S. program in high energy physics to maximize the performance of the Tevatron and, therefore, the scientific output of the collider experiments in this critical period before LHC turn-on.

Because achieving the highest possible integrated luminosity is critical to achieving the physics research goals and to the justification for proceeding to fund planned upgrades to the Tevatron and the CDF and D-Zero detectors for the next stage of operation, Run IIB, the Department of Energy (DOE) has organized this review to examine issues that affect achieving a very high level of Tevatron Run II luminosity performance.

The review committee is asked to review and comment on:

1. The current status of Run IIA luminosity performance and the effectiveness of the current technical and management activities to improve that performance.

2. Fermilab's revised goals and plans for achieving overall luminosity performance for Run IIA and Run IIB, recognizing that plans for Run IIB will necessarily be developed in less detail and be of much broader stroke than Run IIA.

    a. Are the stated technical scopes of work proposed for each major subsystem adequate to support the revised Run II goals and are they reasonable and achievable?

    b. Are the plans to achieve the proposed goals adequate in terms of manpower, costs, and resource-loaded scheduling?

    c. Does the laboratory have a strong management team and appropriate structure in place to successfully execute the plans?

3. In the Review Committee's judgment, do the proposed plans and processes give reasonable assurance of meeting Fermilab's luminosity goals set for the Tevatron for Run II? How might these plans and processes be improved?

The achievement of high luminosity performance is dependent on reliable machine operation. Consequently, the committee is also asked to be sensitive to infrastructure issues in each subsystem of the Tevatron complex that may be impacting performance and how these are being or should be addressed.

The chairman of the review has been asked by Dr. John R. O'Fallon, Director of the DOE High Energy Physics program, to provide a written report of the review results by Friday, December 6, 2002. The assistance of the Review Committee technical consultants in carrying out this very important review is greatly appreciated.

Appendix C

Review Participants

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Department of Energy Review
of the
Fermilab Run II Luminosity Performance Review

Oct. 28-31, 2002

REVIEW COMMITTEE PARTICIPANTS

Department of Energy

David F. Sutter	DOE/HEP, Chair
Michael Procario	DOE/HEP, Executive Secretary

Consultants

Rick Baartman	TRIUMF, Vancouver, BC, CANADA
Alex Chao	Stanford Linear Accelerator Center
Pat Colestock	Los Alamos National Laboratory
Georg Hoffstaetter	Cornell University
Derek Lowenstein	Brookhaven National Laboratory
Jay Marx	Lawrence Berkeley National Laboratory
Flemming Pedersen	CERN, Geneva, SWITZERLAND
Steve Peggs	Brookhaven National Laboratory
Massimo Placidi	CERN, Geneva, SWITZERLAND
Thomas Roser	Brookhaven National Laboratory
Francesco Ruggiero	CERN, Geneva, SWITZERLAND
Karlheinz Schindl	CERN, Geneva, SWITZERLAND
John Seeman	Stanford Linear Accelerator Center
Bob Siemann	Stanford Linear Accelerator Center
Uli Wienands	Stanford Linear Accelerator Center

Observers

John O'Fallon	DOE/HEP
Aesook Byon-Wagner	DOE/HEP
Phil Debenham	DOE/HEP
Bruce Strauss	DOE/HEP
James Decker	DOE/ FORRESTAL
Jane Monhart	DOE/FNAL SITE OFFICE

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Appendix D

Committee Organization

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Chairman – David F. Sutter 020925/1725

Executive Secretary - Michael Procario

Accelerator Physics
(For all Tevatron complex)

Steve Peggs, BNL (Chair)
Francesco Ruggiero, CERN
Rick Baartman, TRIUMF

Tevatron
(The Superconducting Collider)

Thomas Roser, BNL (Chair)
Alex Chao, SLAC
Georg Hoffstaetter, Cornell

Instrumentation
(For all Tevatron complex)

Bob Siemann, SLAC (Chair)
Massimo Placidi, CERN

P Source
(Linac, Booster, & Main Injector)

Uli Wienands, SLAC (Chair)
Karlheinz Schindl, CERN

P-Bar Source
(Target, Debuncher, Accumulator, and Recycler)

Pat Colestock, LANL (Chair)
Flemming Pedersen, CERN

Management and Systems Integration
(For all of Run II Luminosity upgrade)

Jay Marx, LBNL (Chair)
John Seeman, SLAC
Derek Lowenstein, BNL

Observers:

John R. O’Fallon, Aesook Byon-Wagner,
Phil Debenham, Bruce Strauss

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Appendix E

Review Agenda

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DOE Review of Accelerator Run II

http://www-bd.fnal.gov/doereview02/
October 28-31, 2002
Wilson Hall 1-West
Revision 10/22/02

1.
Monday, October 28
2. 8:00 Committee Executive Session

Overview
9:00 Welcome – Witherell (10 minutes)

9:10 Overview of Run II Goals, Current Performance, and Issues – Holmes (25 minutes)

9:40 Description of Shot Mechanics – Johnson (25 minutes)

10:10 Overview of FY03 Goals, Constraints, and Strategies – Church (40 minutes)

10:55 BREAK (15 minutes)

Individual Machine Performance and Plans
11:15 Proton Source (Linac and Booster) – Webber (30 minutes)

11:50 Main Injector – Mishra (30 minutes)

3. 12:30 LUNCH

1:15 Antiproton Source – McGinnis (30 minutes)

1:45 (?) Tevatron – Shiltsev (45 minutes)

2:30(?) Beam Transfers – Lebedev (30 minutes)

3:05 Instrumentation – Pordes (30 minutes)

3:40 BREAK (15 minutes)

Accelerator Physics
4:00 Summary of Accelerator Physics Issues – Syphers (40 minutes)

!1630 Committee Executive Session

Tuesday, October 29

8:00 Executive Session

Accelerator Physics (cont.)

8:30 Shot Data Analysis – Slaughter (25 minutes)

Reliability

9:00 Reliability/availability – Czarapata (30 minutes)

Plan for FY03

9:35 The FY03 plan – Church (30 minutes)

10:10 BREAK (15 minutes)

Run II Beyond FY03

10:35 Overview of Run II Upgrades Beyond FY03 – McGinnis (30 minutes)

11:15 Recycler – Mishra (30 minutes)

11:50 Electron Cooling R&D – Nagaitsev (25 minutes)

4. Summary

12:20 Organization, Resource, and Summary – Holmes (20 minutes)

12:30 LUNCH

Supplementary Discussion and Break-out Sessions

1:15 Break-out sessions – See Attached Schedule of Rooms

1630 Executive Session – Sub Committees

1700 Executive Session – Full Committee

Wednesday, October 30

5. 8:00 Committee Executive Session

0830 Supplementary discussions, break-out sessions, and report preparation as needed

10:30 Executive Session

11:00 Executive Session with Laboratory Management

12:00 Working Lunch

1:00 Committee Executive Session3:00 Close Out Dry Run

5:00 Special Executive Session with Jim Decker, Office of Science

Thursday, October 31

6. 8:00 Committee Executive Session, preparations for closeout, report writing – as appropriate

7. 9:30 All Close Out presentations due to Committee Executive Secretary

10:30 Closeout with laboratory management

12:00 Adjourn

DOE Review of Accelerator Run II

October 28 – October 31, 2002

Breakout Session Room Assignments

Monday, October 28, 2002

Room Reserved	Time	Group Assigned
1 West	8:00 am – 6:00 pm	Laboratory Presentations

Tuesday, October 29, 2002

Room Reserved	Time	Group Assigned
One West	8:00 am – 12:30 pm	Laboratory Presentations
One West	1:00 pm – 5:00 pm	Proton
Black Hole (2NW)	1:00 pm – 5:00 pm	Tevatron
Comitium (2SE)	1:00 pm – 5:00 pm	Management
One North	1:00 pm – 5:00 pm	Instrumentation
The Quarium (8SW)	1:00 pm – 5:00 pm	Accelerator Physics
Small Dng Room (1SW)	1:00 pm – 5:00 pm	Pbar

Wednesday, October 30, 2002

Room Reserved	Time	Group Assigned
One West	8:00 am – 1:00 pm	Proton
One West	1:00 pm – 6:00 pm	Executive Session
Snake Pit (2NE)	8:00 am – 1:00 pm	Tevatron
One North	8:00 am – 1:00 pm	Instrumentation
Sm Dng Room (1SW)	8:00 am – 12:00 pm	Pbar
The Quarium (8SW)	8:00 am – 1:00 pm	Accelerator Physics
RaceTrack (7N)	8:00 am – 10:30 am SDSS has 10:30 – 12:00	Management

Thursday, October 31, 2002

Room Reserved	Time	Group Assigned
1 West	8:00 am – 6:00 pm	Executive Session

Appendix F

Action Items

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Fermilab Run II Luminosity Performance Review

ACTION ITEMS

1. Fermilab will develop a detailed and comprehensive plan for completing the Run II luminosity upgrade by of the end of the fourth quarter of FY 2006 as proposed by the laboratory. This plan should be formally submitted to the Department of Energy no later than June 1, 2003.

2. The Department of Energy will conduct a followup review of the Run II luminosity upgrade no later than two months after receiving the Run II luminosity upgrade plan, that is in June of 2003.

3. Fermilab will provide DOE with the level 1 and level 2 milestones for the FY 2003 Run II improvement plan, including the Recycler, by November 27, 2002. The milestones should be relatively evenly spaced throughout the remainder of FY 2003.

Michael Witherell
Director
Fermilab

John O'Fallon
Director
Division of High Energy Physics

Stephen Holmes
Associate Director for Accelerators

David F. Sutter
Chairman of the Review Committee

Jane Monhart
Manager
Fermi Area Office

Michael Procario
Program Manager