Physics Advisory Committee

April 12-14, 2002

Recommendations and Comments

Run II

The Committee heard reports from the CDF and D0 experiments and from the Beams Division on the progress of the Tevatron Run II. The Committee was pleased to see that the two detectors are now almost completely operational and have begun to produce physics results. Both detectors have new capabilities with respect to Run I. The Committee hopes that, by this summer, the experiments will show new physics results based on the first year's data.

The Committee shares the concern of the Laboratory and other members of the community that the luminosity in Run II has not yet reached the levels attained in Run I. The Committee heard an illuminating report on the progress of the Run II luminosity. A number of problems with the Tevatron performance have been identified and solved, although many more problems remain. In addition the recent experience cautions that there might be further bottlenecks that can restrict the luminosity gains that will be available from the steps in the plan that leads to Run IIb. The Committee supports the efforts of the Director to treat the Tevatron accelerator project as a long-term campaign and to manage it systematically.

The Laboratory must continue to place the Tevatron accelerator project as its highest priority, higher even than the Tevatron experiments. The Committee supports the Director in continuing to divert resources and personnel from within the Laboratory, actively recruit staff, and invite participation from other laboratories and universities to the Tevatron project as necessary for its success. The Committee applauds the efforts that Tevatron experimenters (including BTeV collaborators) have given thus far. More is needed. The Beams Division should identify useful instrumentation and simulation projects in which new workers can become engaged. This larger intellectual participation in the Run II accelerator project will pay off in the long run.

E-918 - BTeV (Butler/Stone)

BTeV is a proposed experiment to study mixing, CP violation, and rare decays in beauty and charm particles at the Tevatron in the LHC era. In June 2000, the Director approved the experiment, in accordance with the Physics Advisory Committee recommendations formulated during the week-long Aspen meeting. Since that time, the financial environment has deteriorated. In January

2002, the final report of the HEPAP Subpanel for Long-Range Planning in High Energy Physics (J. Bagger and B. Barish, co-chairs) stated

> *"The BTeV project cannot be funded with the scope and timetable originally envisaged. The collaboration and Fermilab are considering revised plans that, if approved by the Fermilab PAC, should be brought to P5 for evaluation later this year."*

Indeed, the BTeV collaboration has responded with a descoping plan that the Committee finds to be well thought out and that preserves the key features that motivated the initial approval in 2000. After reviewing the revised proposal and re-evaluating the experiment in light of additional information that has emerged in the last two years, the Committee once again recommends Stage I approval for BTeV. Although the composition of the committee has changed substantially since 2000, this recommendation is again unanimous.

BTeV will have a very broad particle physics program, including charm physics, but the primary motivation is the search for new physics through CP violation. The CP violation in the Standard Model is insufficient to explain the matter-antimatter asymmetry of the universe, so this new physics must exist. In this decade, we have an opportunity to thoroughly probe for it in the B meson systems. As discussed in more detail below, BTeV would be unique in having all of the following four key features needed for a definitive mapping of CP violation in the B meson system:

1) A pixel vertex detector that, in addition to providing extremely high quality information offline, is used by the Level 1 trigger to select events with detached vertices. Combined with the high-throughput data acquisition system, this will allow the accumulation of an unbiased, extremely rich sample of events.

2) A particle identification system that will allow identification of kaons and pions, essential to CP violation studies.

3) A high-resolution crystal electromagnetic calorimeter that enables precision study of events containing photons, neutral pions, and etas, including several modes that provide clear tests of Standard Model CP violation.

4) High-rate production of both B_d and B_s mesons, each of which will allow studies of CP violation beyond the capabilities of BaBar and Belle.

By performing these studies at an existing accelerator, BTeV will exploit the large investment that our nation will have made in the Tevatron over two decades.

In the following paragraphs, we review the physics case for BTeV, note the impressive technical progress that the BTeV collaboration has made since its initial approval, and discuss the priority of BTeV within the laboratory program.

The BTeV Physics Case

Tremendous progress has been made in flavor physics since BTeV received Stage I approval in June 2000, and more is anticipated in the next few years. BaBar and Belle have now observed CP violation in B decays and have already measured sin2β at the 10% level. It is likely that BaBar and Belle will each accumulate in excess of 500 fb^{-1} over the next five to six years, allowing them to make very precise measurements of sin2β and other Standard Model parameters. Among these is a precise measurement of V_{ub}. This parameter, now known to 20%, should soon be measured to 10%, dominated by theoretical uncertainty. At Fermilab, both CDF and D0 should be able to measure B_s mixing in the near future, or to show that the mixing parameter is outside the Standard Model expectation. These three measurements, taken together, will provide a precision check of the CKM model of CP violation.

At the same time, more information about quark mixing angles and CP violation is within reach. The Committee finds that the current BTeV proposal is compelling as a next-generation B experiment that will measure a number of additional angles and CP asymmetries. These measurements could complete the confirmation of the CKM picture, or they could provide evidence for new sources of CP violation from beyond the Standard Model.

Particularly striking features of the BTeV program are theoretically clean measurements of the CKM angles α and γ. BTeV can also measure the CP angle χ, effectively the phase angle of the B_s mixing matrix. In one year at full performance, BTeV can measure α to ~4 degrees in $B \rightarrow \rho\pi$ and γ to ~8 degrees in $B_s \rightarrow D_sK$. BTeV should also be able to measure χ to 1 degree in $B_s \rightarrow J/\psi\eta$. Each measurement allows a new and stringent test of the CKM model. The Committee notes that definitive measurements of these angles are unlikely to be achieved at e^+e^- B factories or at CDF and D0, even with the large data sets that are expected. Obtaining a large number of independent, theoretically clean measurements is especially important if the predictions of the CKM model are violated. From knowledge of all four angles α, β, γ, and χ, it is possible to diagnose whether violations of the CKM predictions come from new contributions to B_d or B_s mixing or from new tree-level diagrams due to, for example, an extended Higgs sector. BTeV will also carry out a broad program of measurements in rare B_d and B_s decays that will complement the search for new physics via precision CKM tests.

BTeV will run in the same era as LHCb, and so it is appropriate to ask what capabilities BTeV will add to those of LHCb. LHCb starts with a larger B production cross section and a higher ratio of this cross section to the total cross section. However, BTeV has a superior trigger which roughly compensates this advantage. LHCb can make the measurement of γ described above with a comparable sensitivity, but, because it does not have the excellent electromagnetic calorimeter proposed for BTeV, it cannot compete on B decays with neutrals such as $B \rightarrow \rho\pi$ and $B_s \rightarrow J/\psi\eta$ which give BTeV precise α and χ measurements.

In more general terms, LHCb uses a conventional trigger which concentrates on specific low-multiplicity B decay modes, while BTeV has designed and prototyped an ambitious trigger that will use B decay displaced vertices as its primary criterion. This capability, together with BTeV's excellent electromagnetic calorimetry and particle ID and enormous yields, will allow this experiment to study a broad array of B and B_s decays. BTeV has a broader physics reach than LHCb and should provide definitive measurements of CKM parameters and the most sensitive tests for new physics in the flavor sector.

Modifications to BTeV Since 2000 Approval

BTeV presented an updated technical proposal with a description of a descoped experiment and an update on technical progress. In the revised configuration, the full magnet and vertex detector will be installed, but only one arm will be instrumented with the downstream tracking system, RICH, calorimeter and muon system. The full trigger electronics and computing are maintained. In principle, the loss of the second arm lowers the acceptance and hence the statistics by a factor of two. However, the retention of the full trigger system allows more sophisticated algorithms and thus recovers about 15% of the loss. In addition, the new proposal advocates using the RICH to identify wide-angle leptons; this increases the lepton acceptance substantially. Further cost savings are proposed from recycling the beamline elements from one of the existing interaction regions instead of constructing new final-focus and tune-matching quads and electrostatic separators.

Simulations of the RICH beyond those in the 2000 proposal showed that K/p separation at momenta below 9 GeV/c would not be possible due to pattern recognition problems in separating the faint aerogel rings from the more intense rings from the gas radiator. BTeV proposes to replace the aerogel with a liquid C_5F_{12} radiator, which has the added advantage of producing Cherenkov light at large angle, away from the gas radiator photons, allowing an independent detector using standard photomultiplier tubes.

Detector Development Since 2000 Approval

The collaboration has made significant progress in detector R&D since the 2000 proposal. Pixel sensors were tested in 1999 and achieved the required 5-10 micron resolution. Radiation tolerant 0.25μ CMOS readout electronics have now been beam tested. A system test of the integrated sensor/readout system is planned for the 2002 Fermilab test beam run. The Level 1 trigger has been implemented on FPGA/DSPs, and simulation and timing studies on real devices have been done. General purpose CPUs are also being explored as an alternative to DSPs. The 2000 proposal used a custom network in the DAQ. The collaboration now plans to use several smaller commercial switches, substantially reducing the technical risk.

The BTeV trigger project was considered interesting by the NSF IT research program and has attracted a $5M grant on "Real-Time Embedded Systems." This is a collaboration with computer scientists interested in the construction of fault-tolerant dynamic data systems for a wide variety of applications.

Prototypes of the silicon-strip forward-tracking sensors, based on the CMS design, are being bench tested. Full-length prototypes of the straw tubes exist and are scheduled for beam tests in 2002. The Hybrid Photo-Diode (HPD) used to read out the RICH has been developed, is being bench-tested now, and awaits a beam test next year. Prototype calorimeter lead tungstate crystals have been procured from Bogoroditsk and two vendors in China. Beam tests of a 5x5 array were done at Protvino in 2001 and achieved resolutions of 0.7% at 10 GeV. The support system has been redesigned with significant cost savings. Full "planks" of muon drift tubes will be beam tested this summer.

In summary, full scale prototypes of most detector systems exist and will be beam tested by the end of the year. Though the BTeV detector is a significant technical challenge, the excellent progress in detector R&D enhances the Committee's confidence concerning the technical implementation of the project.

Priorities and Schedule Constraints

In reaffirming our recommendation for Stage I approval, the Committee also reaffirms its view of the priority of BTeV within the Laboratory program as stated in the recommendations from the June 2000 PAC Meeting:

> *"The Committee had extensive discussions of the impact of BTeV on the ability of the Laboratory to carry out the other parts of its physics program. The Committee reiterates that the highest priority of the Laboratory in the coming decade is Run II of the Tevatron, and the most exciting goal of this program is the discovery of the Higgs boson or other new physics. For this, it is essential*

that the CDF and D0 collaborations write to tape the highest possible integrated luminosity. The Laboratory's efforts to develop, construct and install BTeV absolutely must not be allowed to interfere with the discovery potential of Run II. The Committee also reiterates the importance of the NuMI/MINOS program, which should continue to be supported as planned."

The diversion of resources away from BTeV is a direct result of those priorities.

In June 2001, the Laboratory also granted Stage I approval to the CKM experiment. The Committee's June 2001 report stated:

"In judging relative priorities after Run II, the Committee rated CKM behind the physics programs of MINOS and BTeV. Noting that both these experiments have competition from others, CKM must not prevent MINOS and BTeV from reaching their physics goals in a timely fashion."

This assessment of the priority remains the position of the Committee, and such a priority constrains the schedule of BTeV's construction and running. The Laboratory's projections show that the first large increment of construction funding can come no earlier than FY2005, after NuMI construction ramps down and the Run IIb detector upgrades near completion. The BTeV collaboration presented a construction schedule, with a funding profile consistent with the Laboratory's projections, that indicated completion in FY2008. It is possible that Run IIb may continue beyond this date, and BTeV can expect no significant luminosity before Run IIb ends. This delay would be exacerbated by the time to move the interaction-region optics and might put BTeV at an initial disadvantage with respect to LHCb. While BTeV can commission many of its subsystems with beam halo on a wire target as they are installed, the Committee encourages, as resources allow, the search for an interaction-region option that would avoid these further delays of BTeV.

This timeframe for BTeV brings up another issue of priority. The U.S. high-energy physics community proposes to take part in an international effort to build a Linear Collider, and the Laboratory has proposed that Fermilab be considered as a possible U.S. site for this facility. The Committee believes that having the LC at Fermilab would be of great benefit to science, our field, and our national program. The Committee recommends approval of BTeV with the understanding that it must not, and with the belief that it will not, adversely affect the prospects for the LC project.

Run IIb Upgrades P-924 CDF (Bedeschi/Goshaw) P-925 D0 (Weerts/Womersley)

Overall Comments

The Committee was impressed with the progress made by CDF and D0 since the November PAC meeting. The dialogue between the collaborations and the recently formed Technical Review Committee (TRC) provided a forum to explore the most urgent cost, schedule, manpower, and technical issues. The report of the committee offered numerous recommendations, to which the collaborations have recently provided written responses, and as a result of which some design changes have been adopted. Despite these encouraging signs, the Committee remains seriously concerned by the scope of challenges that remain and the difficulty posed by the as-yet unresolved tension between the simultaneous demands of physics performance, resource limitations, and schedule. The Laboratory and the two collaborations *must work hand-in-hand* to maximize the combined potential for discovery of new physics in Run IIb by optimizing the use of constrained Laboratory resources, both manpower and financial.

At the Aspen meeting in June, the Committee will reconvene to consider a recommendation for Stage I approval of the upgrade projects. This process will require new or refined information on various aspects of the proposed upgrades, which will be noted in the paragraphs that follow. More broadly, in presentations at the Aspen meeting, the Committee would like to hear from each collaboration a critical evaluation of progress with respect to plans that were presented at the November 2001 PAC. In the case of the additional CDF upgrade components whose inclusion in the scope is most in question, this discussion should include latest feasible dates for a decision on implementation. Above all, the Committee will be looking to see the Laboratory and the collaborations converge on a baseline plan that is shown quantitatively to be consistent with the primary physics goals.

The Committee is encouraged that the projects are moving toward Stage I approval and baselining this summer. The Committee would appreciate an overview of the high-level project milestones for all items of the upgrade projects at the Aspen meeting.

The Technical Review Committee

The Committee commends the work of the Run IIb Upgrade Technical Review Committee (TRC), chaired by Jim Pilcher. The TRC held its first meeting in December, and in its report made several specific suggestions for design changes and additional studies. The Committee requests that the TRC now consider in detail the CDF and D0 responses to its report and provide a preliminary assessment for the Aspen meeting in June. Additionally, the Committee requests that the TRC

provide input on the components of the CDF upgrade plan that have been added since the December review. That input, along with detailed reports from the upcoming Director's Cost and Schedule Review, will be extremely valuable for the Committee's consideration of Stage I approval at our meeting in Aspen.

The Silicon Upgrades

For both CDF and D0, the silicon tracker upgrades are essential to the ultimate success of the physics program and are the schedule and cost drivers for the Run IIb upgrade projects. Both experiments have made significant progress in optimizing the design of their silicon trackers since the November PAC meeting.

CDF

Following the TRC review, the CDF collaboration has made a number of changes to their silicon detector design, specifically the elimination of 90-degree stereo layers and the adoption of the outer-layer stave design for Layer 1. These have resulted in significant simplifications for the project, improved pattern recognition, and very clear benefits to the cost and schedule. They have also altered their sensor specification to reduce sensor costs by 15-20%, streamlined the mechanical design, and transferred more QC/QA steps to the vendor to reduce assembly time. The Committee strongly commends these positive steps.

D0

The Committee notes that D0 has moved forward in several areas, including design of almost all components, procurement of prototype sensors, cables, hybrids, and other key items, R&D on flex cables, and mechanical design and prototyping of the inner two layers. The collaboration's response to the TRC report was restrained, however, and included many items that were identified as "works in progress." The Committee looks forward to seeing at Aspen the results of several investigations that are under way or being planned.

Both

The collaborations have assessed a number of descoping options. For example, the effect of eliminating a silicon layer was presented by both collaborations in terms of b-tagging efficiency, which directly impacts Higgs sensitivity. The CDF upgrade TDR showed that elimination of an outer layer, which would result in a significant reduction of 27-30% in the number of staves, would reduce b-tagging efficiency by 4% relative to the efficiency with all layers. This increases to 13% if the inner COT layers are dead*. The D0 presentation

* The CDF study was performed using the Run I silicon geometry.

showed that eliminating Layer 4, which would result in a significant cost reduction of $1.15M, would reduce double b-tag efficiency by 12-14% relative to the efficiency with all layers.

In light of remaining shortfalls in resources and the extremely tight construction schedule, and in order to retain nearly the full scope of their proposed upgrades, the collaborations should continue to search for cost reductions and for simplifications that would shorten construction time. Estimates of potential cost savings, time savings, and effects on Higgs sensitivity should be quantitative. The justifications to retain scope may include redundancy arguments; however, these arguments should be quantitative, in terms of the usual Higgs metric.

The Committee notes the delay incurred in the submission of the first prototype SVX4 chip, and will look forward to an update on the status of this part of the project at Aspen. The Committee also notes that both collaborations have rejected the TRC's suggestion to use edge alignment during ladder production; the Committee accepts this conclusion.

Non-silicon Upgrades

In anticipation of higher rates and occupancies in the Run IIb era, both experiments are proposing upgrades to their Trigger and Data Acquisition systems, and CDF has introduced for consideration some further detector upgrades.

CDF

The Committee was shown a number of new requests for upgrades in CDF, including EM calorimeter timing, Level 1 and Level 2 Trigger upgrades, and DAQ upgrades. Quantitative evaluation of the impact of these proposed upgrades on Higgs sensitivity and SUSY searches should be presented at Aspen. In addition, the collaboration should specify for each upgrade component the latest date for a decision on whether or not to implement that upgrade.

1. *EM Calorimeter Timing*. This would allow suppression of out-of-time hits that can contribute to backgrounds in exotics searches involving photons, and rough estimates suggest the suppression could be as much as an order of magnitude. Caution is warranted in making changes to the phototube bases, but the Committee was pleased to hear that the bases have been handled recently without any damage. Options such as splitting anode signals are still being evaluated and might provide an even less invasive course of action. Overall cost of this upgrade is modest, and the Committee notes that the funds are proposed to come from university grants and INFN. Possibilities for further simplification through ganging of channels should be investigated.

2. *3D XFT.* Inclusion of stereo information in the Level 1 tracking trigger may allow the Level 1 trigger to be more selective and more robust with respect to chamber occupancy. The project is relatively non-invasive, but is the most expensive of the new proposals. The Committee looks forward to seeing a quantitative assessment of impact on Higgs sensitivity presented at the Aspen meeting.

3. *Level 2 Speed.* The Level 2 trigger has a number of vulnerabilities that could be addressed in a modestly priced upgrade. These include remaining problems with the Magic Bus, obsolete processors, and maintenance and possible unreliability of interface boards. It is not clear yet if any of these will be a limiting factor, but there may well exist a need for greater bandwidth, selectivity, or both. The collaboration plans more studies to clarify the needs and the options.

4. *TDC Bandwidth.* Inadequate bandwidth in the TDCs may be a DAQ bottleneck limiting readout rate to 300Hz. Operational experience will be important in evaluating the need for partial TDC replacement, and the Committee requests the collaboration to provide a specific plan and proposed timetable for this upgrade at the Aspen meeting.

Beyond these additions, the Committee was reminded of the proposals for the Central PreRadiator upgrade and the Event Builder upgrade. Slow response in the current gas chamber preradiator will integrate over four beam crossings in Run IIb, severely degrading its performance. The replacement device would use scintillator and optical fiber with phototube readout, with about half the cost proposed to be borne by collaborators. In the case of the Event Builder, a new ATM switch is proposed to increase the throughput from 16MB/s to 64MB/s.

D0

For D0, trigger upgrades are essential to the ultimate success of the D0 Run IIb physics program. Proposed upgrades are:

1. *Level 1 Trigger.* The sum of projected Level 1 output rates at Run IIb luminosities for four example physics channels was shown to be 77kHz, well in excess of the 5kHz input capacity of Level 2. Proposed upgrades include a tracking trigger upgrade (narrowing roads from double to single fibers), a calorimeter trigger upgrade (involving signal filtering to reduce pile up and clustering to sharpen energy thresholds), and higher resolution calorimeter-track matching. In combination these should bring the Level 1 output rate for the four example channels down to 3.7kHz; no one trigger improvement alone

suffices to reach this level. While the calorimeter trigger is the most costly component of this package, experimenters argued that the more sophisticated cluster calculation gains a factor of three rejection for constant efficiency when compared against a simple alternative of raising tower thresholds. The Committee, in concurrence with the TRC, judges an upgrade of the Level 1 trigger to be essential and looks forward to progress reports at Aspen.

2. *Level 2 Trigger*. The collaboration proposes an upgrade of processors for Level 2, and an upgrade of the Silicon Track Trigger to take full advantage of the expanded silicon detector. The latter is expected to permit a sharper momentum threshold and a lower fake rate. The Committee was not shown details, however, and looks forward to more complete presentations at Aspen, notably on progress in understanding whether the more limited STT upgrade option will be adequate.

3. *Other*. DAQ upgrade and SIFT chip replacements were not discussed at this meeting.

Committee requests to CDF and D0

1. Overview of high-level project milestones.

2. Progress with respect to plans and milestones presented at November 2001 PAC.

3. Dates for decision to implement/descope trigger modifications.

4. Report on cost-reduction/simplification efforts for silicon detectors.

5. CDF: Quantitative evaluation of trigger modifications, individually and in combination, in terms of Higgs sensitivity. Studies of options to reduce the cost of the EM Timing project.

   D0: Detailed evaluation of Silicon Track Trigger update options.

Committee requests to Technical Review Committee

1. Preliminary assessment of CDF and D0 responses to TRC report.

2. Input on CDF upgrade components added since December.