October 22, 2002

Fermilab Accelerator Advisory Committee

Fourth Meeting: May 21-22, 2001

Committee Report

The fourth meeting of the Fermilab Accelerator Advisory Committee took place on May 21 and 22, 2001. The Committee members in attendance were V. Balakin, J.-P. Delahaye, G. Dugan (Chair), M. Harrison, C. Leeman, T. Shintake, J. Seeman, F. Willeke, and J. Wurtele. The charge to the committee for this meeting, and the agenda for the meeting, are included as appendices to this report.

At this meeting, the focus of the presentations was on two recently completed studies related to Fermilab's long range future. The committee heard presentations summarizing the study of a new proton driver for Fermilab, and a study of a staged Very Large Hadron Collider (VLHC) for the Fermilab site. The committee was also presented with brief reports on the status of electron cooling, the plans for Run IIB, and accelerator R&D in support of a linear collider and a muon collider/neutrino source.

The following sections present the committee's responses to each item in the charge, followed by some brief comments on items not expressly addressed in the charge.

Charge Item #1: Proton Driver Study

Proton Driver Study. *The committee is asked to review and comment on the recently completed Proton Driver Design Study. In particular we would like input with regard to the extent to which the committee feels the study establishes a technical basis for the performance goals established for the study and identifies the required R&D that would support moving towards such a facility. We are also interested in comments on the potential application of ideas generated through the study to the improvement of performance in the existing complex.*

SUMMARY

The committee felt that the proton driver study was complete and comprehensive. The committee did not find any major issues not covered. However, several ad hoc assumptions should be backed up with calculations-(e.g, the tracking tune shift requirement, the magnet field quality specifications, the beam loss budgets, and the vacuum specification).

The committee suggested that an 8 GeV or 12 GeV ring, vs. a 16 GeV ring running at 12 GeV, would be a better use of resources in the short term. Such a machine could be upgradeable to a 4 MW proton driver if and when needed, by coupling, for example, to a downstream FFAG.

The committee noted that the remote handling design needs to be done in more depth. Also, in the absence of a beam dump, it was unclear to the committee what happens to the accelerated beam during commissioning, or when the downstream machines are not operating.

The committee supports the general program of developing components through tests in Booster: this seems like a very good approach. The committee also encourages the following R&D that would benefit current operations:

- Linac improvements, ion source and front end especially.
- Booster RF improvements (cavity apertures);
- Inductive insert in the Booster.

If construction of the machine proceeds, the committee suggested that the primary R&D task would be an integrated half-cell test of prototype magnets: dipole, quad, corrector and power systems, running at 15 Hz.

DETAILED COMMENTS

The committee appreciates the hard work of the proton driver team. The proton driver study was comprehensive and professional. There were no significant areas that the committee felt were overlooked. The importance of an upgrade path that does not interfere with ongoing Run IIA or Run IIB operations has been recognized and addressed.

The Booster is a limiting factor in the proton production rate, and its replacement and/or upgrades will benefit existing operations. The study identified numerous components for upgrading as well as the benefits associated with individual upgrades. The committee believes that work that benefits existing operations need not wait until a future decision on a neutrino factory is made. This upgrade work includes improvements to the frontend systems (linac, ion source), booster RF improvements (cavity apertures) and inductive inserts. These efforts are strongly supported by the committee.

The allowable tune shift from the dipole/quad tracking error is estimated to be 0.01. This is an important tolerance since it covers an area of technical complexity and hence could be a significant cost driver. It was not obvious to the committee how this 0.01 limit was derived. Several of the other technical specifications (e.g., for the magnetic field quality, and for the required beam vacuum) seemed to be presented in a somewhat arbitrary fashion.

The allowable beam loss levels were set at 10% at injection energies and 1% at high field. While these levels do not look unreasonable, they will require remote handling of the elements in the collimation regions. There has not be any real attempt to understand the implications, both technical and costs, of remote handling.

Probably the most general technical issue related to potential performance problems is related to the rapid ramping nature of the machine. This manifests itself in issues such as tracking of the various magnetic elements, eddy currents, and power supply complexity. An R&D goal of a "cell test" is the recommended method of demonstrating real progress in these areas.

The upgrade to a high-intensity, multi-megawatt driver requires further theory and experimental R&D and the committee recommends that this research be ongoing. The study of intensity-dependent effects, especially for the 4 MW driver, should be further pursued.

One of the strategic issues requiring further examination is the choice of upgrade path towards a 4 MW driver. The overall goal of a high-average power driver of 4 MW is likely desirable for a future neutrino factory upgrade. An initial neutrino factory would, according to present thinking, require 1 MW. The committee is not convinced of the wisdom of the strategy adopted for the beam power upgrade. Two stages are foreseen, progressing from 1MW to 4 MW by increasing the Booster energy from 12 GeV to 16 GeV, and the number of protons accelerated per cycle from $3x10^{13}$ to $1x10^{14}$. Indeed, this strategy makes the first stage, with a large Booster circumference, not optimum and more expensive than necessary. In addition, the Booster and the Transfer Lines must be equipped with components compatible with a 16 GeV operation when operated at 12 GeV.

Considering the uncertainty about the second phase mainly related to a Muon Collider, the committee recommends optimizing each phase separately with components designed and used at their optimum. The committee suggests studying alternative schemes where, for example, the beam power upgrade in the second phase is provided by an additional ring based on the recently proposed Fixed Field Alternating Gradient (FFAG) scheme, boosting the beam energy by a factor 3 to 4. Such a method, if confirmed by the experimental ring presently under construction in Japan, could become mature if and when requested by a Muon Collider. It would enable efficient acceleration of the Booster beam with a high duty factor without the technological complications due to a fast cycling rate. For the sake of economy, the Booster energy in the first phase could then be reduced from 12 to 8 GeV; the loss in beam power could possibly be compensated by an increased number of accelerated protons per cycle.

Charge Item #2: VLHC Study

VLHC Study*. The committee is asked to review and comment on the recently completed VLHC study. We are particularly interested in comments and opinions regarding the identification of performance-critical subsystems in the study, the R&D program that is motivated by the study, and the next steps.*

SUMMARY

The committee thought that the study was an excellent job, especially considering the limited amount of time in which it was done. Given the brief amount of time afforded for consideration at this review, it was difficult for the committee to assess critically the comprehensiveness of the study or the cost driver analysis. A more thorough, longer review, focused only on the study and the cost analysis, is recommended.

As the next step for design evolution, now that the cost and performance tradeoffs are better understood, the committee encourages a parametric study to focus on optimizing the ring size, and the energy of both stages (with some physics input, at least for the first stage energy). This effort may be started at Snowmass. This parametric study may give some guidance for the range of magnetic fields for a high field VLHC, and it may also help establish cost goals for the high field magnet.

The committee encourages the following R&D items, in the two general categories of R&D for cost and risk reduction, and R&D for performance enhancement:

Cost and risk reduction R&D:

- Continued R&D on Nb_3Sn based high field magnets (short prototypes), with a design guided by the cost goal noted above.
- A program of tunneling R&D, aimed at cost reduction, perhaps as part of a CRADA with industry.
- Continued R&D on low field magnets: long magnet fabrication and measurement, and a half-cell string test.

Performance enhancement R&D:

- Instabilities and feedback systems, particularly for the low field design.
- IR design and power handling for both stages.
- Heating mechanisms (e.g., diffusion) in the high field design.
- Mechanisms for dealing with synchrotron radiation power in the high field design.

DETAILED COMMENTS

The committee acknowledges the progress of the design study for a Staged Very Large Hadron Collider (VLHC) made in collaboration between BNL, Fermilab, the Laboratory of Nuclear Studies (LNS) at Cornell University, and LBNL, under the leadership of P. Limon. A very complete report has been completed in about six months and delivered in May , 2001 as requested in November 2000 by the Fermilab management. A review of the study by an ad-hoc committee was held on April 30 and May 1 at Fermilab already.

The committee was impressed by the quality of the work done in a so short an amount of time. The committee was presented with a fairly comprehensive design study that is based on a 230 km long accelerator tunnel. It learned that the cost of the VLHC would most likely be dominated strongly by the cost of the accelerator tunnel. The design is based on the goal to reach the highest possible beam energy. The size of the tunnel is then given by the maximum field strength that is believed to be achievable and feasible using advanced superconducting magnet technology and feasible amount of cooling power for removing the synchrotron radiation power from the beam pipe inside the superconducting magnets. It is further based on the assumption that the synchrotron radiation will be absorbed inside the superconducting magnets at temperatures that are significantly lower than room temperature. Novel ideas to absorb the synchrotron radiation power at room temperature inside the magnets have been presented. The study demonstrated the feasibility of such a project, with attractive performance, and pointed out the various technology or beam dynamics related limitations in performance as well as the main cost drivers of both stages.

The committee endorses the general design philosophy to go for the highest possible energy. It believes that the presented overall parameters of the VLHC complex are a good starting point for optimizing performance, construction costs and operating costs of the facility. The committee believes that the main lattice design parameters should not be driven by the low-field magnet design but must be optimized for the final high-energy lattice. The circumference and the ultimate energy of the VLHC should remain an open parameter at this stage of the study.

The committee feels that serious efforts have to continue to balance magnet costs and technical risks against operating power expenses and tunnel construction cost. Now that the performance limitations and main cost drivers are better understood, the committee suggests a parametric study optimizing both stages in terms of ring circumference, colliding beam energy and luminosity. If possible, the energy of the first stage should be defined from physics or technological considerations, while the energy of the second phase should be maximized as much as possible, as it would become the future high energy frontier for many years. This parametric study should continue and intensity the search for alternative ways of dealing with the deposition of synchrotron radiation power.

This parametric study would be extremely useful to better define a coherent program of R&D addressing on one hand the components responsible for cost and risk drivers, and on the other hand the components responsible for limitation of performances. In order to focus the R&D effort, the main parameters of these components should be clearly identified, particularly the optimum magnetic field of the high field magnets. The expensive R&D of VLHC components, especially the high field superconducting magnets, should be based on boundary conditions that are as close as possible to a realistic design.

As the cost of the first phase is mainly defined by the cost of the tunnel, it is recommended to derive a target cost of tunnel construction per meter as an objective for tunneling technology development. Also as the cost of the second phase is mainly defined by the cost of the magnets, it is recommended to derive a target cost of integrated magnetic field as an objective for high field magnet development.

Concerning the components responsible for cost and risk drivers, the committee encourages R&D on:

- High field magnets based on Nb_3Sn technology with the required performance and a cost aimed at the target defined above.
- Tunnel technology cost reduction in view of the target defined above (possibly in collaboration with industry or other projects).
- Low field magnets with the required performance and the lowest possible cost as possible.

Concerning components responsible for performance limitations, the committee encourages R&D on:

- Instabilities and feedback systems, particularly for the low field design.
- IR design and power handling for both stages.
- Heating mechanisms (e.g., diffusion) in the high field design.

- Mechanisms for dealing with synchrotron radiation power in the high field design.

Finally, the committee recommends that Fermilab become the world-wide leader both on low cost/low-field super-ferric magnets and on high field magnets based on Nb_3Sn technology. Such a technology is indeed very promising not only for the VLHC but also for special applications like the high field quadrupole of the low beta insertion for the LHC luminosity improvement.

Comments on other items, not explicitly addressed in the charge.

The neutrino source work, although going slowly due to funding limitations, is nevertheless leveraged well with university collaborations. A good example is the development of the absorber test stand at Fermilab

Development of the electron cooling system for the Recycler appears to be going well. The committee suggests that the proponents should think a bit more about diagnostics to measure beam properties (e.g., the momentum spread of the cold electron beam)

The committee endorses the main goals of Fermilab concerning Linear Colliders, as presented by S.Holmes at the meeting. These include:

- Participation in the NLC R&D effort focusing on linac technologies.
- Exploration of opportunities for new contributions to the TESLA R&D program.
- Becoming informed on the various possible technologies for linear colliders.
- Assessing the viability of Fermilab as a potential site for linear colliders.

The committee encourages this increasing engagement in a broad range of linear collider activities.

The committee applauds the increased planning, prioritization, and documentation of the work for Run IIB.

The committee continues to be concerned about the Recycler and the recycling (deceleration). Run 2A is not yet fully "in the bag". A study/workshop with outside experts is suggested if the emittance growth problems in the Recycler remain unresolved.

Appendix 1: <u>Charge (Rev.10-Apr-01)</u>

The May 2001 meeting of the Fermilab Accelerator Advisory Committee (AAC) will focus on the recently completed Proton Driver and VLHC studies. In addition short status reports on activities related to electron cooling, Run IIB planning, muon cooling, and linear colliders will be presented.

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:

- **Proton Driver Study.** The committee is asked to review and comment on the recently completed Proton Driver Design Study. In particular we would like input with regard to the extent to which the committee feels the study establishes a technical basis for the performance goals established for the study and identifies the required R&D that would support moving towards such a facility. We are also interested in comments on the potential application of ideas generated through the study to the improvement of performance in the existing complex.
- **VLHC Study**. The committee is asked to review and comment on the recently completed VLHC study. We are particularly interested in comments and opinions regarding the identification of performance-critical subsystems in the study, the R&D program that is motivated by the study, and the next steps.

The AAC will also be presented with short status reports on planning for Run IIB and on R&D relating to our efforts on electron cooling, muons, and linear colliders. These presentations are 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 June 22, 2001.

Appendix 2: AAC Agenda

May 21-22, 2001

Revision 7-Apr-01

Monday May 21

8:30 Executive Session (Dugan)

8:45 Welcome. Presentation of charge (Holmes/10 minutes)

Proton Driver Study (Chou)

9:00 Overview & Lattice (Chou/35 minutes)

9:45 RF (Griffin/15 minutes)

10:05 Break

10:25 Magnets (Ostiguy/10 minutes)

10:40 Power Supply (Jach/10 minutes)

10:55 Vacuum (Anderson/10 minutes)

11:10 Injection & Collimation (Drozhdin/10 minutes)

11:25 Beam loss and Shielding (Mokhov/10 minutes)

11:40 Linac Improvements (Young/10 minutes)

11:55 Discussion

12:15 Lunch

VLHC Study (Limon)

1:15 Introduction & Overview (Limon/15 minutes)

1:35 Accelerator Physics (Syphers/25 minutes)

2:05 Magnets (Strait/15 minutes)

2:25 Break

2:45 Accelerator Systems (Foster/20 minutes)

3:10 Civil Construction (Garbincius/25 minutes)

3:40 Cost Drivers (Kerby/15 minutes)

4:00 Stage 2 Challenges and R&D Projections (Limon/20 minutes)

4:20 Discussion

Status Reports (Other R&D)

4:30 Electron Cooling (Chemiakine/30 minutes)

5:00 Executive Session

7:00 Dinner

Tuesday, May 22

Status Reports (Other R&D)

8:30 Muons (Geer/30 minutes)

9:05 Linear Collider (Holmes/40 minutes)

9:50 Run IIB (McGinnis/40 minutes)

10:35 Discussion

11:00 Break

11:30 Executive Session

12:00 Working Lunch

1:00 Executive Session

3:00 Closeout (Dugan/60 minutes)