December 23, 2005

P5 Report on Running of the Tevatron and PEP-II

Introduction and Executive Summary:

The charge to the P5 HEPAP subpanel asks the subpanel to examine the plan for continued running of the major accelerator facilities now operating. Current planning calls for the PEP-II B-factory at the Stanford Linear Accelerator Center to be operated until the end of FY2008 and the Tevatron collider at Fermilab through FY2009. We are asked to assess what factors or considerations might lead to stopping B-factory operations one year, or two years earlier than planned? When would we be in a position to make such a determination and what information would be needed? Similarly, for the Tevatron collider, what factors or considerations might lead to stopping operations one year, or two years earlier than now planned? What might lead to running longer than now planned? Again, when would we be in a position to make such a determination and what information would be needed? The ending of data taking with the Tevatron collider and PEP-II will make room for the funding of new initiatives. However it is also essential to fully exploit the discovery potential of these world-class facilities. Therefore it is crucial to evaluate when the significant resources now invested in the operation of these facilities will have a greater scientific impact if they were to be deployed otherwise.

The Tevatron collider and PEP-II accelerator are rapidly accumulating more data. The existing data sets will be doubled and then doubled again by the currently planned stopping dates. Each doubling of the data allows significantly more physics as both of these programs seek to discover how nature works at a deeper level. Early termination would reduce the physics that will come from these world-leading programs. **With the material presently before P5, we see no reason to terminate the operation of either the Tevatron or PEP-II earlier than planned. However we have not yet studied in detail other High-Energy Physics projects that could be started if funds were available. P5 will be looking at the full U.S. particle physics roadmap in 2006. We plan to revisit the issue of the last year of running for the Tevatron and PEP-II programs in the context of a full roadmap.** Input from a number of HEPAP subpanels presently looking at different aspects of the program will be an important component of our planning exercise in 2006.

P5 Process, Physics Summary, and Recommendation Details:
To provide a response to the charge we held three meetings to gather the appropriate information. The first meeting on September 8 and 9, near Washington D.C., provided an opportunity to hear from the DOE and the NSF about both our charge and budget constraints for the field, to hear about parts of the program other than the Tevatron collider and PEP-II, and to discuss issues related to addressing our charge. The other two meetings were at Fermilab on September 12 and 13 and at SLAC on October 6 and 7. At these meetings we heard about overall long-term laboratory plans, as well as the accelerator status, physics potential, and manpower and collaboration issues for the Tevatron collider and PEP-II, respectively. We also had the opportunity at each laboratory for discussion with members of the international teams involved in these experiments, the program leaders, and the laboratory management. The agendas for our three meetings are included in an appendix at the end of the report. For both the Tevatron and PEP-II programs we find that:

1) The physics collaborations are producing many front-line physics results and are exploring a window of opportunity to discover new physics. They are also functioning efficiently.
2) Competition between collaborations (CDF and D0 at the Tevatron and between BaBar and Belle) not only provides crosschecks of difficult measurements but also has led to novel analysis techniques and exploitation of new methods for making important measurements.
3) The accelerators are performing extraordinarily well and pushing the performance frontier with new ideas and techniques.
4) These programs provide models for international collaboration, including the sharing and integration of computing resources across continents.

We summarize our conclusions here and also present our major recommendations. The detailed findings from our meetings are presented after. The U.S. accelerator based program presently has world-leading facilities allowing the exploration of quark-flavor physics (PEP-II at SLAC and CLEO-c at Cornell), neutrino physics (Numi-Minos and MiniBooNE at Fermilab) and the energy frontier (Tevatron collider at Fermilab). These are the major U.S. data taking programs on the particle physics roadmap. Discoveries over the last decade have also opened up major new areas for scientific exploration: dark energy, dark matter, and a set of next generation issues in neutrino physics. Budget constraints create major problems in getting initiatives in these areas started. In addition, increases in funding for the International Linear Collider are required to perform the R&D needed to minimize cost and optimize performance and the expected start of operations of the Large Hadron Collider (LHC) at CERN in 2007 will present a major physics opportunity that needs strong support.

The present plan to run the Tevatron through 2009 and PEP-II through 2008 is a scientifically well motivated plan and we look forward to upcoming results that will provide broad and very precise tests of our picture of particles and their interactions as well as direct searches for new constituents of matter. We mention a few highlights here.

The Tevatron collider, with its continued position at the energy frontier, will remain for the next few years an excellent window onto possible new physics. With ever increasing luminosity, the CDF and D0 collaborations are the dominant experiments with the potential to discover new physics through direct searches. Well-motivated examples include Higgs bosons (key to the understanding of mass), supersymmetric particles (among them the lightest supersymmetric particle, which provides an attractive candidate for dark matter), new gauge bosons (which would signify entirely new interactions in nature), excited fermions (which would indicate a whole new layer of building blocks for matter), and signals for extra dimensions (which are predicted by string theory and could radically change our understanding of gravity). In addition, precise measurements of the top quark and W boson masses provide incisive tests and constraints on our picture of the electroweak interactions. Once we discover the source of electroweak symmetry breaking, for example Higgs bosons, the precision measurements will serve to constrain the physics picture needed to understand the new phenomena. Assuming that our simplest model is sufficient to describe the essentials of electroweak symmetry breaking, the latest values of the masses of the top quark and W boson point to a relatively light Higgs boson. The Tevatron also provides important measurements for the B_s system, where mixing and rare leptonic decays provide important tests of our understanding of flavor processes complementary to the B-factory measurements. With the data expected in the next few years, the B_s measurements will confront directly the Standard Model predictions, allowing searches for new physics contributions.

The PEP-II accelerator is routinely running at approximately five times the design averaged luminosity, allowing a much richer physics program for BaBar than originally planned. The BaBar collaboration is making world-leading measurements of the three angles of the unitarity triangle, in some cases using recently invented techniques, as well as the V_{cb} and V_{ub} CKM matrix elements. The complete set of measurements represent an unprecedented check of the coupling of quark-flavors to the *W* boson, parameterized in the Standard Model by the CKM matrix. These charged current couplings arise from electroweak symmetry breaking, as do the various quark masses. In addition, it has proven possible to do a broad set of measurements for processes where photons or gluons accompany transitions between the b quark and the strange or down quark. These transitions are between quarks that have different flavors but the same electric charge. Such transitions arise in the Standard Model only from rare virtual short-distance processes. Through the comparison to Standard Model predictions, these measurements both probe for new physics as well as serve to constrain any postulated new physics scenarios. At present several important measurements show deviations from their expected Standard Model values but require smaller errors to reach definitive conclusions. All of the most interesting PEP-II measurements are statistics limited and therefore increasing the total integrated luminosity will allow a much more definitive check of the physics. Running through 2007 is required to double the data taken through FY 05. Running through 2008 is required to make full usage of the machine improvements that are scheduled for the summer of 2006, allowing an additional 50% increase in integrated luminosity, resulting in a factor of four increase in integrated luminosity compared to the data sample presently analyzed.

The present review of the status of the Tevatron and PEP-II programs comes at a time when P5 has only a partial picture of the full particle physics roadmap. In many cases we are waiting for other HEPAP subpanels to make recommendations on the leading physics opportunities in given areas, for example in neutrino physics. Our goal in making the roadmap will be to chart the plan that can best answer the key questions regarding our quantum universe:

1) Are there undiscovered principles of nature:
   new symmetries, new physical laws?
2) How can we solve the mystery of dark energy?
3) Are there extra dimensions of space?
4) Do all the forces become one?

5) Why are there so many kinds of particles?
6) What is dark matter? How can we make it in the laboratory?
7) What are neutrinos telling us?
8) How did the universe come to be?
9) What happened to the antimatter?

The Tevatron and BaBar programs (to be followed by the LHC in a few years) are attacking questions 1, 3, 4, 5, 6, 8, and 9, either through direct measurements or the study of rare virtual processes. They are unique and crucial parts of the particle physics roadmap. **We therefore recommend the running of the Tevatron through 2008 and PEP-II through 2007 in any long-term scenario for the roadmap**. **The direct search for new physics at the energy frontier and the precise measurement of essential electroweak and flavor quantities at the Tevatron collider and the measurement of telling virtual processes enabled by the doubling of the present PEP-II data set are compelling reasons to continue running.**

We will be making a full roadmap later this fiscal year. We are deferring making final recommendations for the last year of running of the Tevatron and PEP-II facilities till after we can include the final year in a full updated roadmap. The question we propose looking at is the potential scientific impact of various options as well as the schedule and urgency for new initiatives. **We therefore recommend that P5 revisit the issue of the final year of running, in the context of a better-understood roadmap, in Spring 2006 for PEP-II and Spring 2007 for the Tevatron collider**. In addition to a better understanding of opportunities for new projects we propose looking at several issues for these programs that can be better evaluated at a future date.

These are, for the **Tevatron collider**:
The integrated and projected luminosity for this program, the status of the LHC, the manpower situation for the Tevatron program, the physics picture revealed by earlier Tevatron running, and any new physics results coming from other parts of the program. The issue of whether any running beyond 2009 is warranted should also be looked at.

For **PEP-II** the issues are:
The achieved and projected luminosity of both PEP-II and KEKB in Spring 2006 and the updated values for the key measurements planned by these

projects, in particular the status of the hint of New Physics in the CP asymmetries as measured in gluonic penguins.

In addition:
We strongly encourage the DOE to engage those agencies that fund the major non-US collaborating groups participating in the Tevatron and PEP-II programs in a discussion of issues and timetables for the running of these facilities. Lines of communication with these foreign funding agencies should be strengthened, recognizing that they are partners who have made very significant investments and played a major part in the success of both of these programs. A very important issue at stake is the reputation and credibility of the US in international HEP partnerships.

P5 Findings for the Tevatron Program

Discovery Through Searches

General Considerations:
The Tevatron, with its continued position at the energy frontier and the promise of increasing luminosity, remains a great window onto new physics. As described below, the Tevatron experiments have the potential to discover new physics through direct searches, including Higgs bosons, supersymmetric particles, new gauge bosons, excited fermions, and evidence for extra dimensions. Any of these discoveries would change the course of particle physics.

The critical parameters for these searches are integrated luminosity and detector performance. Each experiment has already recorded ~1 fb^{-1} of data (about ten times the luminosity of the earlier Run 1), with ~1/3 to 1/2 of the total sample analyzed. The projected accelerator performance, see Figure 1, would more than double the total data sets every two years, which would keep direct searches at the Tevatron interesting until superseded by LHC results. (First LHC collisions are expected in 2007, with a few fb^{-1} available by 2009.) The Tevatron is performing very well and we can anticipate significantly more integrated luminosity than the curve labelled base in Figure 1.

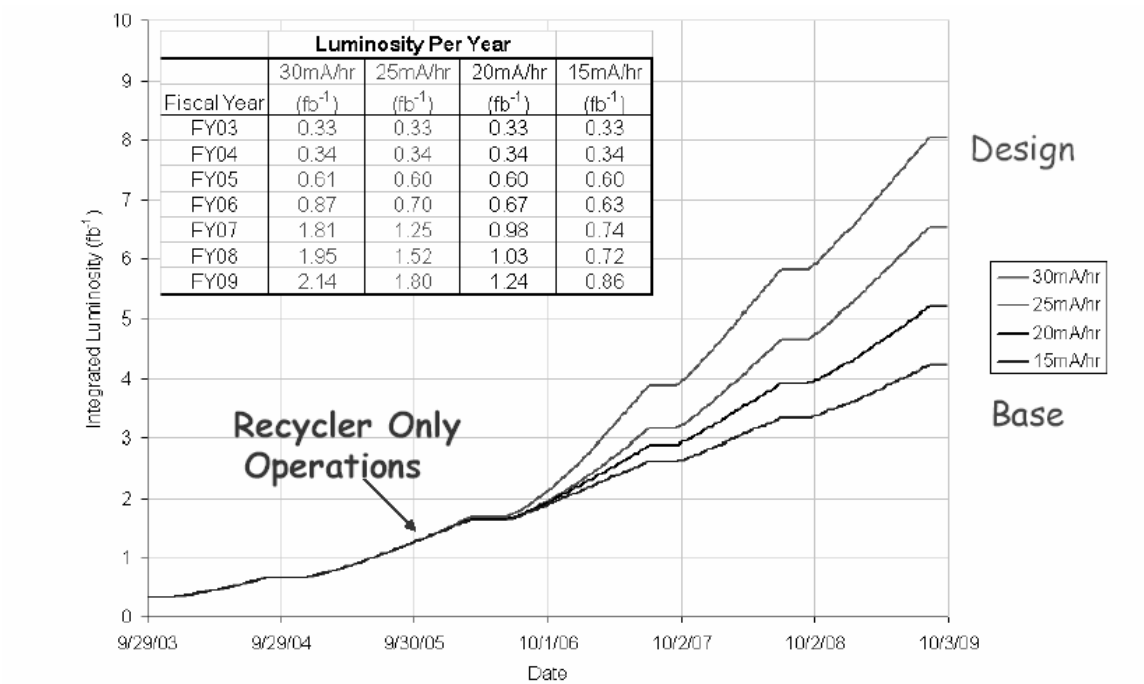


Figure 1: Tevatron integrated luminosity projections, corresponding to different rates of accumulating anti-protons. From the presentation of D. McGinnis to our committee.

A few examples of direct searches have been selected to present the discovery potential of the CDF and D0 experiments as a function of the total integrated luminosity to be delivered by the Tevatron in the coming years. The case of rare B_s-meson decays, which cannot be explored at the B-factories, is also discussed.

Higgs Boson Searches:

The search for the Higgs boson is one of the major goals of high-energy physics experiments today. Studies performed in the framework of the *Physics at Run II* workshop in 1999 and 2000 indicated that the Tevatron experiments CDF and D0 could make significant contributions to this field, provided sufficient integrated luminosity can be collected.

The dominant production processes for a Standard Model Higgs boson at the Tevatron are gluon fusion and associated *WH* and *ZH* production. Despite its lower production cross section the latter contributes significantly to the Higgs boson search in the low mass region (m_H ~ 120 GeV/c^2). In this production mode, the Higgs boson can be searched for using the dominant decays into a $b\bar{b}$ pair. A viable trigger and significant background reduction is obtained when the accompanying vector boson decays leptonically, so the important channels are $WH \rightarrow \ell\nu\, b\bar{b}$, $ZH \rightarrow \ell\ell\, b\bar{b}$ and $ZH \rightarrow \nu\nu\, b\bar{b}$. In the low mass region, the Higgs boson must be reconstructed as a broad resonance in the $b\bar{b}$ invariant di-jet mass spectrum above a large background from $Wb\bar{b}$ and $t\bar{t}$ production. Excellent *b*-tagging performance and an excellent di-jet mass resolution are essential to achieve the necessary signal-to-background ratio.

In the study presented in the *Physics at Run II* report it was concluded that a Higgs boson discovery in a single channel is not possible. However, if all search channels and both experiments are combined, a 95% CL exclusion can be established for Higgs boson masses up to 135 GeV/c^2 provided that an integrated luminosity of 8 fb^{-1} per experiment is collected. Moreover, if the Standard Model Higgs boson happens to be sufficiently light (m_H < 125 GeV/c^2), a tantalizing 3σ effect should be visible with the same integrated luminosity. These studies were repeated with a more realistic detector simulation in 2003 and the conclusions were essentially confirmed. It was estimated that for a Higgs boson with m_H = 115 GeV/c^2, data corresponding to integrated luminosities of approximately 2.5 fb^{-1} and 5 fb^{-1} are needed for a 95% CL exclusion or for a 3σ evidence, respectively.

The studies also showed that the Tevatron experiments have sensitivity for Higgs boson masses around 160 GeV/c^2, where the gluon fusion and the *WH/ZH* production modes can be exploited using $H \rightarrow WW \rightarrow \ell\nu\, \ell\nu$ decays.

Data collected in the years 2002-2004, corresponding to an integrated luminosity of 300 pb^{-1}, have been used for first Higgs boson searches and to re-evaluate the Higgs discovery potential with a realistic performance. From these analyses, first limits on the cross section for Higgs boson production have been set. At present those cross section limits for a single experiment are about a factor of 20 larger than the Standard Model Higgs boson production cross section. If this analysis is scaled up to a sample of 2 fb^{-1}, still a significant factor on the order of 5.5 is missing to achieve the required sensitivity for the combination of both experiments.

It is hoped to close this gap and to achieve the required sensitivity by a series of improvements to the analyses that have yet to be demonstrated. Among these are improvements of the b-tagging performance, an extension of the lepton and b-jet identification to the forward regions of the detectors, an improvement of the jet-jet mass resolution as well as the exploitation of neural network methods. If those factors can be achieved and if systematic uncertainties scale as $1/\sqrt{L}$, it is estimated that an integrated luminosity of 5 fb^{-1} is needed to obtain a 3σ evidence for a Higgs boson mass at 115 GeV/c^2.

Standard Model Higgs production cross sections at the LHC are much larger than at the Tevatron due to the higher center-of-mass energy (14 TeV compared to 2 TeV). In addition the LHC is expected to reach much larger luminosities. Nonetheless, Higgs searches at the LHC are challenging, and will require well understood and well calibrated detectors as well as sufficient integrated luminosities. First collision data at the LHC are planned for 2007 and about 10 fb^{-1} of data should be collected by the end of 2009. For initial data taking, three independent production modes, the gluon fusion in the $H \rightarrow \gamma\gamma$ mode, the vector boson fusion in the $qqH \rightarrow qq\,\tau^+\tau^-$ mode and the associated $t\bar{t}H$ with $H \rightarrow b\bar{b}$ mode, need to be combined for a Higgs boson discovery. In the most pessimistic case, for a Higgs boson with a mass of 115 GeV/c^2, and an integrated luminosity of 10 fb^{-1}, each of these channels would have a statistical significance of 2-3σ. It should, however, be stressed that these estimates have been made using conservative assumptions on the systematic uncertainties and ignoring contributions from higher order QCD corrections which are large in the gluon fusion mode. About 12 fb^{-1} would suffice to obtain a 5σ discovery by a single experiment at the LHC. The combination of all channels from both experiments will give a discovery for luminosities on the order of 6-7 fb^{-1}. For integrated luminosities of 30 fb^{-1} per experiment, both ATLAS and CMS should be able to discover the Higgs boson with analysis of a single decay channel.

The Standard Model Higgs scenario is the simplest, having only one Higgs boson. This is, however, not the only possibility. In the Minimal Supersymmetric Model (MSSM), discussed in more detail in the next section, there are three neutral (called *h*, *H*, and *A*) and one charged pair of Higgs boson states. The primary parameters that determine all the other masses and couplings are one Higgs boson mass (for example m_A) and $\tan\beta$, the ratio of Higgs vacuum expectation values, which determine the coupling of the Higgs bosons to fermions. The optimal Higgs search strategy depends on the values of these two parameters. Some examples of search possibility are discussed below. Figure 2 shows the present status and expectations for the Higgs search in the MSSM.

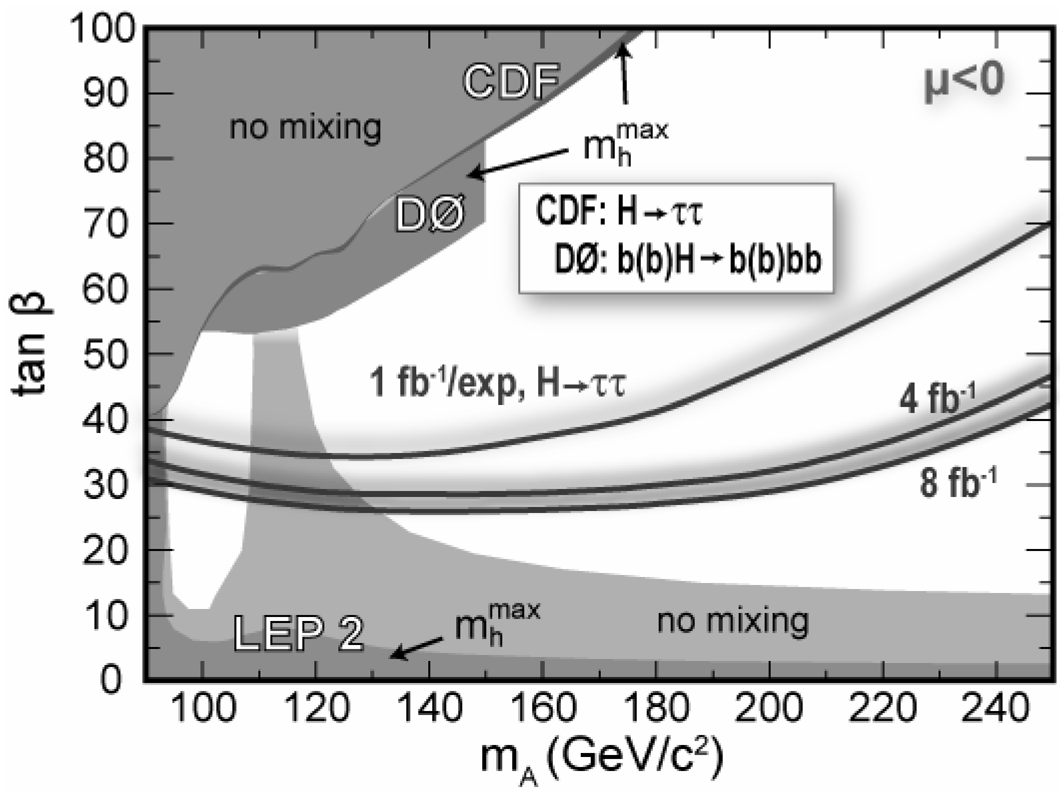


Figure 2: tanβ versus mass of the pseudo-scalar Higgs boson, A, in the MSSM. Shown are the LEP exclusion region (blue), the CDF di-τ analysis exclusion region (pink), the extension of the exclusion region by D0 bbb analysis (green), and the future expected exclusion region for the di-tau channel at the Tevatron with 1, 4 and 8 fb^{-1} of luminosity.

In the Minimal Supersymmetric scenario, Higgs bosons can be searched for in the decay modes h/A *or* $H/A \rightarrow b\bar{b}$ or $\tau^+\tau^-$. Using these final states it is expected that a large fraction of the (tanβ, m_A) parameter space (see below) can be covered at the Tevatron in the high tanβ region, *e.g.*, for tanβ = 40, the m_A region with masses below 225 (240) GeV/c^2 can be excluded at a 95% CL for integrated luminosities of 4 (8) fb^{-1} (see Table 1, which includes also limits for the other Tevatron searches discussed later).

	$1\ fb^{-1}$	$4\ fb^{-1}$	$8\ fb^{-1}$
SM Higgs: 95% CL exclusion M=115 GeV, 3σ evidence M=115 GeV, 5σ discovery	< 100 GeV 5% chance 0% chance	< 130 GeV 35% chance 2% chance	< 135 GeV 75% chance 10% chance
MSSM h/A or H/A, tanβ=40, 95% CL exclusion MSSM h/A or H/A, m_A=140 GeV, 5σ discovery	< 170 GeV tanβ=70	< 225 GeV tanβ=60	< 240 GeV tanβ=55
Charginos, 3 leptons (3l-max) 95% CL exclusion Charginos, 3 leptons (large m_0) 95% CL exclusion	< 170 GeV < 100 GeV	< 200 GeV < 135 GeV	< 230 GeV < 150 GeV
Gluinos, 95% CL exclusion Stop quarks, 95% CL exclusion	385 < 160 GeV	405 GeV < 180 GeV	410 GeV < 185 GeV
$B_s \rightarrow \mu^+\mu^-$ 95% CL exclusion $B_s \rightarrow \mu^+\mu^-$ 5σ discovery	BR < 6.4 10^{-8} BR = 21 10^{-8}	BR < 2.8 10^{-8} BR = 9.9 10^{-8}	BR < 2.0 10^{-8} BR = 6.7 10^{-8}
Z' discovery, e.g. E6 model 95% CL exclusion	M = 720 GeV M < 1.8 TeV	M = 820 GeV M < 2.15 TeV	M = 870 GeV M < 2.35 TeV

Table 1: Projected discovery reach as a function of integrated luminosity in different channels from the combination of CDF and D0 data. From the presentation of B. Heinemann to our committee.

To summarize, if a data sample corresponding to an integrated luminosity of 5 fb^{-1} can be collected at the Tevatron and the anticipated improvements to the analysis can be achieved, the experiments will address the existence of a light Standard Model Higgs boson of mass around 115 GeV/c^2 well before the required data at the LHC can be collected. P5 is concerned that it will be very difficult to achieve all the projected improvements in the Higgs analysis and expects to evaluate the status of this analysis in the recommended review in 2007. A discovery with a significance of 5σ is unlikely and will have to wait for the LHC. (At the Tevatron 14 fb^{-1} per experiment would be required to establish a 5σ effect, after the analysis improvements.) For the MSSM scenario, neutral Higgs boson decays into b quark pairs or τ pairs, will allow the Tevatron to probe large regions of the Supersymmetric parameter space in the next few years.

Searches for Supersymmetry:

One of the most promising models for physics beyond the Standard Model is Supersymmetry. It may solve many theoretical problems, such as the origin of mass through electroweak symmetry breaking, the unification of the forces of Nature, the specific nature of dark matter in the universe, and the stability of the lightest Higgs boson mass under radiative corrections, to name a few. Although the model contains many free parameters, it is highly predictive given a choice for those parameters, so it can be well tested at collider experiments.

The primary prediction of Supersymmetry is the existence of a new particle for every known particle in the Standard Model -- their most essential difference is the spin. For the leptons and quarks (which are fermions), there are bosonic partners called *sleptons* and *squarks*, while for the gauge bosons and Higgs particles there are fermions: the *gluino* is the supersymmetric partner of the gluon, the *charginos* are mixed states of the partners of the W bosons and the charged Higgs bosons, and finally, the *neutralinos* are mixed states of the partners of the photon, the Z boson, and the neutral Higgs bosons. The masses, decay rates, and production cross sections can be calculated unambiguously, given a choice of theoretical parameters, allowing clear predictions for signals at the collider experiments. Squarks and gluinos may be produced with large cross sections, thanks to their color charges. They would decay ultimately to quarks, gluons and the lightest neutralinos, which would give a missing energy signal in a particle detector. Depending on the various particle masses, the lightest neutralinos may result from a cascade of decays through charginos and heavier neutralinos, in which case leptons are produced in the final state along with missing energy. These are distinctive experimental signatures. As discussed earlier in the Higgs section, one of the most important parameters in the model is $\tan\beta$, which parametrizes the way the two Higgs doublets couple to up-type and down-type fermions. The correct value of this parameter is unknown, so one has to consider a range of values - the phenomenology can differ markedly when $\tan\beta$ varies from moderate values, $\tan\beta \sim 1\text{-}5$, to large values, $\tan\beta \sim 25\text{-}60$.

One of the most promising searches for supersymmetric particles at the Tevatron is based on the selection of events with *three isolated leptons* - the so-called tri-lepton search. This final state will arise in the associated production of charginos and neutralinos. The production rate and branching ratios depend on the masses of the sleptons, and the signal tends to be most enhanced when the sleptons are light, and when $\tan\beta$ is not large. For large values of $\tan\beta$, the staus become lighter than the other sleptons, a difficult scenario which requires an optimized analysis. The most recent limits from D0 are much more stringent than those obtained from the earlier data from Run I. The projections for Run II, with integrated luminosities of 4 fb^{-1} and 8 fb^{-1}, show that sensitivities to charginos with masses in the 200 – 230 GeV/c^2 range are very good in scenarios with light sleptons and heavy squarks. There are indications from precision electroweak measurements and astrophysical data that scenarios with light sleptons and squarks might have charginos with masses in the 200 GeV/c^2 range and more work in this direction will be of interest. In general, the cross sections for the associated production of charginos and neutralinos are model dependent. However, scenarios with new light weakly-interacting particles can profit from smaller backgrounds at the Tevatron, in comparison with the LHC. At the LHC, the discovery of charginos and neutralinos through associated production may be difficult due to large backgrounds – we are not aware of any demonstration that this is possible with a small luminosity.

If squarks and gluinos are not too heavy, with masses at most on the order of 400 GeV/c^2, then the Tevatron experiments have a chance to discover them with about 2 fb^{-1}. The LHC, with its much higher center-of-mass energy, will be able to cover the same ranges of squark and gluino masses with only a few tenths of an fb^{-1} of good physics data.

Most studies have focused on the MSUGRA scenarios, but if Supersymmetry breaking is transmitted to the observable sector at energies lower than the Planck mass scale, for instance via standard gauge interactions at energies of a few hundred TeV, then the reach of the Tevatron to discover Supersymmetry would be greater. In such models, the gravitino becomes light and the lightest neutralino becomes unstable, decaying, for instance, to an invisible gravitino and a photon. These photons are energetic and isolated, making such events comparatively easy to identify at the collider.

An interesting discovery possibility arises from the physics of the top squark (stop), the supersymmetric partner of the top quark. The mixing of the two top squark interaction states induced by the large top quark Yukawa coupling can result in a mass state that is much lighter than all the other squarks. The lightest stop, then, stands apart from the other squarks and gluinos, and poses a special opportunity for discovering Supersymmetry. The top squark influences strongly the mass of the lightest Higgs boson through radiative corrections, and a light stop also plays a special role in Supersymmetric models of electroweak baryogenesis and dark matter. In many scenarios it will decay to a charm quark and a neutralino, a signature which is challenging at the Tevatron but nearly impossible at the LHC due to very high backgrounds. Given several fb^{-1} of data (see Table 1), the Tevatron will probe a phenomenologically very interesting range of stop masses well above the limits set by the LEP experiments. This is also true in the case when the top squark decays to a bottom-quark, lepton, and sneutrino. These same regions are difficult to probe at the LHC unless stops are produced in the cascades of squark and gluino decays. If the squarks and gluinos are very heavy, beyond the LHC reach, then light stops will indeed be difficult to discover.

Complementary to a direct discovery is the potential for some of the precision measurements to reveal indirect effects from Supersymmetry. A prime example of this is the very rare decay $B_s \rightarrow \mu^+\mu^-$. This decay proceeds through a flavor-changing neutral current, which is highly suppressed in the Standard Model - the branching ratio has been estimated to be on the order of $3 \cdot 10^{-9}$. Decay amplitudes involving supersymmetric particles can enhance this decay by two orders of magnitude, especially when $\tan\beta$ is large. The Tevatron experiments have placed an upper limit on this decay of $2 \cdot 10^{-7}$, which already constrains the high-$\tan\beta$ regime in a significant way. Projections show that this limit could improve by a factor of ten, given a luminosity of 8 fb^{-1}. This would constrain Supersymmetry at high $\tan\beta$ in a very significant way, if the mass of the CP-odd Higgs boson, m_A, is less than a few hundred GeV/c^2. Notice that this complements the sensitivity of the tri-lepton searches, and that one might expect a signal for $B_s \rightarrow \mu^+\mu^-$ to be accompanied by observations in certain Higgs channels, such as $p\bar{p} \rightarrow b\bar{b}H/A$ followed by $A/H \rightarrow b\bar{b}$ or $\tau^+\tau^-$. It should also be noted that this information is complementary to that obtained on B_u and B_d mesons from the B-factories.

The rate for the production of B-mesons at the LHC is extremely large. Triggering on the relatively soft muons from $B_s \rightarrow \mu^+\mu^-$ decays is more difficult than at the Tevatron for the general-purpose LHC detectors

(ATLAS and CMS), however this is not an issue for LHCb. It has been estimated that an observation of this rare decay would be possible in the first few years of data taking, for the branching ratio predicted by the Standard Model.

There is also an important phenomenological connection between the rare decay $B_s \rightarrow \mu^+\mu^-$ and B_s mixing. In models of supersymmetry with minimal flavour violation, if $B_s \rightarrow \mu^+\mu^-$ is enhanced, then Δm_s will be lower than expected in the Standard Model, increasing the chance that it will be observed at the Tevatron.

Searches for other Physics Beyond the Standard Model:
We have discussed mainly the searches for Higgs bosons and for supersymmetric particles. Physicists at CDF and D0 also search for signs of new physics from other theories. For example, the high-mass di-lepton spectrum is studied for any evidence of a narrow resonance, such as one expects if a new neutral gauge boson (*Z*') is produced, or in some examples of theories with compactified extra dimensions. These searches, although model dependent, often allow the Tevatron to probe scenarios beyond those already constrained by the LEP experiments, and can extend the parameter space tested by LEP. The mass reach of the Tevatron depends very much on the assumed model, but in certain benchmark models, *Z*' masses approaching 900 GeV/c^2 could be excluded.

The LHC can cover these same mass ranges with only a fraction of an fb^{-1}, according to recent studies. It is worth noting, however, that in these processes the Tevatron and the LHC sample the up and down-quark content of the proton differently, so combining an observation of a *Z*' boson at the Tevatron and at the LHC allows one to gain information on the couplings of the *Z*' boson to up and down-quarks. This would constitute the first step towards understanding the theoretical basis for the resonance.

Summary:
The Tevatron program clearly has a lot of potential for uncovering new physics. The current integrated and analyzed luminosity in the two experiments is only a small fraction of the total luminosity that will be available over the next few years. Should some new physics (or some strong hint of new physics) be present in a ~ 4 fb^{-1} sample, the case for pushing the integrated luminosity to its highest level would be very strong.

Obviously the LHC program will eventually overtake the Tevatron. Given the uncertainties in the LHC schedule, the machine performance, and the detector commissioning timescales, it is not easy to predict when that will happen. For some new physics signatures, e.g., squarks and gluinos, the LHC will take over as soon as the experiments have reached a satisfactory level of detector understanding, (almost) regardless of integrated luminosity. For other processes, the situation is more complicated. In the extremely important case of a light SM Higgs, where the signatures at the LHC are challenging, and significant integrated luminosities are required, data from the Tevatron could provide important limits or the first hint of a discovery. This will need large factor improvements to the present Tevatron analyses and sufficient luminosity delivered by the machine. However, a conclusive >5σ discovery will demand the power of the LHC.

Discovery Through Precision Measurements

Examples of Precision Physics at the Tevatron:

With Run II well underway at the Tevatron, CDF and D0 have begun a program of precision measurements. Some of these measurements with the top quark, the *W* boson and the B_s meson seek to more precisely probe our understanding of electroweak symmetry breaking and flavor physics and look for hints of new physics.

The top quark, discovered at Fermilab ten years ago, is by far the heaviest observed constituent of matter. Since it is the only quark or lepton to couple strongly to the Higgs boson, a detailed study of its properties could reveal surprises about electroweak symmetry breaking.

The CDF and D0 collaborations are carrying out a broad program to measure the couplings of the top quark. The strong interaction coupling is determined from the $t\bar{t}$ production cross section. Other couplings can be found from the search for decay modes other than the dominant $t \to Wb$, measurements of the polarization of the final state *W* boson, spin correlations, and the production rate of single top quarks, as well as through generalized coupling analyses. Any of these could provide evidence for physics beyond the Standard Model, and all are statistically limited. With approximately 5% of the Run II design integrated luminosity analyzed, the collaborations have several hundred fully reconstructed $t\bar{t}$ events in a channel with a very good signal-to-background ratio. The power of all of these measurements will improve rapidly with increasing data sample size.

One important precision measurement that can provide indirect evidence for new physics is the mass of the top quark. When combined with a precise measurement of the *W* boson mass, it tests the Standard Model at the level of electroweak radiative corrections. In the context of the Standard Model, the top quark and *W* boson masses provide a prediction of the Higgs boson mass. If m_t and m_W are outside the Standard Model allowed range, new physics is established. If they are within that range, then once the Higgs is discovered, the values of these three masses provide a stringent test of the model. Figure 3 below shows the current status.

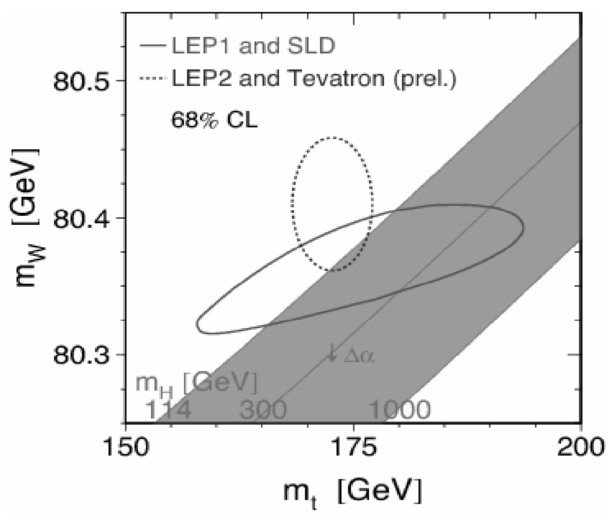
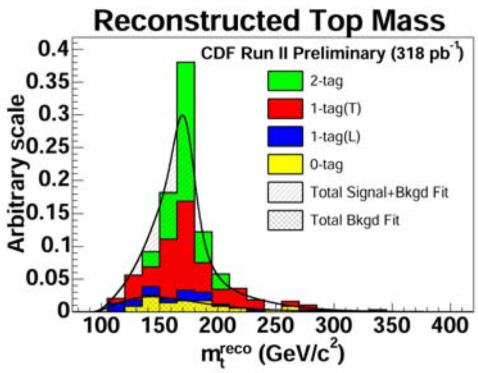


Figure 3: Current status of precision measurement constraints on the Higgs mass.

The Tevatron experiments have now completed analyses of the first 300 pb^{-1} of Run II data. Figure 4 below shows a reconstructed top mass spectrum. The uncertainties of ±4.1 GeV/c^2 and ±4.7 GeV/c^2 from CDF and D0, respectively, are much smaller than had been predicted. The improvement is due to a new technique for reducing the major systematic uncertainty, that associated with the jet energy scale. Other systematic uncertainties can also be reduced as more data are collected. An example is the effect of initial-state radiation, which can be measured with Drell-Yan lepton pair data. The projected total top quark mass uncertainty is 1.4 (1.2) GeV/c^2 for 4 (8) fb^{-1} and is dominated by the remaining systematic uncertainties. This compares favorably with 1-1.5 GeV/c^2 predicted for the LHC experiments. It must be remembered that a precision measurement of the top quark mass is unlikely to be an early result from the LHC because it requires detailed understanding of the response of the calorimeters to hadron jets, the most difficult of collider detector calibrations.



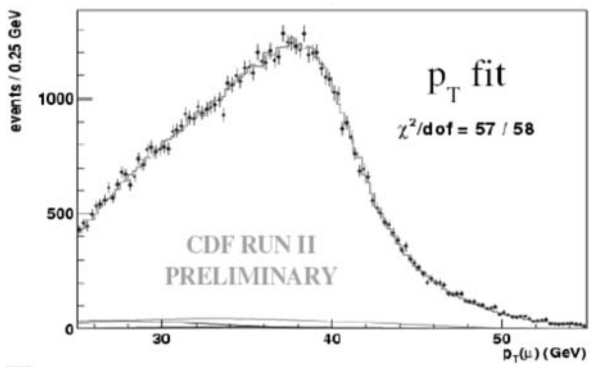


Figure 4: Data on the top mass. **Figure 5:** Data used to extract the *W* mass.

The precision test of the Standard Model also requires the mass of the *W* boson to be measured accurately. At present it is known with an uncertainty of ±34 MeV/c^2, after combining data from the Tevatron and LEP-II. Data from the first 300 pb^{-1} of Run II data are shown in Figure 5 above. The measurement, which relies on fitting the transverse momentum spectrum for leptons, is already limited by systematic uncertainties. However, as with the top quark mass, the systematics can be reduced by studying other data samples. The lepton momentum scale and the vector boson transverse momentum spectrum can be obtained from the *Z* sample, while improved parton distribution functions can be obtained from jet, photon, and *Z* production, as well as the *W* charge asymmetry measurement. It is estimated that remaining systematic uncertainties will limit the *W* mass accuracy to somewhere between 20 and 30 MeV/c^2 for an integrated luminosity above 4 fb^{-1}. The goal for the LHC is to measure the *W* mass with a precision of 15 MeV/c^2, but reaching this goal will be challenging. The *W* boson mass measurement requires low luminosity (few extra *pp* interactions) and a well-understood detector, since systematic uncertainties will be the eventual limiting factor.

Single top-quark production at hadron colliders provides the opportunity to study the electroweak interactions of the top. This is in contrast to top-quark pair production, which is dominated by gluon fusion and quark anti-quark annihilation production mechanisms and thus mainly probes the strong interactions of the top. In particular, single top-quark production is mediated by the *W*-*t*-*b* interaction and allows for direct measurement of the properties of this coupling. In the Standard Model, this yields a determination of the CKM matrix element V_{tb} in the absence of new physics. Run II of the Tevatron collider provides the first opportunity to observe single top-quark production.

The Feynman diagrams responsible for single top-quark production are (*i*) the *s*-channel production of an off-shell *W** which then decays to top and bottom, and (*ii*) *t*-channel *W*-gluon fusion, where a space-like *W* is exchanged between an incident light quark and b-quark resulting in a jet + top final state. Each channel has distinct event kinematics and it is in principle possible to detect them separately. The theoretical predictions in the Standard Model for the single top production cross sections at the Tevatron are 2.4 pb for the *s*-channel mode and 0.86 pb for the *t*-channel. There is an additional production channel of b-quark gluon fusion with a top + *W* final state, which has a small production rate of 0.088 pb at the Tevatron. These rates were computed assuming a top mass of 175 GeV and using the CTEQ4M/L parton densities. The theoretical uncertainties associated with these rates is of the order 5-10%. The current published experimental bounds on these processes are $\sigma_s < 6.4$ pb for the *s*–channel and $\sigma_t < 5.0$ pb for the *t*-channel from D0 with 230 pb^{-1} of Run II data. We see that these limits are a factor of 3 and 5 above the Standard Model predictions for the *s*- and *t*-channels, respectively.

The two single top-quark production channels provide sensitivity to different manifestations of physics beyond the Standard Model. The *s*-channel mode is more sensitive to the existence of new particles. Its topology allows for large resonant contributions from models with new heavy gauge or scalar bosons, such as top-pions, or Supersymmetry with R-parity violation. The effects of new bosons exchanged in the *t*-channel mode are mitigated by the space-like momentum and large mass of the non-standard particle. In addition, the *s*-channel mode allows for the production of a new heavy fermion in association with the top, although these rates tend to be small for Tevatron energies. An example of the possible modifications to the *s*-channel cross section is given by a 250 GeV charged top-pion, which doubles the production rate over the Standard Model expectation. The *t*-channel mode provides clean sensitivity to modifications in the top-quark interactions and decay properties. Examples are given by Flavor Changing Neutral Current (FCNC) operators which involve the top-quark and deviations in V_{tb} due to quark mixing with new heavy quark states. Both of these can substantially increase the *t*-channel production rate. The FCNC operators also contribute to the *s*-channel mode, but lack the final state b-quark necessary for tagging. Deviations in V_{tb} could also be observed in the *s*–channel mode, but such effects could be masked by new resonant contributions.

The analysis procedure for CDF and D0 begins with a basic *W*+2 jet selection, which is then optimized for single top production and includes multivariate selections and a two dimensional likelihood fit to the spectrum. In the case where the *s*- and *t*-channel contributions are combined, a statistical significance of 3 (5) in $S/\sqrt{B}$ can be achieved in a single Tevatron experiment with 1.6 (4) fb^{-1} of integrated luminosity. For the single production channels, a 5 (3)σ observation of the *t*-(*s*-)channel mode can be obtained with 4 fb^{-1}, combining both experiments. With 8 fb^{-1} of data the significance of the *s*-channel production observation grows to 4σ. These estimates assume the current analysis criteria and do not include possible improvements in analysis techniques, efficiencies, resolutions, and tagging. These expectations translate to a measurement of $\delta|V_{tb}|$ to 11% with 4 fb^{-1} and 9% with 8 fb^{-1}. If new physics exists and increases the size of the production cross section, the required integrated luminosity to observe these modes would clearly decrease.

Until the LHC turns on, the Tevatron is the only source of the B_s meson and its antiparticle. Measurements of the mixing frequency in the B_s system, combined with the known mixing frequency for the B_d system, can provide a determination of the ratio of the elements V_{td} and V_{ts} of the CKM flavor mixing matrix and thus the length of one side of the unitarity triangle.

The mixing frequency in the B_d system is well measured, with $\Delta m_d = 0.502 \pm 0.007$ ps^{-1}, while the direct observation of mixing in the B_s system is more challenging. The experimental 95% CL limit, based on measurements from LEP, SLD and the Tevatron Run I data, is $\Delta m_s > 14.4$ ps^{-1}. Global fits assuming unitarity of the CKM matrix predict $\Delta m_s = 18.3$ ps^{-1}, with a range of uncertainty of +6.5 and -2.3 ps^{-1}. With ~500 pb^{-1} of data from Run II at the Tevatron, CDF and D0 have demonstrated the ability to pursue this precision measurement, with a current combined sensitivity of 13.5 ps^{-1}, limited by the statistical uncertainty of the data, yielding a new world average 95% CL limit of $\Delta m_s > 16.6$ ps^{-1}.

Besides collecting more data, key improvements anticipated include a more precise determination of the B_s decay vertex and thus the proper time of the decay, and an increase in the efficiency for correctly determining (`tagging') whether the decaying meson was initially produced as a particle or an antiparticle. Improved hit association in the inner most layer of the CDF silicon detector and installation of a similar layer in D0 is expected to significantly improve the resolution of the decay vertex. The effective tagging efficiency will be significantly improved by augmenting opposite-side tagging with same-side tagging. Opposite-side tagging relies on collecting information about the nature of the other b quark produced in association with the decaying B_s, and is more limited by detector acceptance than same-side tagging, which relies on detecting K mesons associated in phase space with the decaying B_s due to the fragmentation process creating the B_s.

Both CDF and D0 are striving to maintain the trigger bandwidth to support this measurement even as the instantaneous luminosity at the Tevatron increases. With the anticipated improvements, the combined sensitivity for CDF and D0 is projected to obtain a 5σ observation of Δm_s at ~15, ~19 and ~22 ps^{-1} for an integrated luminosity of 2, 4, and 6 fb^{-1} respectively. If Δm_s is close to the value expected in the Standard Model, a direct measurement of the oscillation frequency can be made at the Tevatron before the turn on of the LHC, where the LHCb experiment expects to achieve a 5σ sensitivity at 68 ps^{-1} with one year of data.

In the CKM model of flavor mixing, if the value for Δm_s is large, then the value for the decay width difference $\Delta\Gamma_s$ should also be large. CDF and D0 have both made initial measurements of $\Delta\Gamma_s$ using the decay $B_s \rightarrow J/\Psi\ \phi$. Particle – antiparticle mixing in the B_s system leads to a longer lived CP odd eigenstate and shorter lived CP even eigenstate. The CP eigenstates can be identified by their different angular distributions for the final state particles ($J/\Psi \rightarrow \mu^+\mu^-$, $\phi \rightarrow K^+K^-$). By fitting the data as a function of the angular decay variables and the decay time, one obtains $\Delta\Gamma_s$ as well as the CP odd fraction of the decays.

Figure 6 below shows the results from the direct measurements (e.g. $B_s \rightarrow J/\Psi\ \phi$) and lifetime results from flavor specific (e.g. semi-leptonic B_s) decays, which depend quadratically on $\Delta\Gamma_s/\Gamma_s$. The combined results yield:

$$\Delta\Gamma_s = 0.23 \pm 0.08\text{ps}^{-1}$$

$$\frac{\Delta\Gamma_s}{\Gamma_s} = 0.33^{+0.09}_{-0.11}$$

$$\frac{1}{\Gamma_s} = 1.405^{+0.043}_{-0.047}\ \text{ps}$$

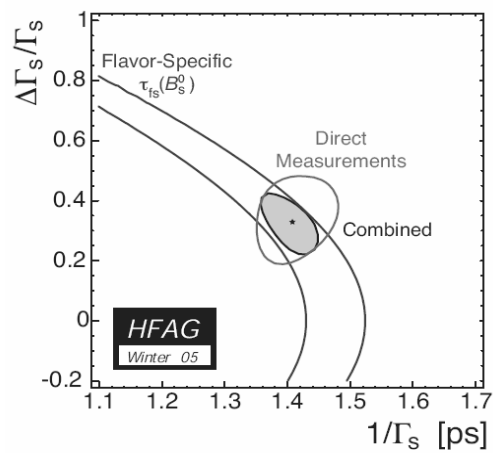


Figure 6: Constraints on B_s Decay Widths.

with negligible systematic uncertainties (e.g. ± 0.01 for $\Delta\Gamma_s/\Gamma_s$ from CDF).

From the combined fit, a nonzero lifetime difference has been observed at about the 3σ level, with a central value larger than the theoretical expectation of $\Delta\Gamma_s/\Gamma_s = 0.12 \pm 0.06$. In addition, current theoretical expectations are that the total decay width for the B_s and the B_d should be equal to approximately 1%; however $1/\Gamma_d = 1.528 \pm 0.009$ ps. More data will determine if a conflict is developing between the measurements and the theoretical expectations.

CDF and D0 will continue to pursue this measurement with more data and project uncertainties on $\Delta\Gamma_s/\Gamma_s$ of 0.12, 0.08, 0.06 and 0.05 for integrated luminosities of 1, 2, 4 and 6 fb^{-1} respectively, using only the mode $B_s \rightarrow J/\Psi\,\phi$. This is to be compared with an expectation of an uncertainty of 0.05 for one year of data with LHCb.

Manpower and Collaboration Issues

Manpower Issues Related to the Tevatron Experimental Physics Program:

With the anticipated turn-on of the LHC in mid 2007 and the strong participation in LHC experiments by many groups that are part of the CDF or D0 collaborations, there is significant uncertainty as to whether there will be sufficient qualified manpower to operate those collider experiments as needed to harvest data in 2008 or 2009 and to complete the analysis of all the data taken. In light of that, there has been recently much activity to begin to understand the manpower availability and needs for the Tevatron experiments.

About a year ago a task force set up by HEPAP surveyed the projected manpower situation for a set of experiments including collider experiments. In his report to P5 the co-chair of that task force indicated that although there are significant uncertainties in the data and in the large extrapolations to several years in the future, the data indicate that by 2009 the available US manpower for CDF and D0 could be only 1/3 of what is needed as people shift their efforts to the LHC experiments. There are, of course many caveats, including the assumption that LHC begins taking useful physics data on the published current schedule. But even with the uncertainties and caveats, the findings of this task force triggered significant concern in the collaborations, the funding agencies and the Fermilab management. For example, the collaborations have now aggressively moved to complete development work early, to identify a core physics program that is interesting and feasible and have realized that they will have to operate the experiments in the future with smaller collaborations.

Within Fermilab, the Director has recently commissioned a Collider Experiment Task Force of about 18 people including members of the CDF and D0 management and Fermilab Division heads (including the co-chair of the HEPAP Task Force), charged with reviewing what is known about the scientific and technical needs for completing the Tevatron program through 2009 and, as the gap between available resources and needs becomes clear, to develop a suite of potential remedies.

P5 was provided with information about the task force's findings and conclusions to date. The task force indicates that by 2007 the available manpower will be less than 75% of that available now. (This is about 20% less of a reduction than indicated by the HEPAP sponsored study.) The data indicates that in 2007, the D0 experiment will barely have the personnel needed to operate the experiment and support the planned broad physics program while CDF is in a more comfortable situation. (The Fermilab task force's estimate of the staff needed in 2007 is significantly below that of the HEPAP Task Force, about 100 FTE per experiment.)

The Fermilab task force has extrapolated the available manpower from 2007 to 2009. The analysis indicates that by 2009 both experiments are likely to be just able to deliver the core physics program and that additional people (something like 30-50 per experiment) and/or significantly greater efficiencies would be needed to deliver a broad physics program. P5 was told that “current extrapolations suggest a significant, but solvable gap between needs and availability” in the 2008-2009 time period.

P5 notes that the analysis of manpower needs does not consider such risks as availability having been over-estimated, more migration to LHC than planned, reduction in funding for collaborating groups, unexpected technical problems that will require more manpower, difficulty of hiring qualified personnel for Tevatron experiments in the LHC era, etc. We encourage Fermilab and the collaborations to do an analysis of the impact of such unplanned situations on the manpower needs for the Tevatron experiments. The result of this analysis weighted by a guess at the probability of each risk occurring would provide a picture of manpower “contingency” that should be part of the planning.

The Fermilab task force indicated a number of remedies that could be considered. The remedies include specific possibilities for more efficient operations of experiments, increasing the Fermilab visitor budget so more overseas collaborators can be in residence, and adding more Fermilab scientific staff in carefully targeted areas.

Fermilab is also planning an on-site LHC Physics Center for the CMS experiment to allow people to actively participate in both Tevatron and LHC experiments. This will help keep some people physically present at Fermilab rather than going to CERN and so will help smooth out the transition. There are currently ongoing discussions about the possibility of creating a similar center for the ATLAS experiment at Argonne.

P5 concludes that there is a risk that there will be insufficient manpower to deliver a significantly broad physics program as we approach 2009 to justify operation of the Tevatron in 2009. This is recognized by Fermilab and the collaborations. There are, of course, many uncertainties and caveats in regard to this concern and remedies have been suggested. The manpower issue will be an important consideration when the question of shutting down the Tevatron before 2009 is considered at the recommended spring 2007 review.

Issues and needs of foreign collaborators:
Foreign collaborators make up a significant component of the CDF and D0 collaborations. Generally, the foreign collaborators are convinced there is an excellent physics program potential through 2009. They want to continue to participate in the Tevatron with most groups having made commitments through 2007. Beyond that, the anecdotal evidence presented to us indicates some divergence in the plans of different groups. Some foreign collaborators look to transition to the LHC then and some want to participate through analysis of data taken in 2009.

The major issue for many foreign collaborators is that there be a reasonably predictable plan for future running of the Tevatron enabling them to carry out a relatively smooth transition to the LHC. They want to be able to plan realistically for their physics program and their personnel. We note that the LHC Physics Center(s) could help foreign groups in their transition from the Tevatron to the LHC.

Uncertainties are also a problem for their institutions and their funding agencies. The decision as to when to shut down the Tevatron will have significant impact on the HEP programs funded by these agencies. We strongly encourage the DOE to engage those agencies that fund the major non-US collaborating groups in a discussion of issues and process related to when to shut down the Tevatron and to consider the impact of shutting down the Tevatron on these overseas programs. A very important issue at stake is the reputation and credibility of the US in international HEP partnerships. We believe that the DOE should strengthen lines of communication with these foreign funding agencies, recognizing that they are partners who have made significant investments in collider physics and played a major part in the success of the Tevatron program.

P5 Findings for the PEP-II Program

Potential for New Physics Discoveries

General Considerations:
The principal goal of the B physics programs at PEP-II and KEKB has become the search for new physics beyond the Standard Model. These programs carry out this search by looking for decays, mixing phenomena, or

CP-violating asymmetries that, either individually or in combination, cannot be described by the four parameters in the Standard-Model CKM quark mixing matrix. Evidence of new physics could take the form of inconsistent values for a single Standard-Model quantity when this quantity is measured in different ways, or a non-Standard-Model rate for a rare decay, or a non-Standard-Model CP-violating asymmetry in some decay.

In Wolfenstein's parametrization, the CKM matrix V is described by the four parameters λ, A, ρ, and η. The parameters λ and A are fixed by $|V_{us}|$ and $|V_{cb}|$. Then, assuming that there is no new physics in any of a fair number of physical quantities, one obtains the constraints on ρ and η shown in Fig. 7. As can be seen from this figure, there is a small region of the (ρ, η) parameter space that is compatible with all the existing constraints. The interesting question is whether there will still be a (ρ, η) region consistent with all constraints when additional quantities have been measured, and the experimental and theoretical uncertainties in the already-measured quantities have shrunk.

Some of the flavor physics tests of the Standard Model may be nicely pictured in terms of the "unitarity triangle" — the triangle with interior angles α, β, and γ in Fig. 7. This triangle is a depiction in the (ρ, η) plane of the Standard-Model unitarity constraint $V_{ud}V^*_{ub} + V_{cd}V^*_{cb} + V_{td}V^*_{tb} = 0$. Its interior angles are CP-violating quantities, and are determined via the study of CP-violating asymmetries in various B decay modes. To test the Standard Model, one would like to measure each of these angles in several different ways, and see whether consistent results are obtained. One would also like to see whether the values obtained for these angles from CP asymmetries agree with those inferred from the measured lengths of the sides of the triangle.

While there must certainly be physics beyond the Standard Model, voluminous data from the electroweak and lower mass scales (the LEP data, for example) agree, with precision, with the Standard Model predictions. This circumstance, and the fact that any new physics from a high-mass scale is generally suppressed at low energies, make it likely that new physics effects in the *B* system are small. Thus, they are most likely to be visible in phenomena where the normally-dominating Standard-Model contributions are suppressed. These phenomena include neutral $B-\overline{B}$ mixing, and rare *B* decays that are induced by penguin (loop) diagrams.

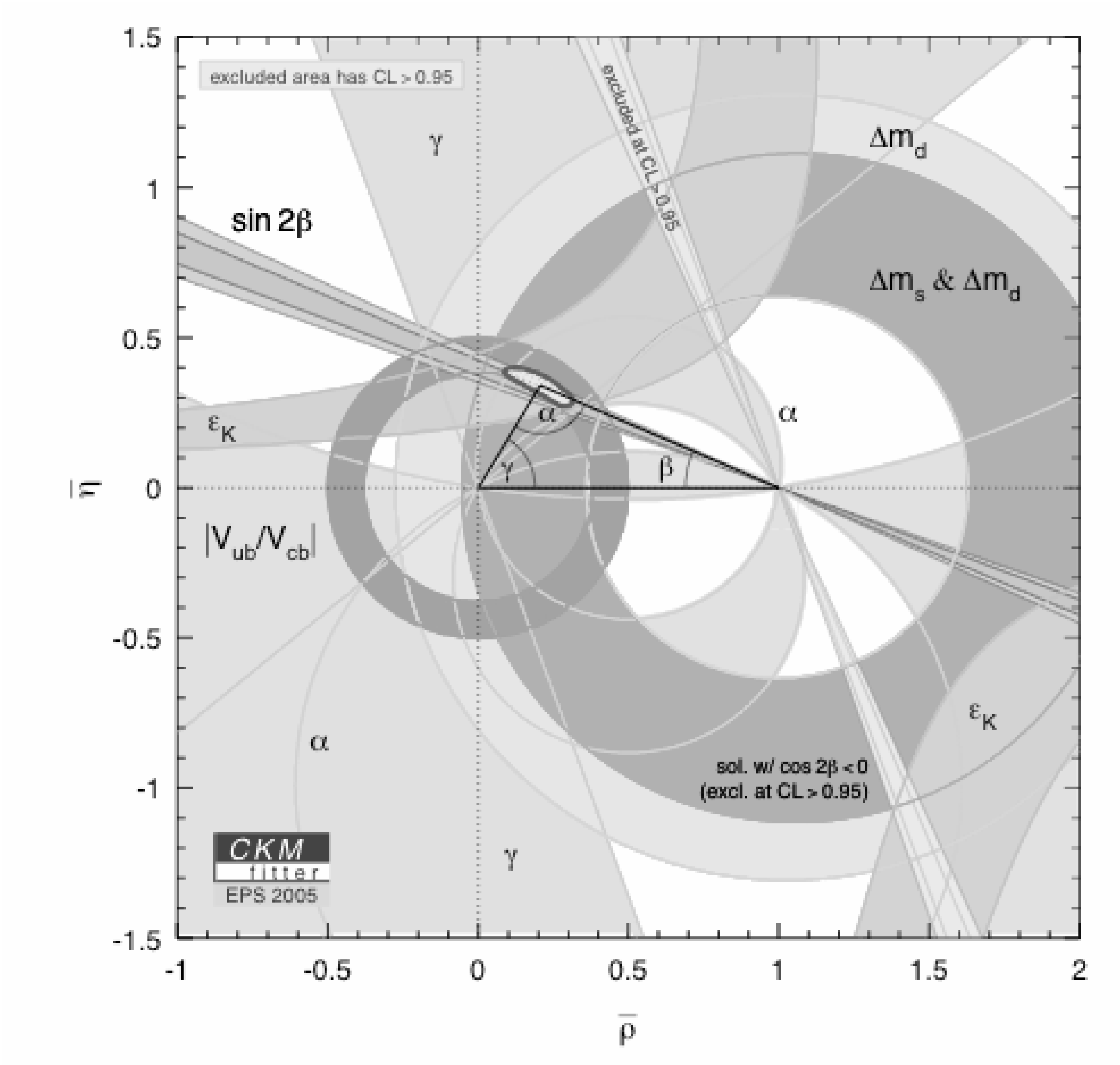


Figure 7: Experimental constraints on the parameters ρ and η in the CKM matrix. The figure is taken from the CKM fitter website, and is current as of August 2, 2005. The axes of the figure are $\bar{\rho} \equiv \rho\left(1-\lambda^2/2\right)$ and $\bar{\eta} \equiv \eta\left(1-\lambda^2/2\right)$. The factor $\left(1-\lambda^2/2\right) \cong 0.975$ is but a slight correction.

Given that the new physics effects are likely to be small, searching for them requires high statistics. The B-factories, PEP-II and KEKB, will have increased the B decay data sample using e^+e^- collisions by more than a hundredfold by the end of 2008. This, combined with the asymmetric energy configuration of the collider, allows a unique and very broad test of the Standard-Model picture of quark-flavor physics. A large number and variety of rates and CP violating asymmetries can be reliably measured and compared to predictions for flavor transitions involving both tree diagrams and loop processes. As already stressed, measurements not only test the CKM mixing formalism, but also probe for new physics coming from virtual high-mass physics. The possibility to measure the phase structure of new interactions, should they be found, is a unique aspect of the physics measurements.

To make additional progress requires significant increases in the data samples analyzed to date. The combined FY2005 and 2006 PEP-II runs are projected to double the BaBar data sample, and the combined FY2007 and 2008 PEP-II runs are projected to give a second doubling. The total BaBar integrated luminosity should reach about 1000 fb^{-1}, with about a third of the total to arrive in FY2008. At the end of the same period, the total Belle integrated luminosity is projected to be about 1500 fb^{-1}.

As statistical errors roughly decrease with the square root of the total luminosity, one might argue that the estimated impact of the PEP-II FY2008 run would be to reduce error bars on world average measurements by less than 10%. BaBar, however, has had better detector performance than Belle. This, combined with a larger asymmetry in beam energies, has meant that BaBar and Belle today contribute approximately equally to world average values. Better BaBar performance due to detector upgrades is expected to increase the impact of the second half of the BaBar data set on many measurements. Furthermore, for difficult measurements, there is significant benefit from the competition, independence, and greater manpower provided by BaBar and Belle. Having two experiments has already been shown to greatly increase the variety of analyses and techniques used to make important physics measurements, and to provide important cross checks on results.

An important consideration in deciding when to stop gathering statistics for B meson decay is how reliably theorists can calculate hadronic processes using the Standard Model. Table 2 below shows a selection of processes whose interpretation will not be significantly theory limited with a quadrupling of the data set.

Measurement (in SM)	Theoretical limit	Present error
$B \to \psi K_S$ (β)	~ 0.2°	1.3°
$B \to \eta' K_S$, φK_S (β)	~ 2°	5, 10°
$B \to \rho\rho$, $\rho\pi$, $\pi\pi$ (α)	~ 1°	~ 13°
$B \to DK$ (γ)	< 1°	~ 20°
$B_s \to \psi\varphi$ (β_s)	~ 0.2°	-
$B_s \to D_s K$ (γ - 2 β_s)	< 1°	-
$\lvert V_{cb} \rvert$	~ 1%	~ 2%
$\lvert V_{ub} \rvert$	~ 5%	~ 10%
$B \to X\gamma$	~ 5%	~ 10%
$B \to X \ell^+ \ell^-$	~ 5%	~ 20%
$B \to K^{(*)} \nu \bar{\nu}$	~ 5%	-

Table 2: Sample of measurements that can be made in B physics for which the theoretical ambiguity in the interpretation is small compared with current experimental errors.

Rare processes, New Physics versus Standard Model Loops:
The BaBar experiment was primarily designed to do a precise study of CP violation (CPV) and to look at many rare processes in B physics. Such processes do not occur in the Standard Model at tree level. Besides testing the Standard Model at the loop level, rare flavor changing processes are uniquely sensitive to the virtual effects of new heavy particles. Particularly important are Flavor Changing Neutral Current (FCNC) processes that are also suppressed by the approximate flavor universality and small mixing angles and masses of the Standard Model. FCNC processes tested at BaBar include B_d mixing, b –> s + gluon (``gluonic penguins''), b –> s + photon (``electromagnetic penguins''), and b –> s + virtual Z boson (``weak penguins''). Confirmation of the Standard Model predictions for CP violation and rates in mixing and FCNC penguin processes would have important implications: any new physics coupling to quarks and leptons is either extremely heavy, or does not possess significant FCNC couplings. A discrepancy with expectations would be clear evidence for the breakdown of the Standard Model.

Such information may become even more important should the Tevatron or LHC discover new physics. Although the LHC has great potential to discover new particles, interpretation of their nature is going to be very difficult. Knowing whether or not the new particles have flavor violating couplings is a vital clue. Any new physics connected with the origin of the different masses and mixing angles for the different generations of fermions is likely to lead to non standard FCNC and CP violating B physics. In many models, B physics can also be measurably affected by virtual effects of new particles that are too heavy to be made directly at the LHC.

The Phase of B_d Mixing:

The Standard Model unambiguously predicts that the time dependent CPV observed in $B_d \rightarrow J/\psi K_s$ comes from the phase in B_d mixing relative to the phase in $b \rightarrow c$ decay, and that this relative phase is twice the CKM parameter β. However, many alternative models of electroweak symmetry breaking allow for a non-standard contribution to the phase in B_d mixing, which would mean that the B factory measurements of CPV in $B_d \rightarrow J/\psi K_s$ is not really $\sin(2\beta)$, nor is time dependent CPV in $B_d \rightarrow \rho\rho$ measuring $\sin(2\alpha)$. The effect of new physics on the B_d mixing phase typically depends on the inverse square of the masses of new particles, and has to compete with Standard Model processes, which are suppressed by a loop factor and small CKM angles for the third generation. Therefore B_d mixing is an excellent place to look for new physics.

According to the current success of the fit of a large number of flavor changing and CP violating processes to the Standard Model, non-standard contributions to B_d mixing with an arbitrary phase must be typically less than 20% of the Standard Model value. However, for about half the possible phases the new physics contribution is only limited to be less than 40% of the Standard Model. By the end of FY2008, the quadrupled data set is expected to lead to improvements in BaBar and Belle measurements for a large number of different CPV and FCNC channels. These improvements will either constrain new physics contributions to B_d mixing to 5-10% of the Standard Model, or (if the more tightly constrained CKM fit fails) provide evidence for new physics. This improvement translates into an approximate doubling of the energy scale being probed through virtual particles.

CPV asymmetries in gluonic penguins:

There is currently intense theoretical and experimental interest in measurements of the CPV time dependent asymmetries in decay modes dominated by b –> s gluonic penguins. The Standard Model contribution is suppressed by V_{ts}, the b quark Yukawa coupling, and a loop factor, while new physics contributions are generally suppressed by only two powers of a new heavy scale. For some final states, however, one cannot rule out the possibility of ``tree pollution'' from the standard model process b –> $u\bar{u}$ s. In some cases such tree contributions violate the OZI rule, in addition to being proportional to small CKM elements, and so are expected to be small. Furthermore, tree processes contain a $\Delta I = 1$ component, and in some cases could be experimentally constrained by isospin analysis of branching fractions in different processes involving charged as well as neutral mesons. The tree contributions can also sometimes be constrained by flavor SU(3). In the absence of tree pollution, the Standard Model prediction for all b –> s modes is that the phase should be almost exactly the same as in B_d –> $J/\psi K_s$. At both BaBar and Belle the phase determined by CPV asymmetries in b –> s modes is consistently low, as shown in Table 3 below. The modes ϕK_s and $\eta' K_s$ are theoretically ``clean'', that is the Standard Model tree pollution can be reliably bounded. The samples of ϕK_s and $\eta' K_s$ decays are just becoming large enough to do precise measurements. The intriguing hint of new physics in the clean modes is not statistically compelling. Figure 8 below shows how increased luminosity in the future might affect the statistical significance of the discrepancy. Assuming the central world values do not change, 1000 fb^{-1} at BaBar and 1500 fb^{-1} at Belle would result in about a 4σ discrepancy between the data and the Standard Model at the end of FY08.

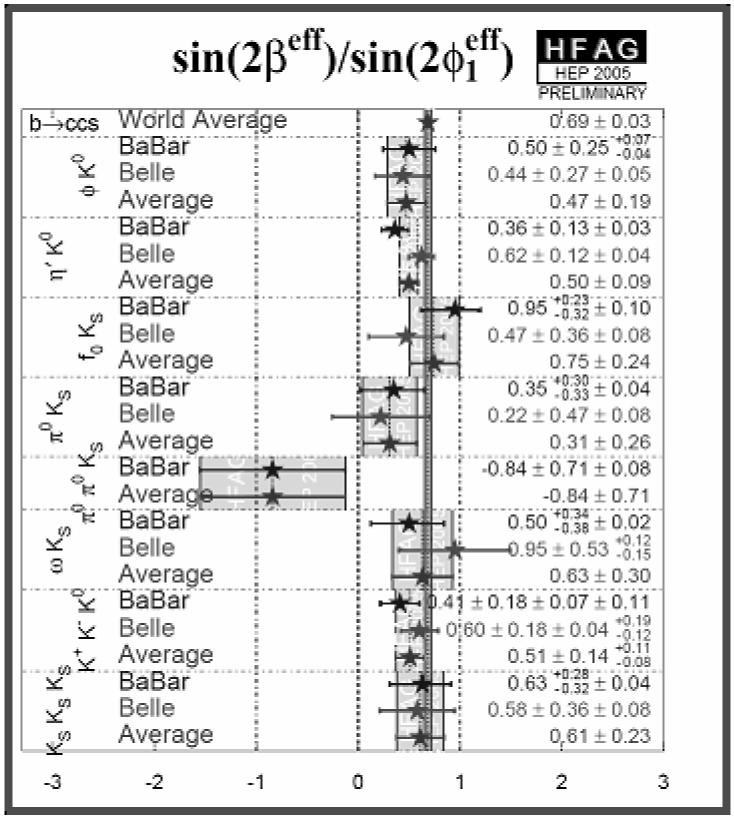


Table 3: sin(2β) measured in various modes at BaBar and at Belle, assuming these modes are dominated by Standard Model b –> s gluonic penguins. Note these values are generally low compared with the world average measurement of sin(2β) in b –> c $\bar{c}$ s modes.

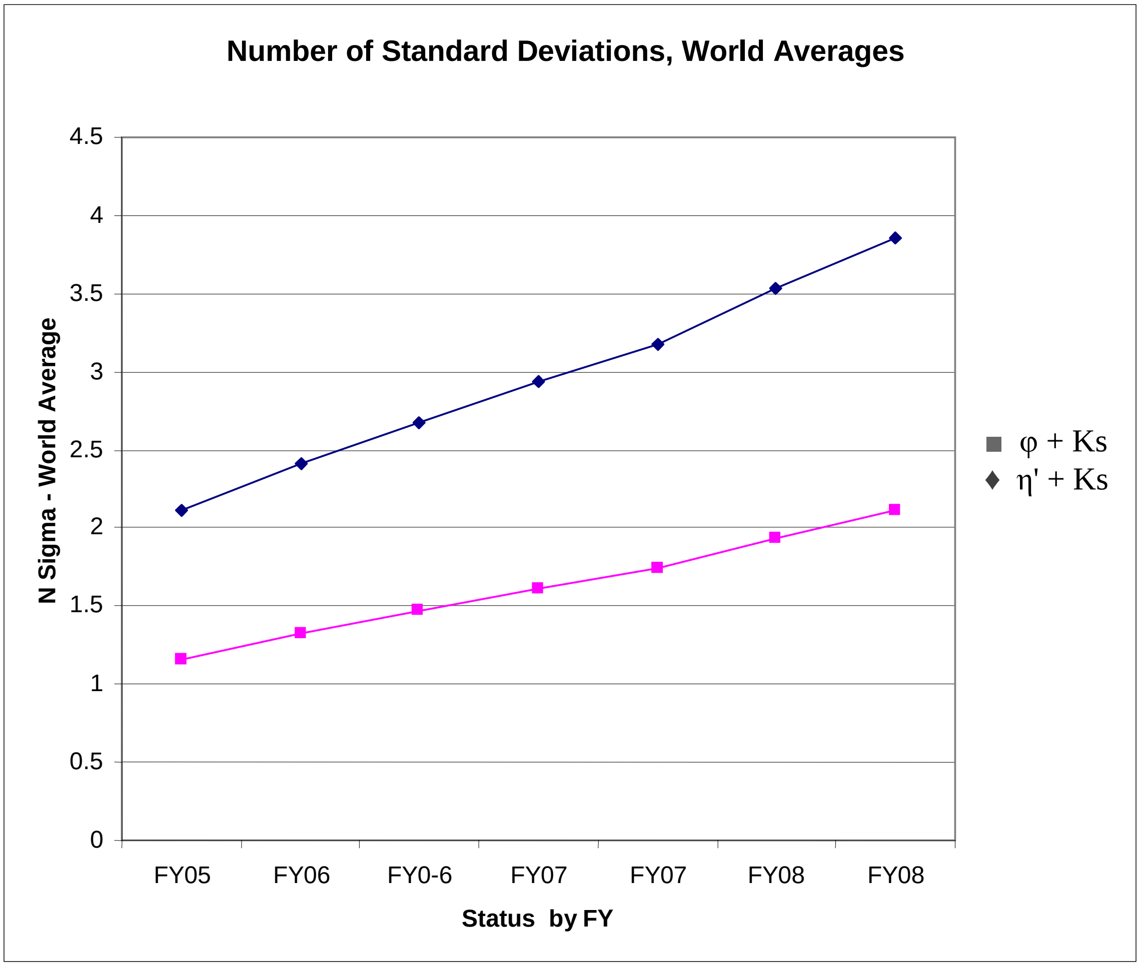


Figure 8: Number of standard deviations of the combined discrepancy of BaBar and Belle with the Standard Model of the CPV asymmetries for the ``clean'' gluonic penguin decay modes, assuming the central world value remains unchanged as more data is accumulated.

b -> sγ, sl$^+$ l$^-$:

Intense theoretical effort has gone into precise calculation of the inclusive decay rates B -> X_s γ, B –> X_s l^+ l^- in the Standard Model. These decays result from loop suppressed electromagnetic or weak penguin contributions to b -> sγ, s l^+ l^-. With heroic effort, inclusive rates for such decays can be fairly reliably calculated in the Standard Model, with the B –> X_s γ rate now computed at 5% accuracy and B –> X_s l^+ l^- to 10% accuracy, in both cases a factor of two smaller than the present experimental error. The effects of physics such as Supersymmetry or an extended Higgs sector on these rates may be considerably enhanced if the b and s quarks have larger couplings to the new particles than they do to the Standard Model Higgs. Currently, the BaBar and Belle measurements of these rates agree with the Standard Model and significantly constrain supersymmetry and many other models. There is still room for improvement in these constraints, or for a discrepancy to emerge from increased data.

Forbidden Processes

Some processes are particularly theoretically clean, in that the Standard Model rate prediction is either zero or well below what is experimentally measurable. Examples include CPV in B meson semileptonic decay rates, $\tau \to \mu \gamma$, or CPV in D meson mixing. Evidence for such processes would therefore be unambigously new physics. New physics might contribute to a variety of such processes at just beyond current experimental limits. Since the predicted rates typically depend on the inverse fourth power of the new physics scale, absent a discovery, only very large changes in statistics have significant impact on theory. So far only limits have been set by the B-factories on such decays, and assuming this continues, the impact of the modest increase in statistics from the FY2008 run on theoretical constraints from such processes is minimal.

Standard Model Precision Measurements

The Measurements and Their Role:

In the quest for signals of new physics, the B decay modes that are expected to be dominated by tree-level Standard-Model decay amplitudes serve as reference points. It is from measurements of these modes that many of the constraints on the Standard-Model parameters ρ and η and the unitarity triangle angles shown in Fig. 7 are derived. It should be noted that even these modes, some of which involve $B-\overline{B}$ mixing, might contain significant contributions from new physics, which could reveal their presence through incompatibilities between the various constraints.

The Standard-Model tree-level decays also serve as the modes to which Standard-Model-suppressed decays, such as the gluonic $b \to s$ penguin decays, are compared. As already noted (and displayed in Table 3), if one assumes that no new physics is present either in the tree-level $b \to c\bar{c}s$ decays such as $B \to J/\Psi K_S$, or in the $b \to s$ penguin decays, then there is a tantalizing, but not statistically compelling, discrepancy between the value of sin(2β) extracted from the former decays, and the value implied by the latter ones.

The CP-Violating Angles α, β, and γ of the Unitarity Triangle:

Measurement of the angle β

The time-dependent CP asymmetry in the neutral B meson system is one of the key observables at the asymmetric energy B factory. In 2001, the BaBar and Belle collaborations discovered a large mixing-induced CP violation by measuring the time evolution of B^0 and $\overline{B}^0$ decays to charmonium plus K^0, in particular, $J/\psi\, K^0_S$, and determined the amplitude of the CP asymmetry, sin2β. Since then, the measurement of sin2β has been regarded as a high-precision benchmark measurement at B factories. Recently, following the continued successful operation of PEP-II and equally successful data accumulation, the BaBar collaboration has presented an improved measurement of sin2β. Based on 227 million $B\overline{B}$ pairs, in which one B^0 is fully reconstructed in a final state containing a charmonium meson (J/ψ, ψ(2S), χ_{C1}, or η_C) and the other B meson is determined to be either a B^0 or $\overline{B}^0$ from its reconstructed decay products (called flavor tagging), BaBar determined the value $\sin 2\beta = 0.722 \pm 0.040(\text{stat}) \pm 0.023(\text{syst})$. This measurement has reached an accuracy of 6% and it demonstrates BaBar's ability to perform precision measurements as well as search for new physics. At 1 ab^{-1}, corresponding to a 4-fold increase of the data sample, BaBar projects a factor of 2 improvement on the accuracy of the sin2β measurement. It is noteworthy to point out that BaBar has achieved an excellent flavor-tagging performance, characterized by an effective tagging efficiency of 30.5%. This high flavor tagging efficiency is not achievable at hadron machines.

Measurement of the angle α

An extensive effort has been devoted to determining the angle α using $B^0 \to \pi^+\pi^-$ decay. However, due to the presence of penguin amplitudes, direct determination of sin2α from the time-dependent CP asymmetry in this mode is far from complete. Besides, as of summer 2005, there is a ~2.3σ difference between the amounts of CP asymmetry seen in this decay mode by BaBar and Belle. Belle observes a large CP violation (more than a 5σ effect), while the BaBar result is consistent with zero. The current values of the CP asymmetry amplitudes, $S_{\pi\pi}$ and $C_{\pi\pi}$, measured by BaBar (based on 227 million $B\overline{B}$ pairs) and Belle (based on 275 million $B\overline{B}$ pairs) are :

$$S_{\pi\pi} = -0.30 \pm 0.17 \pm 0.03 \text{ (BaBar)}$$
$$= -0.67 \pm 0.16 \pm 0.06 \text{ (Belle)},$$
$$C_{\pi\pi} = -0.09 \pm 0.15 \pm 0.04 \text{ (BaBar)}$$
$$= -0.56 \pm 0.21 \pm 0.06 \text{ (Belle)}.$$

With the completion of $1ab^{-1}$ data taking by both experiments, we would be in a much better position to make a conclusive statement on B to ππ decay.

BaBar has intensively pursued another method to measure the angle α. It is to use $B^0 \rightarrow \rho^+\rho^-$ decay. This decay mode is similar to $B \rightarrow \pi^+\pi^-$, but initially considered more complicated because the final state is a vector-vector state and, therefore, is not necessarily a single CP eigenstate. However, BaBar has experimentally found that the ρρ final state is fully polarized longitudinally, so that the $\rho^+\rho^-$ final state is nearly a CP = +1 eigenstate. It is also found that the branching fraction of B^0 to $\rho^0\rho^0$ (< 1.1 x 10^{-6}) is much smaller than that for $\rho^+\rho^-$ (~24 x 10^{-6}), indicating that the penguin contribution (or pollution) in $B^0 \rightarrow \rho^+\rho^-$ decay is small. BaBar has selected about 600 $B^0 \rightarrow \rho^+\rho^-$ decays from 232 million $B\bar{B}$ pairs and measured their time-dependent CP asymmetry. BaBar finds $S_{\rho\rho} = -0.33 \pm 0.24^{+0.08}_{-0.14}$ and $C_{\rho\rho} = -0.03 \pm 0.18 \pm 0.09$, and has determined that the angle $\alpha = 100 \pm 13$ degrees. Note that an eventual observation (rather than a limit) of the unseen B to $\rho^0\rho^0$ decay may eventually limit this technique, since the absence of this mode is used to limit the penguin-induced uncertainty in determining α. Taking their ππ and ρπ measurements into account, BaBar obtains $\alpha = 103^{+10}_{-9}$ degrees. Although this is a significant achievement, the results are still statistics limited.

Measurement of the angle γ

Measurement of the angle γ is even more challenging than that of α. Unlike the determination of β and α, for which mixing-induced time-dependent CP asymmetries in neutral B meson decays are measured, the determination of γ entails measuring a direct CP asymmetry in charged B meson decays. This asymmetry arises from the interference between $B^- \to D^0 K^-$ and $B^- \to \overline{D^0} K^-$, where the D^0 and $\overline{D^0}$ decay to the same final state.

The method proposed by Gronau, London and Wyler uses a mode in which the D^0 or $\overline{D^0}$ decays to a CP eigenstate, such as $\pi^+\pi^-$ or K^+K^- (for CP = +1), or $K_S^0\pi^0$ or $K_S\phi$ (for CP = −1). These decay modes have large branching fractions, but the interference is suppressed by a factor of $|V_{ub}/V_{cb}|$ and, therefore, is small. The method proposed by Atwood, Dunietz and Soni uses another mode in which the D^0 or $\overline{D^0}$ decays to $K^+\pi^-$. The interference in this case is large because the two amplitudes are comparable. The overall decay rate, however, is small and the required statistics for a measurement of a direct CP asymmetry is large (>1 ab^{-1}).

Currently, the most promising method is to take advantage of the interferences that occur in the Dalitz plot of the decay $D^0\left(\overline{D^0}\right)\rightarrow K_S\pi^+\pi^-$. Because this analysis utilizes the entire $D^0\left(\overline{D^0}\right)\rightarrow K_S\pi^+\pi^-$ decay phase space, it has good statistical power. A detailed understanding of the structure of the Dalitz plot, necessary for this method, has been done using a high statistics sample of D^0 meson decays obtained at the B factory. Using a sample of 227 million $B\overline{B}$ pairs, BaBar has determined that $\gamma = (67 \pm 28 \pm 13 \pm 11)°$ from $B^\pm$ to $DK^\pm$, $D^{*0}K^\pm$ and $DK^{*\pm}$ decays. This result can be compared with the result obtained by Belle, $\gamma = (68 \pm 15 \pm 13 \pm 11)°$, based on 275 million $B\overline{B}$ pairs. It should be noted that the statistical accuracy of this measurement is very sensitive to the ratio for the two interfering amplitudes, r_B=|A(b –> u)/A(b –> c)|. From the B –> D^0K decay, BaBar measures for this ratio $r_B=0.12 \pm 0.08 \pm 0.03 \pm 0.04$, while Belle measures $r_B = 0.21 \pm 0.08 \pm 0.03 \pm 0.04$. Again, more statistics are required for a definitive measurement.

Measurement of $|V_{cb}|$ and $|V_{ub}|$

In addition to studying the angles α, β and γ, BaBar has made significant progress in the measurement of the CKM matrix elements $|V_{cb}|$ and $|V_{ub}|$. These elements determine the lengths of two sides of the unitarity triangle (Fig. 9). As shown in Fig. 10, the ratio $|V_{ub}/V_{cb}|$ and its associated uncertainty define an annulus in the ρ–η plane within which the "α" vertex must lie.

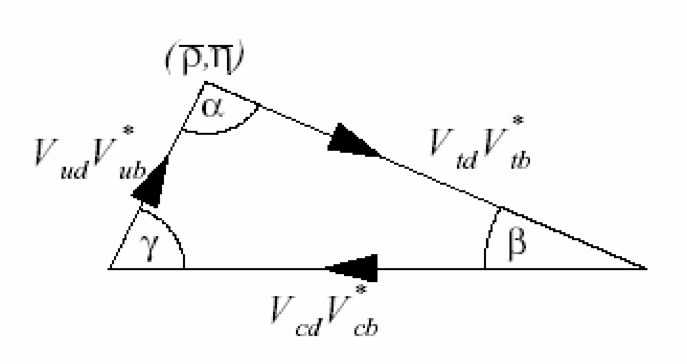


Figure 9: The unitarity triangle.

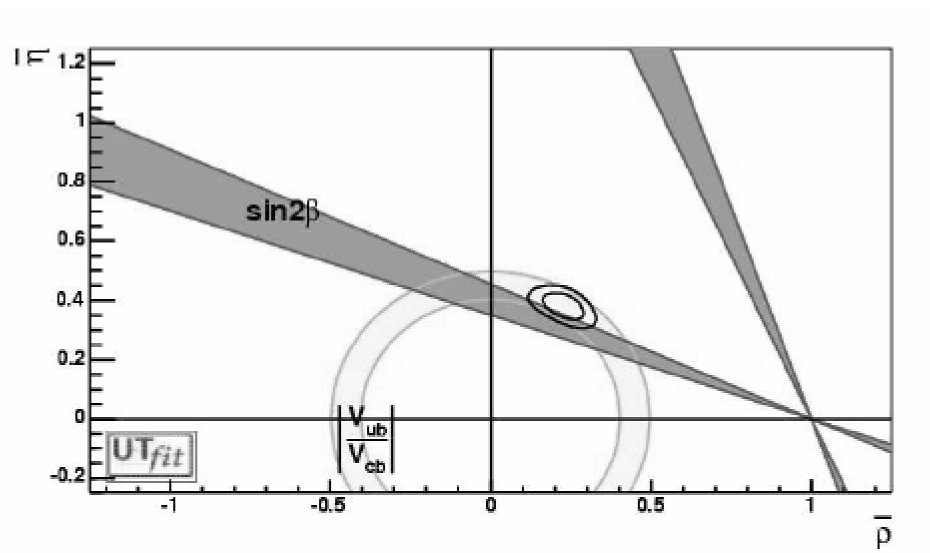


Figure 10: The constraint on ρ and η from $|V_{ub}/V_{cb}|$ (From Silvestrini).

By comparing the measurements of carefully chosen observables with their Standard-Model predictions, $|V_{cb}|$ and $|V_{ub}|$ can be inferred from the semileptonic decay of B mesons. The matrix element $|V_{cb}|$ can be extracted from the inclusive decays $B \to X_c\, l\nu$, whose rate is proportional to $|V_{cb}|^2$. However, the rate also depends on the mass m_c of the c quark, which must therefore be known accurately. The required precision in m_c has been achieved by computing the $D^{(*)}$ meson masses using heavy quark expansions (HQE) in powers of Λ_{QCD}/m_c.

BaBar has measured the inclusive electron energy spectrum for $B \rightarrow X_c\, e\nu$, as well as the mass distribution of the hadronic system X. Using the moments of these distributions, together with data from Belle, CLEO, CDF and DELPHI, global fits have been performed by Bauer *et al*. (hep-ph0408002), which have yielded the following 2% measurement of $|V_{cb}|$:

$$|V_{cb}| = (41.4 \pm 0.6_{exp} \pm 0.1_{th}) \times 10^{-3}$$

The measurement of this quantity to that accuracy is a spectacular achievement.

The matrix element $|V_{ub}|$can be extracted from measurements of the rate for the inclusive decay $B \rightarrow X_u l\nu$ or that for the exclusive decay $B \rightarrow \pi\, l\nu$. Determining $|V_{ub}|$ is much more difficult than finding $|V_{cb}|$. For example, if one uses the inclusive $B \rightarrow X_u$ decay, there is a large background from $B \rightarrow X_c$ decay, as well as from continuum events, and stringent cuts are required to suppress it. Consequently, the results are more sensitive to uncertainties in the predictions for kinematic distributions.

For the exclusive decay $B \rightarrow \pi\, l\nu$, the decay rate is proportional to $|V_{ub}|^2$ $|f_+(q^2)|^2$, where $f_+(q^2)$ is a form factor that models the effects of the strong interactions, and $\sqrt{q^2}$ is the mass of the lepton-neutrino system. By binning the data into 5 bins, BaBar has measured the q^2 dependence of the form factor, as has Belle, which uses 3 bins. This provides a way to discriminate between different calculations of the form factor, which, above a q^2 of 15GeV^2, can be performed using lattice QCD (hep-lat/0408019, hep-lat/0409116). For $q^2 > 16$ GeV^2, and using the FNAL04 lattice calculations, Forti reports the result

$$|V_{ub}| = (3.75 \pm 0.27 \, {}^{+0.64}_{-0.42}) \times 10^{-3},$$

based on the exclusive decays.

The inclusive decays $B \rightarrow X\, l\nu$ have been analysed by several different methods , of which one – the end-point method – relies upon the fact that the masses of the u and c quarks differ appreciably. Because of this mass difference, the end-point of the lepton energy spectrum for $b \rightarrow u\ l\nu$ decays extends beyond that for $b \rightarrow c\ l\nu$. Given the lepton energy E_l and a measurement of $q^2 = (p_l + p_\nu)^2$, where p_l and p_ν are the lepton and neutrino 4-vectors, respectively, one can compute the maximum value of the mass of the hadronic system X. Should that mass exceed 1.9 GeV, one vetoes the event and thereby suppresses $b \rightarrow c$ decays. The results of several very consistent analyses are summarized by Forti (hep-ex/0511010). The analyses yield a world average of

$$|V_{ub}| = (4.39 \pm 0.20_{exp} \pm 0.27_{th}) \times 10^{-3},$$

based on the inclusive B decays. The inclusively and exclusively derived values are consistent with being measurements of the same physical quantity. However, it should be noted that they are *independent* measurements, which, therefore, provide constraints on possible deviations from the Standard Model. In principle, new physics could induce different relationships between the inclusive and exclusive decays than those predicted by the Standard Model.

At present, there is a slight incompatibility, visible in Fig. 10, between sin2β and $|V_{ub}|$. Although this disagreement is tantalizing, the only valid conclusion that can be drawn at the moment is that more data are needed to ascertain whether or not the disagreement is real. If it were shown to be real, it would be a major discovery.

A further independent determination of $|V_{ub}|$ can be made by measuring the branching fraction for $B \rightarrow \tau\nu$. This will require an increase in statistics, and will make use of a lattice calculation of the B meson decay constant, f_B.

The matrix elements $|V_{cb}|$ and $|V_{ub}|$ determine the lengths of two sides of the unitarity triangle. The length of the remaining side is determined by $|V_{td}|$. As discussed in the section "**P5 Findings for the Tevatron Program**, *Discovery Through Precision Measurements*," a measurement of the $B_s - \overline{B_s}$ mixing frequency, when combined with the known $B_d - \overline{B_d}$ mixing frequency, would give us the ratio $|V_{td}/V_{ts}|$. Since CKM unitarity requires that $|V_{ts}| \cong |V_{cb}|$, and $|V_{cb}|$ has been measured, we would then know $|V_{td}|$. While the $B_s - \overline{B_s}$ mixing frequency cannot be measured at a B factory, it can be determined at a hadron facility, and, as already described, a major effort is being made to determine it at the Tevatron.

At a B factory, $|V_{td}/V_{ts}|$, hence $|V_{td}|$, could be extracted from the ratio between the branching fractions for $B \to \rho + \gamma$ and $B \to K^* + \gamma$. Comparing the value of $|V_{td}|$ determined in this way with that found from the neutral B mixing frequencies would be very interesting, and could reveal a discrepancy signaling the presence of new physics. However, at present the theoretical uncertainty associated with the extraction of $|V_{td}|$ from the $B \to \rho + \gamma$ and $B \to K^* + \gamma$ branching fractions is fairly large.

B^o and $B^+ \to \pi\pi, \pi K, KK, VV$:

Many nonleptonic B decays probe both new physics and the Standard Model. These decays are an area of active theoretical and experimental interest. New theoretical tools include "soft collinear effective field theory'', which places some older methods such as factorization on much firmer ground for certain processes. The theory of charmless two-body B decays is under rapid development, and experimental measurements of rates, CPV, and polarization in VV (two vector mesons) can both test and help refine the new theoretical techniques and, with further development, may test for new physics.

The B –> πK modes are sensitive to both gluonic penguin and tree contributions. Analysis of all modes, including an isospin decomposition for both charged and neutral B's, gives sensitivity to direct CPV, strong phases, the Standard Model CP-violating phase γ and new physics in electroweak penguins. Currently there are several puzzles with the data that have led to theoretical speculation about new physics contributions to electroweak penguins.

The decays of B to two vector mesons have also been puzzling. Heavy quark symmetry and the chiral structure of the Standard Model have been claimed to imply that the vector mesons will be mostly longitudinally polarized. Longitudinal polarization appears to be reduced in some penguin dominated modes (see Table 4 below). More theoretical work is needed, however, and better experimental statistics, before this could be understood as an unambiguous signal for new physics.

B decay	Logitudinal polarization fraction BELLE	BABAR
$\rho^-\rho^+$		$0.98^{+0.02}_{-0.03}$
$\rho^0\rho^+$	0.95 ± 0.11	$0.97^{+0.05}_{-0.08}$
$\omega\rho^+$		$0.88^{+0.12}_{-0.15}$
$\rho^0 K^{*+}$		$0.96^{+0.06}_{-0.16}$
$\rho^- K^{*0}$	$0.43^{+0.12}_{-0.11}$	0.79 ± 0.09
φK^{*0}	0.45 ± 0.05	0.52 ± 0.05
φK^{*+}	0.52 ± 0.09	0.46 ± 0.12

Table 4: The longitudinal polarization of VV modes.

New Charmed and Charmonium States:

The physics of the PEP-II/BaBar program extends well beyond precision testing of the Standard Model and the search for new physics. Indeed, thanks to the discovery by both Belle and BaBar of a large number of new charmed and charmonium hadrons, some of whose properties challenge and constrain our understanding of nonperturbative QCD, one of the most exciting areas being pursued at both B factories is hadron spectroscopy. Increased statistics would likely result in the discovery of additional states, as well as helping to elucidate the properties of those already discovered. While such spectroscopy does not *test* the Standard Model, it does *illuminate* it, allowing us to refine our models for how to approximate QCD in a nonperturbative region. Such improvement has value for fundamental physics, not only because it allows for better estimates of nonperturbative QCD corrections to weak processes, but because it may allow for better understanding of any new phenomena indicating strongly coupled physics at the TeV scale.

D_s*(2317), D_s(2460):

The D_s*(2317) was discovered by BaBar in 2003. It was immediately recognized as the 0^{++} p-wave state of $c\bar{s}$. The decay D_s*(2317) –> D_s(1968) π^0 violates isospin, but still has a significant branching fraction since the only alternative is the radiative decay to D_s*(2112) γ. This discovery was confirmed by CLEO and Belle. They also discovered, in 2003, the $D_s(2460)$, which is certainly the p-wave 1^{++} state. It decays to $D_s^*(2112)\,\pi^0$ and $D_s(1968)\,\gamma$, as it should for this J^{PC} assignment. The masses of these states, however, do not easily fit quark model expectations.

Charmonium (?) States:
A large number of new charmonium ($c\bar{c}$) states have been discovered at Belle and confirmed by BaBar, or vice-versa. Some of these have puzzling decay modes, which seem to indicate that they may not be pure charmonium, but might have a more exotic $c\bar{c}$ gluon or 4-quark assignment.

For example, the X(3872) was first seen by Belle in 2003 in decays $B^- \to K^- X$ ($\to J/\psi\pi^+\pi^-$). Since this resonance is above the threshold for $D\bar{D}$ decays, it is assumed that the $D\bar{D}$ decay must be forbidden by parity conservation so that the kinematically suppressed $J/\psi\pi^+\pi^-$ decay is visible. This requires a non s-wave spin-parity assignment such as: 0^-, 1^+, 2^-,... The mass is just at the $D^0\bar{D}^{0*}$ threshold (the charged $D^+ D^{-*}$ is higher by several MeV). A good candidate seemed to be the $2^{--}\ {}^3D_2\ c\bar{c}$ state. However, the Belle evidence for $X(3872) \to J/\psi\,\gamma$, indicates a positive charge conjugation assignment. In $X(3872) \to J/\psi\pi^+\pi^-$, the distribution of the π-π mass suggests the presence of a ρ, which has isospin 1. A $c\bar{c}$ state can't have I=1. Belle has also seen an indication of $X(3872) \to J/\psi\pi^+\pi^-\pi^0$, with the three pions apparently coming from omega decay.

The decays $X(3872) \to J/\psi\pi^+\pi^-$ and $X(3872) \to J/\psi\pi^+\pi^-\pi^0$ would indicate a violation of isospin. Perhaps the explanation for isospin violation has to do with the proximity of the X(3872) to the threshold in $D^0\bar{D}^{0*}$. The angular distribution seen in $X(3872) \to J/\psi\pi^+\pi^-$ fits J^{PC} of 1^{++} which is consistent with an s-wave bound state of $D^0\bar{D}^{0*}$. More data are needed here to confirm the results on the decay channels to measure the angular distributions.

Other puzzling states include the Y(3940) and Y(4260), which are well above threshold for $D\bar{D}$ decays, but, surprisingly, decay into other channels. These states were discovered by Belle and BaBar, respectively, in 2005. In a study of $e^+e^- \to \gamma\pi^+\pi^-\,J/\psi$, BaBar observed the Y(4260) as a broad resonance in the $\pi^+\pi^-\,J/\psi$ invariant-mass spectrum, shown in Fig. 11. The unbinned likelihood fit using a single relativistic Breit-Wigner function plus a second-order polynomial background yielded 125 ± 23 signal events with more than 8σ statistical significance. The fitted mass and width are 4258 ± 8 MeV and 88 ± 23 MeV, respectively. In order to ascertain the number of new states possibly contained in this broad resonance, greater statistics are required. Indeed, much more data is needed to determine branching fractions and quantum number assignments.

Perhaps the new states indicate that traditional charmonium analyses need a better method to include the coupled $D\bar{D}$ and $D\bar{D}^{*}$ channels. However, some theoretical models suggest that interpretation of the puzzling data grows even deeper, perhaps indicating a more important role for chiral symmetry than previously thought.

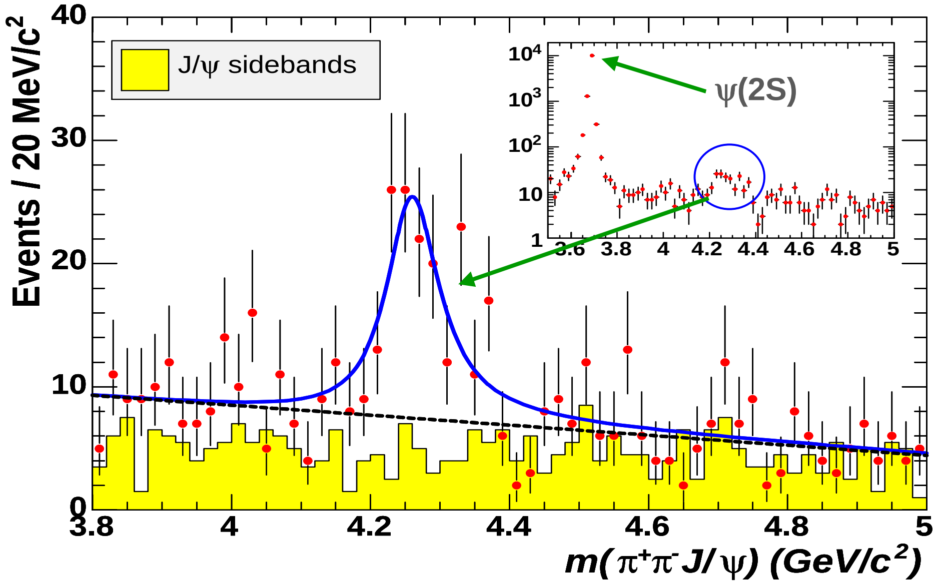


Figure 11: The $\pi^{+}\pi^{-}J/\psi$ invariant mass distribution.

The discovery of interesting new states in 2005 indicates the utility for hadron spectroscopy of obtaining large data samples.

Summary:

A large increase in statistics for BaBar will yield numerous scientific payoffs. It will dramatically increase BaBar's chance for discovery of new physics via tests of Standard-Model loop effects. Sizable new physics corrections are present in many well-motivated extensions of the Standard

Model, and are hinted at by some interpretations of current data. For example, if future data continues the trend of current data, it is conceivable for BaBar and Belle to achieve a world average 4σ evidence for new physics in clean gluonic penguin modes by the end of FY08.

Increased statistics will also significantly tighten the constraints on all of the interior angles, and on the length of at least the $|V_{ub}|$ side, of the Standard-Model unitarity triangle. The improvement in statistics will help resolve the present discrepancy between the BaBar and Belle observations of CP violation in $B \to \pi\pi$, and will allow exploration of the present hint of incompatibility between sin(2β) and $|V_{ub}|$.

Growing statistics have also been shown to be useful for hadron spectroscopy. Some of the new charmonium states discovered have puzzling decay modes, which seem to indicate isospin violation and/or a nontraditional interpretation as a hybrid state. More statistics would help elucidate their quantum numbers and interpretation. Past experience indicates that more statistics will likely lead to the discovery of new states as well.

Luminosity Prospects and Collaboration Issues

Achievements to Date:
The instantaneous PEP-II luminosity has already exceeded the original design goals by a factor of 3, and set new records even as the P5 meeting was in progress with an instantaneous peak luminosity of $9.4\text{x}10^{33}$ $cm^{-2}s^{-1}$. The accelerator has now exceeded $1\text{x}10^{34}$ $cm^{-2}s^{-1}$ and the time averaged luminosity is about 5 times the design value. Despite some setbacks, Run 5 luminosity is integrating well (the slope matches predictions though the integral is a bit behind), and the trickle-charge filling appears to have paid off well. Feedback and RF upgrades, as well as attention to operations, which has increased reliability from 53% to 68%, have contributed to excellent performance overall. The integrated luminosity delivered to BaBar over the lifetime of the machine is now 312 fb^{-1}. Correspondingly, BaBar has maintained a very high efficiency in logging luminosity, averaging around 96%, and peaking around 99%.

Upgrade Plan:
A luminosity upgrade plan aiming to increase instantaneous luminosity by a factor of two is well underway. The essential elements of the plan include

increasing beam currents, reducing the vertical β* and bunch length, and increasing the tune shift slightly. These changes imply significant upgrades to the RF and vacuum systems, and involve an extensive program of machine studies covering beam-beam effects, instabilities, optics, HOM damping, LER emittance, and backgrounds at the machine-detector interface. Task forces have been assigned to study each set of issues, and a regular schedule of reporting has been established. Most of the long-lead-time items have been ordered, and principal installations are scheduled for a shutdown in the period August – November, 2006. The upgrade project is described by SLAC as "ballistic", with little room to speed it up or otherwise alter the trajectory.

The Committee believes the upgrade plan is ambitious in its goals but has a good chance to achieve most or all of the planned luminosity increase, inasmuch as it is built on a set of several more or less conventional improvements without a single point of failure.

Luminosity Projections:

The currently underway Run 5b is projected to bring the total delivered PEP-II luminosity to 470 fb^{-1} by the end of FY06; Run 6, to 653 fb^{-1} by the end of FY07; and Run 7 to 1000 fb^{-1} by the end of FY08. The Committee notes that *if* it were possible to delay the 2007 shutdown by some months, Run 6 could bring the integrated luminosity to ~800 fb^{-1} instead of the 653 fb^{-1} presently envisioned. The year-by-year luminosities are summarized in Table 5.

End of Fiscal Year	Total PEP-II Projection Delivered (fb^{-1})	Yearly Luminosity Increment (fb^{-1})
FY04	256	117
FY05	311	55
FY06	470	159
FY07	653	183
FY08	1004	351

Table 5: Expected PEP-II Delivered Integrated Luminosity.

KEKB Luminosity:

In Japan the KEKB machine has exceeded design luminosity by a factor of 1.5, achieving a peak luminosity of 15.8 $x10^{33}$ $cm^{-2}s^{-1}$. Belle has logged 480 fb^{-1}. KEKB is also working on a luminosity upgrade, but we note that in contrast to the distributed upgrades of the PEP-II plan, the KEKB upgrade plan depends on the success of a single piece of (novel) technology, the crab cavity. Given that extensive R&D has already been done, the KEKB plan is likely to be successful, but it does have a significant single point failure mode. Assuming success, the luminosity delivered to Belle should reach approximately 1500 fb^{-1} by the end of FY08. At present, however, the Japanese government has only authorized operation for 1000 fb^{-1}.

Discussion:

From the information provided to the Committee and summarized above, we conclude that shutting down at the end of FY07 would yield a BaBar data set of approximately 650 fb^{-1}, while running to the end of FY08 will yield a data set of approximately 1000 fb^{-1}. An extension of Run 6 as suggested above, *if possible*, would change these numbers to 800 fb^{-1} and 1000 fb^{-1}, respectively. The most luminosity-hungry of BaBar's physics results are searches and measurements of rare decay parameters such as branching ratios and CP asymmetries, which at this time are based on analyzed data samples of approximately 210 fb^{-1}. The range of luminosity gain under consideration therefore lies between a factor of x3 and a factor of x5.

In the context of the world luminosity, we believe it is reasonable to assume that both the PEP-II and KEKB luminosity upgrades will be substantially successful, and that the world Y(4S) luminosity at the end of FY08 will therefore be between 1650 and 2500 fb^{-1}, with the smaller number corresponding to an FY07 shutdown date for PEP-II operations and the minimum anticipated KEKB luminosity, corresponding to that presently authorized by the Japanese government.

The PEP-II upgrade will not be complete until after Run 5b, which suggests that the investment will be realized only by the luminosities to be integrated in Run 6 and Run 7 (183 fb^{-1} and 351 fb^{-1} respectively).

BaBar Manpower Considerations:

BaBar manpower is projected to decline somewhat over the next 2-3 years, but not to a point where operations or physics output will be affected. As BaBar management noted, the recent extended shutdown of all operations at SLAC *could have* induced some to leave BaBar, but in fact did not. Both U.S. and non-U.S. collaborators remain very enthusiastic about the continued BaBar program. Many of the physics measurements to be done by the B-factories are not being taken over by newer experiments (in contrast to the situation at the Tevatron and LHC), and therefore there isn't a natural experiment to migrate to. We conclude that manpower issues in this case will not be a decisive factor in the response to our charge.

Finally, we note that BaBar is a very successful international collaboration with manpower split roughly evenly between U.S. groups and non-U.S. groups. Therefore our earlier comments regarding the strengthening of lines of communication with the foreign funding agencies applies to the BaBar participants as well as the participants at the Tevatron.

Appendix

- Letter establishing new P5 Subpanel
- P5 Charge
- P5 Membership
- Agenda for Rockville
- Agenda for Fermilab
- Agenda for SLAC

U.S. Department of Energy
and the
National Science Foundation

March 21, 2005

Professor Fred Gilman
Chair, HEPAP
Carnegie-Mellon University
5000 Forbes Avenue
Pittsburgh, Pennsylvania 15213

Dear Professor Gilman:

As you recall, in January 2002 the High Energy Physics Advisory Panel (HEPAP) unanimously endorsed the report of the Long-Range Planning Subpanel chaired by Jonathan Bagger and Barry Barish, which created a twenty-year vision for the field of particle physics, and in November 2002 HEPAP implemented one of the central recommendations of this Subpanel by creating a Particle Physics Project Prioritization Panel (P5). P5 was created as a HEPAP subpanel with a two-year lifespan, and a final report was requested in November 2004.

We are writing now to request that HEPAP establish a new P5 Subpanel for a period of two years. The membership of the Subpanel should represent those communities in particle physics and related fields that can give independent advice on the relative merits of the various proposals considered. As before, P5 should evaluate for HEPAP the merits of specific proposals, and make recommendations concerning their priority standing in the context of the national high-energy physics program. In particular, this Subpanel should recommend priorities for mid-size and medium-term proposals as requested by the agencies. These proposals will typically, but not necessarily, have already received endorsement from their respective laboratories' Program Advisory Committee(s) (if based at a national lab), or an equivalent external peer-review process that can assess the scientific merit of the proposals.

The funding agencies will convey to you particular sets of proposals for P5's consideration with background information on estimated available resources in separate communications over the life of the subpanel.

In assessing physics priorities, the Subpanel should weigh physics importance and the overall balance of the field within the context of available resources, including available funding and manpower, timescales, and other programmatic concerns. It will consider proposals across particle physics, broadly defined, and across funding sources. Where relevant, the Subpanel should consider the international context of proposals, their relation to the programs of related fields such as nuclear physics and astrophysics, and their broader impacts on science and society. While understanding the broad physics program context in which these proposals exist is vital for properly evaluating and prioritizing the individual proposals, that context itself is outside the purview of P5. Advice on the general direction and overall priorities for the U.S.

particle physics program is properly the responsibility of HEPAP itself, and any advice provided to the Department of Energy and the National Science Foundation should reflect HEPAP's views.

We look forward to the establishment of the new P5 Subpanel in the near future. We would like to have periodic status reports to HEPAP on the work of the Subpanel with a final report by the end of 2006.

We wish you success in this challenging and important endeavor.

Sincerely,

Dr. Robin Staffin
Associate Director
Office of High Energy Physics
Office of Science
Department of Energy

Dr. Michael Turner
Director
for Mathematical and Physical Sciences
National Science Foundation

U.S. Department of Energy
and the
National Science Foundation

JUN 0 8 2005

Professor Abraham Seiden
Chair, P5 Subpanel of HEPAP
University of California, Santa Cruz
1156 High Street
Santa Cruz, California 95064

Dear Professor Seiden:

As you know, the role of the P5 Subpanel is to advise and prioritize specific projects, at the request of the Department of Energy (DOE) and National Science Foundation (NSF), and to maintain the roadmap for the field. We would like P5 to begin the task of making a new roadmap for the next decade. This roadmap should be based on input from the various HEPAP subpanels, formed over the last few months, looking at specific sub-areas of particle physics. The roadmap should integrate the various projects into a coherent plan based on scientific promise, cost, and technical and budgetary constraints. There are major opportunities ahead of us – the Large Hadron Collider will soon be producing data, there is a consensus among high energy physicists worldwide towards an International Linear Collider, and a number of study groups and subpanels have laid out the opportunities in such other areas as neutrino physics, dark matter and dark energy.

Of course, the U.S. high energy physics program already has a suite of highly productive accelerator-based efforts at Fermilab, SLAC, and Cornell, and is now reaping the scientific output of the world-leading user facilities that were built in the 1990's. The particle physics community has been aggressive in trying to exploit these investments, and the payoff has been and continues to be a rich and diverse set of physics results. Now is the time to begin considering the next phase: a plan for the Tevatron Collider and PEP-II B-factory that also makes room for other initiatives important to realizing the grand opportunities of elementary particle physics. While the opportunities are great, the budgetary environment is difficult at best. Like all experimental programs, the Tevatron and B-factory will eventually reach the point where the scientific returns diminish, or are eclipsed by other facilities. The immediate question on which we ask your advice is: when would the significant resources that are now invested in operations of these facilities have a greater scientific impact if they were to be deployed otherwise.

Current planning calls for PEP-II to be operated until the end of FY2008 at the latest, and the Tevatron collider to be operated until the end of FY2009. What factors or considerations might lead to stopping B-factory operations one year, or two years earlier than planned? When would we be in a position to make such a determination and what information would be needed? Similarly, for the Tevatron collider, what factors or considerations might lead to stopping operations one year, or two years earlier than now planned? What might lead to running longer than now planned? Again, when would we be in a position to make such a determination and what information would be needed?

In considering and commenting on these issues, you should understand these questions within the international context of HEP and what is planned at KEK-B and the LHC. For definiteness, you may assume a constant funding level for the overall US HEP program; do not assume that the geographic or programmatic distribution of those funds must remain as now. For the purposes of this exercise you should understand that there would likely be no funding for any new initiatives in neutrinos, dark matter and/or dark energy, and no significant ramp-up in ILC R&D until the operations of these facilities are completed. Again, for this exercise, you should assume the availability of redirected resources will strongly impact our ability to carry out smaller initiatives within the roadmap (for example in neutrino physics, dark matter, and dark energy), but will likely impact only weakly the start date for ILC construction, which will largely be determined by other factors.

The DOE and the NSF would like a draft recommendation regarding the two major facilities, in the context of an initial roadmap, by the end of October 2005, with a final report by the end of November. A separate request to construct a final roadmap will be made after the conclusion of the work being done by the various HEPAP subpanels addressing the sub-areas of particle physics.

Thank you in advance for your dedication to addressing these important and challenging questions.

Sincerely,

Dr. Robin Staffin
Associate Director
Office of High Energy Physics
Office of Science
Department of Energy

Dr. Michael Turner
Assistant Director
Mathematical and Physical Sciences
National Science Foundation

cc: Fred Gilman

Membership List
Particle Physics Project Prioritization Panel (P5)

Abe Seiden (UCSC) Chair

Hiroaki Aihara (University of Tokyo)

Andy Albrecht (UCDavis)

Jim Alexander (Cornell)

Daniela Bortoletto (Purdue)

Claudio Campagnari (UCSB)

Marcela Carena (FNAL)

Fred Gilman (Carnegie Mellon University) (Ex-Officio)

Dan Green (FNAL)

JoAnne Hewett (SLAC)

Boris Kayser (FNAL)

Karl Jakobs (University of Freiburg)

Jay Marx (LBNL)

Ann Nelson (U. of Washington)

Harrison Prosper (Florida State U.)

Tor Raubenheimer (SLAC)

Steve Ritz (NASA)

Michael Schmidt (Yale)

Mel Shochet (U. of Chicago)

Harry Weerts (Michigan State U.)

Stanley Wojcicki (Stanford U.)

Agenda for September 8 and 9
Rockville, MD

Sept 8

9:00 – 9:30	P5 Charge, DOE View Point	Robin Staffin
9:30 – 10:00	P5 Charge, NSF View Point	Michael Turner
10:00 – 10:30	General Question and Answer Session on Charge	

Break 10:30 – 11:00

11:00 – 11:45	DOE Budget Presentation and Discussion	Glen Crawford
11:45 – 12:15	NSF Budget Presentation and Discussion	Marv Goldberg

Lunch 12:15 – 2:00

2:00 – 2:45	International Linear Collider	Barry Barish
2:45 – 3:45	LHC Status	Mike Tuts
3:45 – 4:30	EPP 2010 Status and Discussion	Sally Dawson

Break 4:30 – 5:00

5:00 – 5:45	HEP Resource Study Task Force	Chip Brock

Sept 9

9:00 – 9:45	Dark Energy Task Force	Andy Albrecht
9:45 – 10:30	Neutrino Scientific Assessment Group	Peter Meyers

Break 10:30 – 11:00

11:00 – 12:30 Discussion of Fermilab meeting, issues and writing assignments.

Lunch 12:30 – 1:30

1:30 – 2:30 Extra time for discussion if not finished

Agenda for P5 meeting at Fermilab: Sept 12 and 13

Sept 12

8:30 – 9:00	Executive Session (closed).	
9:00 – 10:00	Fermilab Long Range Plan	P.Oddone
10:00 – 10:45	Machine Status and Performance Projections	D.McGinnis

Break 10:45 – 11:15

11:15 – 12:30	**RunII Physics Potential.**	
	Discovery through searches (30’)	B. Heinemann
	Discovery through precision experiments (30’)	J. Hobbs
	Discussion (15’)	

Lunch 12:30 – 1:30

1:30 – 3:45	**Collaboration Issues**	
	CDF Performance and improvements (25’)	YK Kim
	D0 Performance and improvements (25’)	J. Blazey
	Manpower Proj./Needs/Solutions (55’)	H. Montgomery R. Roser T. Wyatt
	Non-US Collaboration Issues (30’)	G. Chiarelli P. Petroff
3:45 – 5:30	Executive Session (closed). P5 internal discussion, formulation of questions to collaborations and lab.	
5:30 – 7:30	Public Reception, committee available for discussions with community.	

Sept 13

9:00 –11:00	Session with spokespersons, lab management (closed) Response to questions of previous day.
11:00 –2:30	Executive Session, committee discussion (closed).

Agenda for P5 meeting at SLAC: Oct 6 and 7.

Oct 6

8:30 – 9:00	Executive Session (closed).	
9:00 – 9:45	SLAC Long Range Plan and BaBar program	Jonathan Dorfan
9:45 – 10:30	PEP-II performance and plans	John Seeman

Break 10:30 – 11:00

11:00 – 11:45	Overview of BaBar Physics goals	David MacFarlane
11:45 – 12:10	CP Violation and rare decay physics with BaBar	Jeff Richman
12:10 – 12:40	Standard Model Opportunities in heavy flavor physics	Zoltan Ligeti

Lunch 12:40 – 1:30

1:30 – 2:00	New physics opportunities in heavy flavors	Luca Silvestrini
2:00 – 2:25	New physics sensitivity with BaBar	Riccardo Faccini
2:25 – 3:10	Belle plans and goals	Steve Olsen

Break 3:10 – 3:30

3:30 – 3:45	Perspectives from the U.S. BaBar community	Stew Smith
3:45 – 4:00	Perspectives from the International BaBar community	Marcello Giorgi

4:00 – 5:30 Executive Session (closed).

5:30 – 7:00 Public Reception, committee available for discussions with community.

Oct 7

8:00 – 9:00 Breakfast with BaBar ExecBoard members
9:00 – 11:00 Response to questions; collaboration and SLAC issues
11:00 –2:30 Executive Session, committee discussion (closed)