Physics Advisory Committee

June 18-22, 2000

To make a prairie it takes a clover and one bee,
One clover, and a bee,
And revery.
The revery alone will do,
If bees are few.

- Emily Dickinson

General Comments and Recommendations

Scientific Priorities

Since the Aspen meeting one year ago, there has been a traumatic but necessary rescheduling of the start of the Run II Collider program. The report presented to the Committee this year, a summary of the recent DOE Project Reviews (Lehman Reviews) of CDF and D0, indicated that the commitment of both the experiments and the Laboratory to the new schedule has made it a realistic one, and the Committee applauds all concerned for the progress in the past year.

With the indirect experimental indications of a light mass for the Higgs boson holding firm and no hint of the Higgs at LEP, the physics situation reinforces the fact that the mounting of Run II must remain the highest priority of the Laboratory. This means not only that nothing must interfere with the March 2001 roll-in of the detectors for data-taking, but that, with that milestone accomplished, the Laboratory must give highest priority to the development of the accelerator upgrades necessary for Run IIb, the steps taken to maximize the collider luminosity in the period before the LHC experiments are running. The Committee heard a report on the recent Run II Physics Workshop, which emphasized that the Tevatron Run II program has the potential to make thrilling discoveries, but that every increment of integrated luminosity improves the likelihood of such discoveries. The emphasis on integrated luminosity means that the focus must be not only on accelerator technology, but also on management of schedules and shutdowns.

The second important goal of the Laboratory remains accelerator-based neutrino oscillation experiments. Two neutrino experiments are currently under construction, each with a new neutrino beam. MINOS, a long-baseline experiment using the NuMI beam, is scheduled to first take data in 2003, and MiniBooNE, a short-baseline experiment, is scheduled to first take data at the end of 2001. This is an exciting physics program, and the Committee encourages the Laboratory to do what it can to maintain these schedules, consistent with the high priority granted to Run II.

Another high-priority activity at Fermilab must continue to be accelerator R&D directed toward a future high-energy facility in the United States. Fermilab is now engaged in research for all three likely contenders: a linear electron-positron collider, a muon storage ring for a neutrino factory or a muon collider, and a very large hadron collider. Fermilab participation, including specific working-group reports commissioned by the Laboratory, has been very useful in clarifying the status and promise of these projects.

As construction for the NuMI project ramps down in 2003-4, the Laboratory should have the opportunity for a new initiative. This will be an important time of transition for Fermilab – it seems unlikely that we will be ready, either technologically or politically, for the construction start on a new accelerator, and Fermilab must be in a position to produce physics results of the highest quality. The major focus of the Committee's discussions at Aspen was BTeV. This project is currently in an R&D phase, and the BTeV collaboration submitted a proposal for a staged construction of the experiment that could be run in this era.

P-918 - BTeV (Butler/Stone)

The BTeV collaboration proposes an ambitious program of measurements with a new detector at the C0 intersection region of the Tevatron Collider, the main focus being the study of CP violation using B and B_s mesons. Noting the extensive array of running and approved B experiments, the Committee set a very high threshold for approval of BTeV, requiring that it be competitive with all these experiments and superior to all in at least a few key measurements.

The Committee has spent a large part of its effort over the past three years on the consideration of the BTeV experiment. For the final phase of its consideration, the Committee received in May the formal BTeV proposal. The Committee also received detailed evaluations from the Laboratory of the overall BTeV cost and manpower requirements, the technical feasibility of the BTeV trigger, the requirements for the C0 interaction region, and the overall picture of Laboratory resources. The Committee is grateful to the Laboratory for providing us with these very useful studies. Based on all of this information, the Committee has come to the following conclusions:

1. The physics of CP violation in the B system will still be compelling when BTeV runs, with important measurements still needed to test our theories of its origin.

2. BTeV has proposed a very powerful detector. Its pixel-based tracker, detached-vertex Level 1 trigger, RICH particle ID system, and lead tungstate electromagnetic calorimeter make it capable of measuring the full suite of CP violation parameters in the B system. BTeV's physics reach exceeds that of all other experiments in some of these important measurements.

3. The BTeV collaboration has done excellent work in developing advanced technologies needed to make the experiment possible, and in deploying the simulation and analysis tools needed to make its physics case.

These conclusions are documented in a longer section at the end of this report.

The Committee believes that BTeV has the potential to be a central part of an excellent Fermilab physics program in the era of the LHC. With excitement about the science and enthusiasm for the elegant and challenging detector, the Committee unanimously recommends Stage I approval for BTeV.

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.

In a period in which significant material and intellectual resources will be dedicated to the accelerator upgrades needed for Run IIb and to accelerator R&D for long-term projects, the construction, installation and commissioning of a new interaction region at C0 would be an additional burden. The Committee therefore urges the Laboratory to manage this aspect of the mounting and startup of BTeV with utmost care. The Committee recognizes that the details of how this is best done will depend on the circumstances of Run II as they develop and believes that no specific commitments can be made at this time concerning the data-taking schedule of BTeV. The Committee stresses that all decisions about the use of the Tevatron in this period must reflect the unambiguous priority of maximizing the physics discovery potential of Run II.

Future Options

The Committee considered many aspects of the scientific direction of high-energy physics and the facilities needed to further research in the field. The Committee heard presentations on the potential physics program at a neutrino factory based on a muon storage ring and at a linear e^+e^- collider, as well as reports on accelerator R&D for the neutrino factory, the NLC, and superconducting magnets for a VLHC. In addition the Committee heard a very informative report from Gerry Dugan, chair of the Accelerator Advisory Committee. Finally, the Committee and laboratory management had an open and wide-ranging discussion of the future, stimulated by comments from the Director.

The Committee has found the reports on the neutrino factory and its physics program very helpful in clarifying the potential and difficulties of such a facility. It looks forward to learning of new developments. The Committee notes that a study of the physics case for linear colliders is underway at Fermilab and would like a report on its findings at a future meeting.

As Fermilab deliberates on the long-term future, its users will have much to say. The Committee strongly encourages the user community to involve itself in the question of what Fermilab should be doing ten years from now, and the Laboratory should find ways to stimulate such a discussion. Finally, there is great concern about how the field as a whole communicates its progress and aspirations to the public, and the Committee requests a structured discussion of the issue at a future PAC meeting.

CDF/D0 Initial Plans for Run IIb

The CDF and D0 collaborations have begun to develop plans for the replacement of radiation-damaged silicon detectors and other upgrades to ensure effective operation during the high-luminosity Tevatron Run IIb. The Committee welcomes these efforts, and looks forward to presentations of the detailed plans at the fall meeting.

Achieving the physics goals of the Tevatron collider program before LHC turn-on is the Laboratory's highest priority. Careful planning and oversight of the detector upgrade projects, and close coordination of these with accelerator upgrade projects, will be essential for success. It is therefore imperative that the scope of the upgrades be defined very soon, that the plans require limited R&D with realistic goals, and that the necessary downtime for installation and commissioning be minimized.

P-919 (Green) CMS Tracker

The Committee heard a presentation of the proposed US and Fermilab role in constructing an expanded silicon tracking system for the CMS detector. The collaboration decided in December 1999 to adopt an all-silicon design for its tracking system, including the outer tracker. The TDR Addendum describing this modification was approved by the LHCC in May 2000. A consortium of Fermilab and US-university-based physicists has proposed an expanded role in the CMS tracker group, with principal responsibility for the Tracker Outer Barrel (TOB). This device consists of six layers of 500 μm-thick silicon sensors, including three double layers. The US group would also be responsible for installation of these modules on their "rod" support structures, as well as for assembly of support structures for the inner barrel. The schedule for the project is for TOB preproduction to begin in Fall 2000, with module production completed by Fall 2003. The Committee will make its recommendation in the fall, after US CMS is re-baselined.

P-916 (Bedeschi/Goshaw)

The Committee recommends Stage I approval for P-916, "Study of Hard Diffraction and Forward Physics" by the CDF collaboration. The studies of hard diffraction and rapidity gaps using the proposed detector would provide an interesting extension to the physics capabilities of the CDF detector and complement nicely the program of diffraction studies at D0. Continuous coverage in rapidity out to $|\eta|$ of 7.5 is a particular strength of the proposal. This approval should be subject to the condition that no engineering resources be diverted from baseline Run II preparations to this project.

P-907 (Raja)

The Committee heard a description of a revised P-907, "Proposal to Measure Particle Production." The Committee will not make a final recommendation on this proposal before the Fall 2000 PAC meeting.

Review of the BTeV Detector and Physics Program

Motivation and Main Goals of BTeV

The origin of CP violation will be one of the key issues in high-energy physics in this decade. A tremendous effort to measure the basic parameters of CP violation has already been started at the e^+e^- B-factory experiments (BaBar, Belle, and CLEO) and at hadron-machine experiments (CDF, D0, HERA-B). Over the next five years, these efforts will lead to many precise measurements of some of these parameters. The Committee believes, however, that the program of measuring a comprehensive set of CP asymmetries in the B_d and B_s systems will not be completed by these experiments. New experiments will be needed at the end of this decade to provide crucial pieces of information. BTeV has the potential to supply these missing pieces of information and could in fact be the definitive experiment that finally clarifies the picture of CP violation.

The BTeV experiment represents a major effort to exploit the enormous b-bbar cross section (100 μb) at the Tevatron, which yields $2x10^{11}$ b-bbar events per 10^7 s. Although the existing Tevatron experiments, CDF and D0, have significant capabilities for B physics, notably from silicon microstrip detectors and new, detached vertex triggers, the BTeV detector is optimized for b physics rather than for the study of high-P_t processes. It has sophisticated particle ID and photon-detection capabilities, as well as a pixel-based vertex detector/trigger system with pixels extending down to 6 mm from the beam axis. It is designed to record 1 kHz of b-bbar events and 1 kHz of c-cbar events, with a 4 kHz total event rate. BTeV's capabilities should give it a significantly greater B physics reach than either CDF or D0.

While the experiments at the e^+e^- B factories have some advantages for B_d studies, including very clean and kinematically constrained events, B_s mesons are not produced at the Υ(4S), and any B_s physics program at such experiments would be quite limited. In addition, the large rate of B_d production at the Tevatron, together with the capabilities of the BTeV detector, should allow it to perform measurements of B_d decays that are completely inaccessible or very difficult at the B factories.

The main goals of BTeV are:

- Tests of the standard-model and searches for new physics through the measurement of CP asymmetries with B and B_s decay modes that have minimal theoretical uncertainties. These measurements will allow the accurate determination of the angles α, γ, and χ, as well as improvement in the precision on β.

- Measurement of rare B and B_s decays to search for effects of new physics.

- Measurement of a broad range of B_s decays that become accessible with the particle ID and photon measurement capabilities of the BTeV detector.

The Committee notes that current knowledge of B_d meson decays is much more extensive than our knowledge of the B_s meson; this is a consequence primarily of a long program of high-statistics B_d measurements at the Υ(4S) and at the Z resonance.

The Committee's review of BTeV is divided into the following sections:

- Theoretical assessment of the BTeV physics case
- Summary of CP asymmetry measurements that will be performed before 2006
- The BTeV detector
- Comparison of the capabilities and physics reach of BTeV with LHCb
- Comments on BTeV simulations
- Conclusions

Theoretical Assessment

The subject of CP violation was opened by experimentalists in 1964 with the unexpected discovery of CP asymmetries in the neutral kaon system. The theoretical importance of CP violation was emphasized by Sakharov, who showed in 1967 that it was a necessary ingredient for the generation of a baryon-number asymmetry in the universe.

The CP asymmetries in the neutral kaon system, which are parametrized by the quantity $\varepsilon \sim 10^{-3}$, did not pin down the origin of the effect; instead, they were interpreted phenomenologically in terms of interference between complex amplitudes that arise in K^0-K^0bar mixing. Kobayashi and Maskawa pointed out that, with three quark generations, CP violation can potentially arise in the standard model as a consequence of a single, CP-violating phase in what is now called the Cabibbo-Kobayashi-Maskawa quark-mixing matrix. Although important progress in CP violation studies has been made using neutral kaon decays, notably in the measurement of direct CP violation in $K \rightarrow \pi\pi$ decays, these measurements have not been sufficiently constraining to determine whether CP violation originates entirely within the standard-model framework of the CKM quark-mixing matrix, or whether CP-violating phases introduced by new physics outside this framework play a significant role in either K or B decays.

The standard-model CKM framework predicts very large (order unity) CP asymmetries in certain B and B_s decays, and the discovery of CP violation in the B system may well occur within the next year. This would start a new era in our understanding of CP violation. It is not obvious, however, how far this program needs to be taken. We consider below the ways in which new physics might affect such measurements and how we can pin down these possibilities in a systematic manner.

The parameters describing CP violation include the magnitudes and phases of weak-interaction couplings of quarks and the magnitudes and phases of the loop diagrams that contribute to meson mixing amplitudes. We are especially interested in quantities that can be (eventually) extracted from measurements with little or no theoretical uncertainty. These are first the phase angles extracted from time-dependent CP asymmetries,

β_d : measured from $B_d \rightarrow J/\psi K_s$
α_d : measured from $B_d \rightarrow \rho\pi$ (time-dependent Dalitz-plot analysis)
γ_s : measured from $B_s \rightarrow D_s K$ (four time-dependent rates)
χ_s from $B_s \rightarrow J/\psi\eta$, $J/\psi\eta'$, or $J/\psi\phi$
γ_A from $B_u \rightarrow DK$,

where we have used subscripts on the conventional angles to indicate the source of the measurement. Also accessible are the magnitudes extracted from weak interaction rates and mixings:

$|V_{ub}|$ measured from $B \rightarrow \pi l\nu$, $B \rightarrow \rho l\nu$, $B \rightarrow X_u l\nu$
$|V_{cb}|$ measured from $B \rightarrow D^* l\nu$, $B \rightarrow X_c l\nu$
$|V_{td}|$ measured from B_d mixing
$|V_{ts}|$ measured from B_s mixing.

In all cases, the parameters are extracted assuming that the standard CKM model of CP violation is correct. We can then test for non-standard effects by asking whether the CKM model relations of these parameters are satisfied.

To demonstrate the importance of a comprehensive set of measurements, we consider the (plausible) scenario in which tree-level weak interactions are described by the CKM model, but new physics appears in loop diagrams contributing to B_d and B_s mixing. The new contributions potentially affect both the magnitudes and the phases of the mixing amplitudes. We use the standard phase convention for the CKM matrix, in which γ measures the angle of the line from the origin to the apex of the unitarity triangle. The length of this side is $|V_{ub}|/\lambda|V_{cb}|$, where $\lambda = \sin\theta_c$, and the angle is given by

$$\gamma_{SM} = \pi - \beta_d - \alpha_d = \gamma_s - \chi_s = \gamma_A,$$

where the SM indicates that this γ is the angle associated with tree-level processes. Under our assumption that new physics contributes only to loops, γ_{SM} is the "true angle" of the CKM matrix derived from tree-level weak interactions, even in the presence of new physics contributing to the mixing amplitudes. The base of the triangle has length unity, so the angle (γ_{SM}) and length ($V_{ub}/\lambda V_{cb}$) of this side fully specify the standard-model triangle, which we call the reference triangle. The equality of these three expressions for γ_{SM} is a test of our hypothesis that new physics enters only in the mixing amplitudes. Each expression contains at least one angle that will be difficult to measure in the first-round B-factory experiments: α_d, γ_s, χ_s, and γ_A.

Given the reference triangle, the remaining quantities can be interpreted simply. A deviation of β_d indicates a nonstandard contribution to the phase of the B_d mixing amplitude. A deviation of γ_s (or a value of χ_s larger than a few degrees) indicates a nonstandard contribution to the phase of the B_s mixing amplitude. A deviation of $|V_{td}/V_{ts}|$ signals a deviation of the magnitude of one of the mixing amplitudes, which can be assigned to one amplitude or the other (or both) by comparing the mixing rates to standard-model predictions.

Without the reference triangle, the interpretations of the CP-violating parameters can be confusing and ambiguous. In particular, it is not obvious how to assign a deviation from the standard-model relation of the parameters $|V_{ub}|$, $|V_{td}/V_{ts}|$, and β_d, which will be measured with good precision by the B-factory and Tevatron collider experiments in the next several years. And, even if these parameters obey the standard-model relation, it is possible for new physics to be hiding. One scenario in which this is likely is that in which new physics contributes to B_s but not B_d mixing. The standard-model contribution to B_s mixing is almost real, with a phase of order λ^2. A nonstandard model contribution could have a magnitude of order λ and a large phase. Then the overall magnitude of B_s mixing would not be shifted, while the phase would acquire a contribution of order λ~13 degrees. This contribution would be revealed only when χ_s or both γ_s and α_d are measured.

Only when the full set of parameters listed above are accurately measured can we be convinced either that the CKM model completely describes CP violation or that all the possible non-standard sources of CP violation have been probed. In the event of a disagreement with the standard relations, the full set of parameters is needed to unambiguously interpret this deviation.

The Program of CP Violation Measurements in the B System Before 2006

In the next few years, our knowledge of CP violation in the B meson system will improve dramatically:

- BaBar, Belle, CDF, D0, and HERA-B will measure β to high precision. By the end of 2006, BaBar may have as much as 500 fb^{-1} of integrated luminosity, and $\sin(2\beta)$ may be known with a statistical precision of ±0.01.

- CDF will measure the rate for B_s mixing, if it is in the range predicted by the Standard Model. This may be interpreted as the precise determination of $|V_{td}/V_{ts}|$ from the ratio of B_d to B_s mixing rates. The magnitudes of V_{td} and V_{ts} will be extracted from the individual mixing rates as lattice calculations for the relevant hadronic parameters improve.

- If current luminosity projections are correct, BaBar (and Belle) may obtain the significant information on $\sin(2\alpha)$ using $B \rightarrow \rho\pi$ or other modes. However, the measurements are extremely difficult, and more precision would likely be desirable.

- Information on γ could be available. However, measurements of γ from B branching fractions to hadronic final states (rather than from CP asymmetries) may suffer from large theoretical uncertainties. It is possible that information on γ may well be extracted from time-dependent asymmetry measurements of $B \rightarrow D^*\pi$. This measurement will be challenging, however, because one of the interfering diagrams has a very small amplitude, leading to a very small CP asymmetry.

It appears very unlikely that this program will yield a comprehensive set of time-dependent CP asymmetries in the B_s system. Although CDF will be able to measure the B_s mixing rate, current studies indicate that measurement of γ using $B_s \rightarrow D_sK$ will be difficult because the CDF particle ID system is not sufficiently powerful. Measurements in the B_s system will also be necessary to determine χ. In principle, χ can be extracted from the decay $B_s \rightarrow J/\psi\phi$, but this would require a helicity analysis (analogous to that needed to extract the angle β from $B \rightarrow J/\psi K^*$ rather than $B \rightarrow J/\psi K_s$). BTeV would be able to use its photon detection and particle ID capabilities to determine χ from the decays $B_s \rightarrow J/\psi\eta$ and $J/\psi\eta'$.

It must be emphasized that, given the large effort currently invested in B physics, it is difficult to predict the state of any particular measurement five to six years in the future. This is especially true for one as complicated as $B \rightarrow \rho\pi$. To our knowledge, *no experiment* has satisfactorily demonstrated its reach in α, allowing for the full range of theoretical complexities. Given the complexity and richness of the subject, we believe that decisive measurements will remain, especially involving the B_s meson. To pursue this physics program and to respond to interest in decay modes not currently fashionable, a detector with a very broad range of capabilities will be needed.

The BTeV Detector

The Committee is impressed with the high quality of the BTeV design as described in detail in the proposal, and congratulates the collaboration on the work performed since the last Aspen PAC meeting. This work resulted not only in a credible detector design, but also in a much improved evaluation of the physics capabilities. Furthermore, the collaboration prepared a cost estimate in great detail.

The Committee is very grateful for the impressive work done by a 32-person team to review the BTeV proposal cost. This team not only performed a detailed line-by-line cost assessment, but in the process evaluated the progress of technical R&D in order to assign contingency. The result was mainly to increase contingency for a number of items, and to flag certain items for particular attention. Many aspects of the detector design can be described as conceptually advanced with proof-of-principle existing as a result of either BTeV work or LHC work. However resources for detailed engineering have thus far been lacking for most systems; hence the increase in contingency.

The Committee is also very grateful for a presentation on the impact BTeV would have on the Computing Division and related work in the Particle Physics Division. This included an evaluation by four reviewers from the division.

The BTeV detector is optimized for b physics rather than for the study of high-P_t processes, and it is based on a two-arm geometry covering $1.9 < \eta < 4.5$, in both forward and backward regions. The goal of performing a broad range of time-dependent CP asymmetry measurements led to four essential features of the experiment:

- A state-of-the-art pixel vertexing system that is placed as close as possible to the beam axis. The detectors have a rectangular aperture for the beam that has a half-length of only 6 mm. The BTeV collaboration is exploring the idea of moving the pixel system even closer, which may be possible with newer, more radiation-hard detectors.

  The pixel system has undergone two prototype cycles by the BTeV collaboration which has led to a credible design related to the ATLAS pixel system, with modifications appropriate to BTeV.

- A first-level trigger system that uses information from the pixel detectors to recognize events with separated vertices, providing for a factor of 100 reduction in the inelastic rate with typical signal-mode efficiencies typically ranging from 50% to 74% for the key modes studied. The trigger system performs a rough momentum determination to eliminate low-momentum tracks that may have suffered large multiple scattering. The DAQ system for BTeV is also quite ambitious: it is designed to record 1 kHz of b events, as compared to 200 Hz for LHCb.

  The trigger system was evaluated not only by the cost assessment team, but also by an ad hoc committee. Again the Committee is grateful for the high quality of this assessment, which concluded that “fast and robust trigger algorithms should be achievable,” but that several issues “must be addressed before this is convincingly demonstrated.”

  The most critical need is for an increase in physics and engineering support. The Committee would expect that this support be marshalled by collaborating institutions, to augment the current effort which is dominated by Fermilab staff.

- A ring-imaging Cerenkov system to provide excellent K/π separation over the momentum range 3 GeV/c to 70 GeV/c. For the measurement of γ using the decay $B_s \rightarrow D_sK$, the dominant background is from $B_s \rightarrow D_s\pi$, which is expected to be ten times larger, so particle ID is essential.

- A lead-tungstate electromagnetic calorimeter with excellent photon detection capability. Because π^0s can be reconstructed with good efficiency and excellent mass resolution, this system substantially broadens the physics reach of the experiment. In particular it permits the measurement of the three $B \rightarrow \rho\pi$ modes and the measurement of the CP-asymmetry angle α. This quantity is extremely important, but it is possibly the most difficult to measure. The calorimeter also allows for the measurement of χ using $B_s \rightarrow J/\psi\eta$ and $B_s \rightarrow J/\psi\eta'$.

The calorimeter system has benefited from R&D by CMS and simulation packages adopted from other experiments. Mounting and procurement issues need to be addressed; an R&D program within BTeV is necessary.

The detector is built in two arms, doubling the efficiency with respect to a single-arm design. Because the b and bbar hadrons tend to be produced either both forward or both backward, however, tagging is not compromised if only one arm is installed initially. The measurement of the primary vertex is improved if both arms are present, because tracks from the underlying events go into both arms. The single-arm option may be especially relevant to staging considerations.

General Comparison with LHCb

Because BTeV would compete directly with LHCb, which will be operating at CERN in the same time frame, it is essential that BTeV be compared with that experiment. In fact, the June 1999 PAC recommendations included the statement: "The Committee would like to see a clear and convincing demonstration that BTeV has a physics reach superior to LHCb."

Table 1 summarizes some of the main features of the experimental environments of BTeV and LHCb. The b-bbar cross section at the LHC is five-times higher than at the Tevatron, due to the higher energy, and the ratio of the b-bbar to total inelastic cross section is about 2.5 times higher at the LHC. Furthermore, the number of interactions per beam crossing is lower at the LHC than at the Tevatron at the same luminosity, which simplifies vertexing and makes the events simpler to analyze overall.

Table 1: Cross Sections and Environments

	BTeV	LHC-B
Collision energy/type	2.0 TeV p-pbar	14.0 TeV pp
σ (b-bbar)	~100 μb	~500 μb
σ (c-cbar)	>500 μb	
$\sigma_{inelastic}$	~50 mb	~80 mb
σ (b-bbar) / $\sigma_{inelastic}$	0.2%	0.6%
L	2×10^{32} cm^{-2}s^{-1}	2×10^{32} cm^{-2}s^{-1}
# b-bbar events/10^7 s	2×10^{11}	1×10^{12}
DAQ: b event Rate	1000 Hz b-bbar, 1000 Hz c-cbar	200 Hz b-bbar
<interactions/crossing>	2	0.5
Bunch spacing	132 ns	25 ns
Luminous region: σ_z	30 cm	5 cm

$\langle P_b \rangle$	40 GeV/c	80 GeV/c
$(\langle P_b \rangle / m_B)\, c\tau_B$	3.6 mm	7 mm
L/σ_L	~35 (P_B > 20 GeV/c)	similar
P (B decay products)	<70 GeV/c	<140 GeV/c

The BTeV collaboration has designed an experiment that appears to have substantially offset the higher b-bbar cross section at the LHC. The key elements that allow BTeV to do this are:

- A gain in rate from building two arms instead of one. It is not feasible for LHCb to build two arms: as a consequence of the higher center-of-mass energy, the LHCb needs to be longer and much wider transverse to the beam than BTeV, so two arms would be prohibitively expensive. The relative geometrical acceptance of the two experiments is LHCb(one arm)/BTeV(two arm) = 0.6.

- A much more sophisticated trigger, which in BTeV processes information from a pixel vertex detector, rather than from a silicon-strip detector, as in LHCb. Due to the high bunch crossing frequency at LHC, LHCb uses a pretrigger before the vertex trigger that reduces the overall efficiency, giving a factor of two advantage to BTeV.

- A DAQ system that is designed to write 1 kHz of B events as compared to 200 Hz for LHCb. Although LHCb will trigger with good efficiency on many of the key modes, it appears that its trigger is much more selective and will therefore have a narrower coverage of B physics.

- A 30 cm long luminous region rather than 5 cm long at LHCb, reducing the difficulty of performing vertexing in the presence of multiple interactions.

- A $PbWO_4$ crystal electromagnetic calorimeter that is superior to the Pb-scintillator calorimeter of LHCb. It provides excellent photon energy resolution and π^0 mass resolution (2-5 MeV, depending on energy). It does very well in resolving photons from "merged" π^0s up to 60 GeV π^0 energy.

We have compared the physics reach of BTeV with that of LHCb for several key modes. The BTeV proposal states that BTeV will reconstruct 9400 (untagged) $B \rightarrow \rho^{+-}\pi^{-+}$ events per 10^7 s as compared with 2140 for LHCb, with S/B=4.1 as compared with 0.8 for LHCb. This mode is valuable for the determination of α. The calorimeter will also enable BTeV to perform superior measurements of $B_s \rightarrow J/\psi\eta$ and $B_s \rightarrow J/\psi\eta$, which are used to extract χ. BTeV has comparable or possibly better physics reach for $B_s \rightarrow D_sK$, which is used to determine γ. Of course, these are preliminary studies used in Technical Design Reports, but we believe that there is a good basis for concluding that BTeV will be competitive with LHCb and better in some significant respects.

The BTeV proposal also gives some comparisons with e^+e^-B factories for the decays $B \rightarrow \pi^+\pi^-$ and $B^+ \rightarrow D^0K^+$. For $B \rightarrow \pi^+\pi^-$, one expects about 13 tagged events/10^7 s at a B-factory

($3x10^{33}$ $cm^{-2}s^{-1}$ luminosity), while BTeV expects 2370 tagged events/10^7 s. For $B^+ \rightarrow D^0K^+$, the expectation for a B factory is 2 tagged events/10^7 s as compared with 300 events at BTeV.

The proper time resolution for LHCb and BTeV are very similar, around 45 fs, for most of the modes of interest.

The BTeV proposal contains only a brief section on the critical issue of b-flavor tagging. In the Committee's judgment, this area needs substantially more work, but the present results are adequate for the purposes of the PAC. The effective tagging efficiency is estimated to be εD^2=10%. A lower value is reported in the LHCb proposal (6.4%), but we are not able to judge whether this difference is actually meaningful. Comparisons between BTeV and LHCb that are made in the BTeV proposal use a common value of 10% for both experiments.

Comments on BTeV Simulations

The BTeV physics/performance studies are based on simulations using two packages: a fast Monte Carlo (MCFAST) and a GEANT3-based package (BTeVGeant). Overall, the collaboration has responded well to the Committee's June 1999 request that "Simulations used in detector-performance and physics-reach studies must be detailed and realistic, and they must include both physics and beam-related backgrounds, secondary interactions and decays, all significant environmental effects such as multiple interactions, and detector/electronics noise." The BTeVGeant simulation of critical modes ($B \rightarrow \rho\pi$, $B_s \rightarrow D_sK$) appears to have largely met this requirement, with one exception: backgrounds in the IR are not included. The proposal argues that, because the pixel-based trigger is so robust against noise hits, additional background is unlikely to result in significant problem. Nevertheless, the Committee believes that the collaboration should investigate these possible backgrounds, as well as those due to neutrons produced by hadronic interactions in the calorimeter.

At the request of the Committee, the BTeV collaboration also investigated the effect of degraded performance in the following areas:

- effect of loss of pixel efficiency on trigger performance
- effect of degraded decay-length resolution
- effect of lower photon yield from the RICH
- effect of degraded calorimeter energy resolution

The results from these studies appear to indicate that the detector performance is not excessively sensitive to any of these possible degradations.

Conclusions

Based on the capabilities of the detectors, and on the preliminary studies presented in the Technical Design Reports of BTeV and LHCb, the Committee believes that there are solid reasons for concluding that BTeV will be competitive with LHCb and superior in some significant respects. The BTeV Collaboration has conducted an impressive R&D program focusing on the systems at the heart of the experiment: the pixel-based vertex-detector system and the trigger. The collaboration has pursued a successful development program on the pixel sensors and readout chips, and impressive results have been obtained in a series of beam tests. The external review of the trigger, while noting the many challenges of this project, confirmed that the effort on this system has been extremely competent and effective. The detailed review of the BTeV cost estimate organized by Fermilab contributes greatly to our confidence in this estimate, within the modifications resulting from the review.

The Committee also concludes that BTeV will have a physics reach for CP violation studies that extends significantly beyond that of current experiments and those that will exist when BTeV runs. The Committee expects major progress from experiments at e^+e^- B-factory experiments over the next few years, and for certain quantities it is difficult to predict the physics reach of these experiments. However, due to BTeV's extremely high rate for recording b-bbar events, the importance of B_s decay modes, and the need for sophisticated particle ID and photon detection, the Committee believes that it will play an important and possibly even definitive role in clarifying the picture of CP violation.