REPORT of the

Fermilab Accelerator Advisory Committee Meeting

December 12-14 2001

Committee: Vladimir Balakin, BINP; Norbert Holtkamp, ORNL; Joseph Rogers, Cornell; Lucio Rossi, CERN; Thomas Roser, BNL; Ronald Ruth, SLAC; Tsumoru Shintake, KEK; Jonathan Wurtele, LBL; Ferdinand Willeke, DESY
Apologies: Jean-Pierre Delahaye, CERN

1. Introductory Remarks

The committee met on December 12-14. It enjoyed the lively discussions and the good spirit of the meeting. Information was shared quite openly with the committee.

The main topic of the meeting was an extensive review of the TEVATRON operation including the current Run IIa and the future Run IIb. This report begins with some general remarks and then proceeds with more details in the following areas:

- TEVATRON performance
- Injector performance
- RF Manipulations, Slip Stacking, Coalescing
- Lithium Lens Improvement and Transport Line (AP2) Upgrade
- Recycler Performance
- Electron Cooling
- Stochastic Cooling Upgrade
- Accelerator R&D

2. General Comments

In the year 2001 the TEVATRON and its injector chain succeeded in making the transition from re-commissioning to luminosity production after a shut down of several years for upgrading the injector chain. This is an important achievement. The committee would like to congratulate the operations team.

The main goal of the TEVATRON Run IIb is to further increase the number of antiprotons for collisions to eventually collect an integrated luminosity of 15 fb^{-1}. This is a very ambitious goal, which requires that this program be in the main focus of the laboratory.

The laboratory is in a critical phase. Further optimization of the TEVATRON complex is needed to obtain the benefits from the extended and expensive upgrade program. At the same time, the laboratory has to prepare for its future under difficult boundary conditions. The committee believes that the success of the TEVATRON program in a timely manner will be of great importance for the future role of FERMILAB in particle physics. The committee recognizes that the laboratory begins to focus the efforts on the success of the TEVATRON program. Such focus is fully endorsed by the committee. Moreover, the committee feels that this effort should be strengthened and enhanced even if this would temporarily be in conflict in pursuing other, longer-term efforts in accelerator R&D.

In reviewing the progress and the plans to reach the goals of the TEVATRON upgrade, the committee perceives a certain lack of support and shortage of manpower in many areas. The committee is aware that the reasons for the lack of human resources are very complex but it believes nevertheless that management should continue its effort to mitigate these deficiencies in order to avoid delays in the progress of the upgrade program. The committee noticed especially the need to involve more expertise in accelerator physics to help in solving the complex problems related to optimizing the performance of the whole accelerator complex.

The committee recognizes that many of the obvious problems in pushing the performance of the TEVATRON complex have already been addressed or solved. The remaining issues appear to be non-trivial and the committee recognizes that quite some effort will be necessary for further progress. The committee is pleased to see that in some areas a systematic approach has been adopted to deal with these issues such as, for example, the work on the analysis of the beam-lines. There are other issues where the committee feels that a more systematic and less pragmatic procedure would be beneficial for making steady progress.

Recommendation: The committee recommends to prepare and to plan for necessary accelerator studies with improved coordination between all accelerators and subsystems in order to ensure that the studies are carried out in an optimum order and with optimum preparation and evaluation.

Particular attention should be paid to improving general reliability. Some of the components of the TEVATRON complex are already quite old and approach the end of their life cycles.

Recommendation: The committee suggests that the Laboratory consider global measures to deal with this situation. For example it might be helpful if a senior engineer or scientist were placed in charge of general reliability issues.

To prepare for the improvements which are necessary to achieve the goals of Run IIa and RunIIb a comprehensive document has been produced which addresses all the important issues. The committee wants to congratulate the authors of the report for their excellent work.

Recommendation: The committee feels that further steps should be taken to provide overall strong coordination of the RunII improvement program.

3. TEVATRON Performance

The TEVATRON Run IIa started in March this year using the new Main Injector. The achieved peak luminosity so far is about L = 8 x 10^{30} $cm^{-2}sec^{-1}$ using 36 proton and anti-proton bunches as compared with 6 bunches per beam each used during the last TEVATRON Run Ib with the Main Ring. The TEVATRON is now operated at a new record energy of 980 GeV in proton-antiproton collisions. It is planned to reach the design luminosity for Run IIa of L=5 x 10^{31} $cm^{-2}sec^{-1}$ by doubling the proton bunch intensity from the present N_p = 1.5 x 10^{11} particles and improving the presently poor anti-proton transfer efficiency of only 30% by a factor 3. With good reliability an integrated luminosity of up to 25 pb^{-1} per week would then be possible.

There are indications of transverse instabilities in the proton beam in the TEVATRON that are stabilized with a relatively large chromaticity. Also, the observed persistent longitudinal coherence could indicate the onset of a longitudinal instability.
Recommendation: Early investigation of the TEVATRON performance with higher proton beam intensity would be very useful to identify the type of instabilities and develop ways to overcome possible intensity limitations.

Improving the anti-proton efficiencies will require careful and systematic investigations and beam tuning. About 30% of the anti-protons are lost in the TEVATRON due to bad lifetime at 150 GeV and losses during acceleration and the beta squeeze. Tests without the proton beam show very little loss indicating that these losses are due to (long-range) beam-beam interaction. Beam-beam interactions in the TEVATRON are greatly enhanced by the 36-bunch operation and are expected to get even stronger with higher proton beam intensity.
Recommendation: A shorter injection period and improved helical separator orbits, which minimize beam-beam interactions, should be investigated.

With the Recycler-ring fully operational it is planned to further increase the bunch number to 103. The difficulties with instabilities and beam-beam interactions are then expected to be even more severe.
Recommendation: The investigations on beam instabilities and separator orbits should also prepare for this mode of operation. Also, the effect of the increased number of parasitic collisions should be investigated.

No improvements or upgrades are planned in the TEVATRON for Run IIb with the exception of the beam-beam compensation lens. The electron lens consists of a 10 kV, 3A electron beam running collinear with the anti-proton beam over 2.5 m. The lens should be able to shift the tune of individual bunches by up to 0.01. A non-uniform electron beam profile could introduce amplitude-dependent tune shifts that could be used to compensate the beam-beam tune spread. One lens is installed in the TEVATRON and a tune shift of 0.007 was successfully demonstrated. The lens however reduces the beam lifetime probably due to noise in the electron beam. The complete system will consist of two lenses for horizontal and vertical tune control.

More studies and development will be needed to fully commission the lens and reduce its detrimental effect on the beam lifetime. It is expected that this will be successful. However, the benefit of bunch-by-bunch tune control to the TEVATRON operation is primarily useful for the multi bunch operation of Run IIb but may not outweigh the potential problems with possible beam heating from the lenses.

The possibility of compensating the nonlinear beam-beam effect is very exciting. It is very difficult to achieve this with just two non-linear elements located away from the two TEVATRON interaction regions. Extensive numerical and analytical simulations with a new working point showed that with an appropriately shaped electron profile a 50% reduction in tune spread and a good beam lifetime is possible. However, if the operating parameters are chosen incorrectly the lenses can increase the nonlinear beam-beam effect.
Recommendations: The committee feels that this very complicated and ambitious project should either receive significantly more resources and machine study time or should not be continued.

4. Injector performance

The injector complex provides beams of the necessary intensity and emittance for injection into the TEVATRON and is essential to the success of Run II. Further studies and hardware modifications will be needed to meet the goals of Run IIa and IIb. During this review we were informed of the present performance of the injector systems, known problems, and plans for increasing the performance of the injector systems to meet the goals of Run IIa and Run IIb.

Commissioning of the Main Injector has progressed well and the Main Injector is largely ready to achieve the goals of Run IIa. Slip stacking in the Main Injector for Run IIb will require beam-loading compensation with rather stringent gain requirements. Modelling of the beam loading compensation is in a preliminary stage. More complete modelling is needed, but we do not foresee any fundamental difficulties. For Run IIb specification of the longitudinal emittance of coalesced bunches is 2.0 eVsec, which has not yet been achieved. The Run IIb proton bunch intensities have nearly been achieved, and we recommend gaining as much operational experience at high intensities as possible.

The Debuncher ring has known aperture limitations that are believed to limit antiproton intensity. A program of alignment and removal of aperture limitations to address this problem was outlined during this review. Completion of this work is necessary to meet ultimate Run IIa and Run IIb goals. It was noted that the momentum cooling is an order of magnitude slower than calculated, and that the equilibrium longitudinal emittance is larger. This results in a slower cycle time, because it takes longer for the Accumulator ring longitudinal cooling to clear the beam from the deposition orbit. A plan for improvement of the Debuncher cooling was not described in this review, but was noted as a high-priority item for Run IIb.

The Accumulator ring functions well, but is known to have an unidentified source of transverse heating of the core that must be reduced to meet the $L = 5 \times 10^{31} cm^{-2} sec^{-1}$ peak luminosity goal and later the Run IIa and IIb goals. This heating may be due to a resonant mode in the stack-tail kicker or due to an instability created by unfavorable chromaticity of the core. We urge that the origin of the resonant mode in the kicker be systematically investigated, including modeling and computation. An Accumulator core cooling upgrade to a 3-band system was described, and we urge that sufficient engineering and technical support be provided to accomplish this goal by mid-2002.

There is a significant (30 to 40%) loss of antiprotons between the Main Injector and the TEVATRON. It is not known whether these losses occur in the transfer line or during the first few turns in the TEVATRON.

<u>Recommendation</u>: We recommend a systematic investigation of orbits, betatron phases, beta functions and dispersion, similar to that of the successful investigation of the AP1/AP3 line, to determine the likely aperture limitations.

<u>Recommendation:</u> We recommend a re-examination of the diagnostic system needs throughout the accelerator complex, so that orbit and emittance measurements can be made at all relevant locations.

5. RF Manipulations, Slip Stacking, Coalescing

The progress in this area has been continuous and very impressive as evidenced by the recent production intensities close to the values required for Run IIa in the main injector after coalescing. This could not be demonstrated on a regular basis yet but should be operational within the next few weeks. As an outstanding issue it was reported that so far the longitudinal emittance of the proton beam is of the order 4 eVsec while the required value is more like 2 eVsec. A more recent measurement showed that this is achievable but the combination of the higher intensity and the small longitudinal emittance is expected to be demonstrated within the next weeks. Whether this has impact on beam loss observed during injection into the TEVATRON needs to be seen.

Slip stacking has been intensively simulated and has also been demonstrated. For the simulation it was reported that so far an idealized Q of zero for the cavity has been used which might neglect issues related to the presently foreseen beam loading compensation scheme. The present system uses a local beam loading compensation feedback loop with a loop gain of 25 dB. Under present operating conditions this seems to work fine. For the final intensity required for run IIb, it was pointed out that beam loading compensation is absolutely required for stability and the loop gain would have to be increased. Modeling of the beam loading compensation is in a preliminary stage. More complete modeling may be needed, but we do not foresee fundamental difficulties.

For the RF systems most of the required hardware is installed. Most of the future studies aimed to demonstrate technical feasibility may be performed parasitically which allows for significant study time. It was reported that in the main injector a 7.5 MHz system has to be built and installed over the coming year.

Recommendations:
While the intensities and necessary RF manipulations and hardware modifications for Run IIa have been basically commissioned and shown to be functional for Coalescing as well as for Slip Stacking. In order to make the systems operational an attempt should be made to run the systems on a more regular base.

For Run IIb the present RF system is expected to be capable of handling the required intensities. In order to ensure functionality in a timely manner, the lead engineer will need the support of 6 FTE years over the next 2 years as presently foreseen. This includes support from experienced staff. For the beam loading compensation test that are ongoing the effort is actually smaller but continuous and should continue in a parasitic mode.

The committee takes note that the workload of the RF design team is focusing on beam loading compensation for Run IIa and is now starting to get more involved in Run IIb issues is quite large. While the installation of the hardware and the initial testing has to be done by the lead engineer and the development team, commissioning of the system and bringing it up to full operational capability could benefit from stronger accelerator physics involvement during dedicated study times.

6. Lithium Lens Improvement and the Transport Lines (AP2)

The present status of the Lithium lens operation was presented together with the history of the lenses that have been used in the target station so far. It is apparent the lifetime significantly varies and that reliable operation at this time can only be guaranteed if operated at a gradient of 7.5 T/cm. There are two lenses available today and two more are in production at this time. In parallel two development efforts are going on. The first one focuses on the improvement of the solid lithium lens design and the second one aims to develop a liquid lithium lens in collaboration with BINP. The development of the solid lens has made use of extensive simulation to ensure that the stress and electromagnetic interaction issues are understood. This has lead to a significantly increased understanding of the lithium–titanium interaction as well as heating issues, crack development, lithium separation and fatigue behavior.

For the Liquid Lithium lens effort it was reported that, while the supporting systems for the lithium lens seem to work appropriately, the lens itself has not been operated reliably even at values that have been achieved already with the solid lens. In order to make use of this development, the whole effort has to be transferred to FNAL and the liquid lens has to be integrated into the present target station. It therefore appears necessary that within the next few months crucial milestones need to be achieved to ensure the usefulness of the liquid lens project for Run IIb.

For Run IIa antiproton production rates seem sufficient. However reliability of the presently foreseen lenses is an issue. The upgrade of the Lithium Lens and the AP2 line promise the biggest improvements factor of (2-2.7) in antiproton flux for Run IIb. At this point it is not clear to the committee whether the increase in flux can be achieved by increasing the aperture in the AP2 line and the Debuncher (15 to 40 π) or by increasing the lens gradient (7.5 to 10 T/cm) or a combination of both.

Recommendations:
The efficiency of antiproton production is sufficient for Run IIa. The committee endorses the production of more lenses in a timely manner to ensure availability as several lenses have shown high infant mortality and the present production rate could threaten continuity of operation if this would happen again.

Run IIb requires a much more elaborate plan to ensure the factor of 2-2.7 in antiproton production rate. We strongly recommend that a plan be developed and presented to the Run IIB coordinator to address the question of lithium lens gradient versus AP2-line aperture increase. The optimum choice for the upgrade as well as the benefits from the different upgrade paths will very much depend on the outcome of this experimental program.

Before the planned upgrade programs in the AP2 line and the Debuncher can be started, some further analysis should be carried out. It is crucial to delegate at this time significant resources for investigating the required hardware changes, for supporting the survey and alignment plan, and for developing a plan for performing the beam based alignment that was in the presentation. This is a typical accelerator physics task and should be supported with appropriate manpower.

The lens development plan presents a very interesting technological advance and additional expertise in the laboratory should be consulted while continuing the present R&D plan. In case the increase in lens gradient turns out to be the more promising of the upgrade schemes, we endorse the construction and fatigue testing of several lenses per year to allow for several iteration cycles on the design as soon as possible. Technical suggestions for improvement include the development of a scheme, in which the pre-load is kept constant during the life of the lens by monitoring and controlling during operation, and possibly by applying external high pressure.

Also, it would be desirable to measure the impedance (voltage drop) across the lens during operation, although it is understood that this is a difficult measurement. While the first proposal aims to ensure that lithium separation be prevented over the life of the lens, the second proposal aims to give indication of any performance degradation.

7. Recycler Performance

The Recycler ring performance is a critical element for achieving the Run II luminosity. It is necessary to achieve a luminosity in excess of $L=5x10^{31}cm^{-2}sec^{-1}$ for Run IIa. In addition, it is required for Run IIb in conjunction with the electron cooling.

While there are many other issues that need to be addressed for achieving a luminosity of $L=5x10^{31}cm^{-2}sec^{-1}$, it is very important that steady progress be made on understanding and resolving the Recycler ring problems. The committee believes that the Recycler needs to perform reliably already during Run IIa to ensure that the future electron cooling upgrade can be integrated smoothly.

The history of the Recycler is well known at Fermilab. Prior to the shutdown there were many problems including efficiency, poor lifetime, small aperture, beta beating, alignment problems and vacuum issues.

During this review we learned about recent progress in addressing each of the issues above. It appears that progress has been good since the improvement in the accelerator alignment. The lattice is now well understood. There is a carefully considered plan to improve the vacuum in the Recycler to allow it to meet Run II goals for emittance growth and lifetime. We congratulate the Recycler group on its excellent progress.

We note that antiprotons are needed to fully test the rather complex stochastic cooling in the Recycler.

Recommendation: We recommend that antiprotons should be made available well in advance of Run IIa Recycler operation.

8. Electron Cooling

The electron cooling experiment has shown significant progress since it was last presented to the committee. The achievements included the installation and initial testing of the accelerator, the building and testing of two prototype cooling solenoid magnets, the construction of 12 solenoids with magnetic shielding. Beam transport has been studied with a transport model that includes space charge and angular momentum. A system for precise alignment and tuning of the magnetic field has been built and tested.

This is an ambitious project with important impact on Run 2b performance. Major issues have been identified and a plan for commissioning the system was presented. The committee notes that the schedule is tight, and includes both building an initial beam line and then moving the apparatus to a new building and installing it in the ring. Over the next year the debugging beam line needs to be built and tested.

We note that the electron accelerator is operated at high-voltage and current. Stable operation at the design parameters is one of the R&D issues being faced.

Recommendation: The committee encourages the continuation of the ongoing testing at high-voltage/current to reduce risk of failures.

9. Stochastic Cooling Upgrade

It seems that the primary limitation for the present luminosity is the large emittance of the antiprotons. This appears to have been caused by an effective reduction of about a factor of 2 in the core emittance cooling applied in the accumulator. In order to address this issue there are plans to identify and hopefully eliminate the heating sources. In addition there are plans to implement a new three bands system similar to the Debuncher system. We believe that this will probably be a critical system for increasing the luminosity. If all heating sources were identified and eliminated, it might not be necessary, but this may be probably too optimistic. Therefore the three bands system will be a definite improvement.

In the longer range, stochastic cooling of the Recycler will be developed so that this will take some pressure off the core system in the accumulator. However it may take some time to gain experience with stochastic cooling.

The committee learned about a resonance problem in the stack-tail kicker. It was found that the stack-tail kickers have a resonance at 3.2 GHz, which dominates the transverse kicks at present. While microwave absorbers have been installed into the kicker chamber near the electrode to suppress the resonance, the resonance was still found in the kick response.

Stack-tail kickers have a certain amount of transverse kick due to imperfections, which heat the core of the accumulator beam. In Run-I, they were compensated with wide-band transverse “delta” kickers. However, in Run-II, this transverse kick is dominated by a microwave mode at 3.2 GHz, thus the delta kickers scheme may not be adopted.

Recommendations:
To address this issue, we would like to recommend the following steps.

1. We encourage determining the origin of the 3.2 GHz resonance in the kicker chamber by using 3D computer codes like MAFIA or Microwave Office.
2. Since the kicker has a periodic structure in the longitudinal direction, the analysis may proceed by dividing the electrode into small pieces, simulating these small pieces first, then extending the study to a wider area, and finally to the whole kicker chamber. This approach may provide better understanding of mode and the physical origin of the resonance in the kicker tank, and potentially to provide also the cure.
3. To cure the resonance structure, it is essential to electrically short the resonance circuit or loop first. If this is not practically possible, the microwave absorber may be mounted at the location where the EM energy is concentrated. A material with characteristic microwave impedance matched to the resonance structure will provide best solution.

4. We would like to suggest additional manpower be allocated to pursue these studies. This type of the analysis will provide better understanding on the electromagnetic interactions between the high frequency kicker structure and the proton/anti-proton beams, and could be beneficial for other design works on stochastic cooling. The solution of this problem will be very important for upgrading the machine to the Run-IIb.

In parallel to this analysis, we suggest to evaluate the possibility of applying a filter circuit to the kicker amplifier to compensate the resonance.

10. Accelerator R&D

The committee takes note of the wide spectrum of efforts at FERMILAB in R&D for future accelerators. While it is clearly premature to issue definitive comments we offer the following preliminary and incomplete remarks:

The serious effort to understand TESLA cost estimates and to work out a comparison cost table (between the US and EU accounts) is to be encouraged especially in view of the possible "globalization" of this large accelerator project.

The studies for the industrialization of NLC accelerating structures and the studies on the site and infrastructure, in view of the possible placement of NLC in Illinois, is encouraged.

The Proton Driver proposal is an interesting option, which should be kept open at this point. It would be an original contribution of FERMILAB in the field of hadron-accelerators. It offers both new challenges in RF linear acceleration as well as exploitation of the laboratory's special expertise such as cryogenics. It should be noted that a Proton Driver not only opens the way to a neutrino factory but may also benefit the TEVATRON luminosity.

Fermilab is one of the main contributors to Neutrino Factory research in the US. It supports theory, simulation and the muon cooling experimental program, and also participates in ongoing efforts towards the development of an international cooling experiment. This activity should be continued.

The superconducting magnet program is very important for FERMILAB and the HEP community and should be preserved to pursue the VLHC studies, an original contribution of FERMILAB to the accelerator community. The high field magnet program may need careful review in future also in view of the possible extension of the US-CERN collaboration for LHC luminosity upgrade studies. The low field program, again another original contribution of FERMILAB, is going to be terminated. We recommend that, since all hardware has been designed, purchased and delivered the performance of the prototype should be seriously investigated, including cryogenic testing and measurement of magnetic performance.

11. Dates for the next Meeting

The tentative date for next AAC meeting is May 13-15, 2002.

APPENDIX

Charge (Rev. 15-Nov-01)

The December 2001 meeting of the Fermilab Accelerator Advisory Committee (AAC) will focus on the status of the Tevatron Collider Run II startup and the planning for Collider Run IIB. The AAC is asked to review the status of preparations and plans, to comment on their appropriateness, and to recommend the next steps, if any, in the following areas:

- **Run II Startup.** The committee is asked to review and comment on the commissioning/startup activities related to Tevatron Collider Run II. In particular we would like an assessment of the potential for achievement of a luminosity of approximately 5×10^{31} $cm^{-2}sec^{-1}$ in the Tevatron over the next six months, identification of potential impediments, and any suggestions the committee might have on overcoming such impediments.
- **Run IIB Planning and Preparations**. The committee is asked to review and comment on planning and preparations for Run IIB as described in the Run IIB Technical Design Report and in the presentations at the committee meeting. We are requesting specific comments from the committee on: 1)the adequacy of the plan in supporting Run IIB performance goals (~15 fb^{-1} delivered to each collider detector by the end of 2007); 2)areas of technical risk or uncertainty and their potential impact on performance goals; 3)accelerator or theoretical studies that could be undertaken to further characterize areas of uncertainty/risk; 4)alternative implementations that could minimize uncertainty/risk; and 5)the adequacy of the assigned resources to accomplish this task.

The AAC will also be presented with a short status report on R&D relating to our efforts on muons, VLHC, and linear colliders. This presentation is intended to be primarily informative and as such no specific comments are solicited at this time. However, any comments the committee might wish to make are welcome.

It is requested that a concise report responsive to this charge be forwarded to the Fermilab Director by January 15, 2002

AAC Agenda

December 12-14
Revision 15-November-2001

Wednesday, December 12

8:30Executive Session (Willeke)
8:45 Welcome and Presentation of Charge (Holmes)

Run II Startup and Commissioning
9:00 Summary of Run IIA Commissioning and Schedule for the Next Year (Church)
9:25 Antiproton Source Performance and Plans (McGinnis)
9:50 Main Injector Performance and Plans (Kourbanis)

10:15 Break

10:30 Tevatron Performance and Plans (Martens)
11:00 Recycler Performance and Plans (Mishra)
11:30 Discussion

12:00 Lunch

Run IIB Planning and Preparations
1:00 Run IIB Overview (McGinnis)
1:30 Slip Stacking (Steimel)
2:00 Antiproton Collection (Lebedev)

2:30 Break

2:45 Lithium Lens Upgrade (Morgan)
3:15 AP2 & Debuncher Aperture (Gollwitzer)

3:45 Break

4:00 Accumulator Stochastic Cooling (Derwent)
4:30 Recycler Electron Cooling (Nagaitsev)

5:00 Executive Session
Requests for supplementary or breakout presentations on Thursday
7:00 Dinner

Thursday, December 13

Run IIB (continued)

8:30 Antiproton Transfers (Lebedev)
9:00 Tevatron Electron Lens (Shiltsev)
9:30 Run IIB Schedule and Cost (Montgomery)
10:00 Discussion
10:30 Break

Future Accelerator R&D

10:45 Overview of Future Accelerator R&D Activities (Holmes)
11:30 Discussion
12:00 Lunch

1:00 Supplementary presentations and/or breakout discussions as requested by the committee.
Committee Executive Session

Friday, December 14

8:30 Committee Executive Session
12:00 Working Lunch
1:00 Closeout