Beauty97 Conference Summary

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Abstract

CP–violation is one of the least understood phenomena in our field. There are major experimental programs in all high energy laboratories around the world which will hopefully remedy this within the next decade. The study of CP–violating effects in B meson decays will allow stringent tests of the Standard Model to be made and may point the way to New Physics.

The Beauty97 conference provided a forum for these experiments to discuss their physics potential and experimental challenges relating to these studies. This paper reviews the ongoing and future experimental B–physics projects. I will summarize the status and future plans of these projects, as well as the highlights of the physics and key R&D results presented at the conference. At the end, a critical comparison of the CP–violation B experiments will be given.

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1 Introduction

The origin of CP violation in the Standard Model is due to a non-zero complex phase in the Cabibbo-Kobayashi-Maskawa (CKM) matrix which describes the interaction of left-handed quarks with the charged gauge bosons. Using the standard phase convention, the two elements of the CKM matrix acquire large phases; $V_{ub} \sim e^{-i\gamma}$ and $V_{td} \sim e^{-i\beta}$. Since these elements involve the 3rd-generation, the CP violation effects are expected to be large in B systems. The study CP-violating effects in B meson decays will allow stringent tests of the Standard Model to be made and may point the way to New Physics.

Unitarity of the CKM matrix implies triangular relations such as

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0.$$  \hspace{1cm} (1)

Figure 1 shows the so-called Unitarity Triangle using the Wolfenstein parametrization \([2]\). In drawing the triangle, $V_{ud}^* \approx 1$, $V_{tb} \approx 1$ and $V_{cs} \approx -\lambda$ are used, and the sides of the triangle are scaled by $A\lambda^3$. We already have some information on the magnitudes of the sides of the Unitarity Triangle from present experiments. For example;

- $b \to c$ transitions in inclusive and exclusive B meson decays provide information on $|V_{cb}| = A\lambda^2$ and set the scale of the Unitarity Triangle,
- $|V_{ub}/V_{cb}|$, which is related to the length of the left side of the Unitarity Triangle, is obtained from $b \to u$ transitions in charmless B meson decays,
- $|V_{td}|$ is extracted from $B^0 \leftrightarrow \bar{B}^0$ oscillations.

The primary goal of future B experiments (including the ones being upgraded) is to measure both the sides and the angles of the Unitarity Triangle and thereby over-constraining it, test the consistency of the Standard Model.

The study of Flavor-Changing-Neutral-Currents (FCNC) in B decays also provides quantitative information on the CKM matrix-elements, $V_{td}, V_{ts}$ and $V_{tb}$. In the Standard Model, FCNC are allowed only through loop (box and penguin) diagrams and are therefore strongly suppressed. If contributions from New Physics beyond the Standard Model are comparable in
magnitude to loop diagrams, FCNC decays could provide one of the earliest routes to discover such physics.

An extensive experimental program is underway to study CP violation in B meson decays. There is at least one experiment under construction or planned at every high energy physics laboratory, as summarized in Table I. The Beauty97 conference provided a forum for these experiments to discuss their physics potential and experimental challenges relating to these studies. The status and future plans of these projects, as well as the recent results from key R&D projects on various sub–detectors were presented. In addition, there were presentations on new B physics results from ongoing experiments and theoretical talks on the latest developments in the field. The recent advances in theoretical B physics discussed at the conference were summarized by Jon Rosner [3]. Therefore, in this paper, I only give the summary of the experimental B physics program. Readers should refer to individual contributions at these proceedings for further details.

2 General remarks

The Standard Model description of CP–violation and the formalism used to extract some of the CKM matrix elements from B meson decays is found throughout the literature (see, for example, a recent review by R. Fleischer [4] and the references therein). Experiments usually make simplifying assumptions when applying these formalisms to demonstrate their physics potential. Without explicitly examining these formalisms, some of which may not always apply, we can not understand the measurements. Here we comment on some of the analysis simplifications and limitations in the B program.

2.1 $B^o \leftrightarrow \bar{B}^o$ oscillations

Second–order weak–interactions involving box diagrams allow $B^o \leftrightarrow \bar{B}^o$ transitions. If one ignores CP violation, the resulting decay distributions for a $B^o$ produced at $t = 0$, and decaying at time $t$ into flavor–specific final states, $B^o$ or $\bar{B}^o$, corresponding to non–oscillation and oscillation, respectively, are:

$$R(B^o_{t=0} \rightarrow B^o(t)) \sim e^{-\Gamma t} \left[ \cosh \left( \frac{\Delta \Gamma}{2} t \right) + \cos (\Delta mt) \right] \quad (2)$$
\[ R(B^0_{t=0} \to \overline{B}^0(t)) \sim e^{-\Gamma t} \left[ \cosh\left(\frac{\Delta \Gamma}{2} t\right) - \cos(\Delta m t)\right] \] (3)

where \( t \) is the proper time, \( \Gamma \) is the average decay width of the two mass eigenstates and \( \Delta \Gamma \) and \( \Delta m \) are the decay width difference and the mass difference between the heavy and light B mesons, respectively. Similar decay distributions exist for \( B^0 \).

In order to observe the oscillations in the two decay distributions, the flavor of the B meson at production has to be established (referred to as flavor tagging). Since, for various reasons, flavor tagging is imperfect, the experimentally observed decay time distributions are mixtures of the two ideal distributions, Eq. 2 and 3:

\[ R_{\text{obs}}(B^0_{t=0} \to B^0(t)) \sim A(t) e^{-\Gamma t} \left[ 1 + D \cos(\Delta m t)\right] \] (4)

\[ R_{\text{obs}}(B^0_{t=0} \to \overline{B}^0(t)) \sim A(t) e^{-\Gamma t} \left[ 1 - D \cos(\Delta m t)\right] \] (5)

where, for simplicity, we assume \( \Delta \Gamma = 0 \) (a good approximation for \( B_d \), but not for \( B_s \)). \( A(t) \) is the experimental acceptance and \( D \) is the dilution factor, defined as \( D = \frac{N_g - N_b}{N_g + N_b} \) with \( N_g \) and \( N_b \) are the numbers of good and bad tags, respectively.

For \( B_s \) oscillations, the vertex resolution, and hence the proper time resolution, limits the experiments ability to observe very large \( \Delta m_s \) values. Figure 2 shows the effect of a finite vertex resolution for two values of \( x_s = \Delta m_s/\Gamma = 25 \) and 50, assuming ideal tagging, D=1. The solid curves are the ideal decay distributions, Eq. 3, for B decays after oscillation, with \( A(t) = 1 \). The shaded functions are the same distributions smeared with a proper time resolution of 4%. The effect of the finite proper time resolution is to damp the amplitude of the oscillations similar to a large dilution (small D). In this case, the measured amplitude of the oscillations would be the combined effects of the dilution and the proper time resolution.

Although the frequency of very small amplitude oscillations could be measured using a large sample of events (collected over many years), in practice, the observation of the oscillations will be limited to \( x_s < \frac{3-4}{\sigma_r/\tau} \).

2.2 Angles of the Unitarity Triangle

The most straightforward way to measure the angles \( \alpha \) and \( \beta \) of the Unitarity Triangle is to measure the asymmetry between \( B_d \) and \( \overline{B}_d \) decays to a CP
eigenstate, \( f \). In this case, the time–dependent asymmetry is given by:

\[
A(t) = \frac{R(B_d(t)\rightarrow f) - R(\bar{B}_d(t)\rightarrow f)}{R(B_d(t)\rightarrow f) + R(\bar{B}_d(t)\rightarrow f)} = A_{CP}^{dir}\cos(\Delta mt) + A_{CP}^{mix}\sin(\Delta mt)
\]

where the amplitude \( A_{CP}^{dir} \) and \( A_{CP}^{mix} \) of the cos and sin terms are the direct and the mixing–induced CP–violating contributions. In Eq. 6, \( B^0 \) and \( B^* \) refer to the flavor of the B meson at production which must be identified by means of tagging.

If only a single phase dominates the decay, as is the case for \( B_d \rightarrow J/\psi K^0 \), then

\[
A_{CP}^{dir} = 0
\]

\[
A_{CP}^{mix} = \xi \sin(\Phi_M - \Phi_D)
\]

where \( \xi \) is the CP eigenvalue of \( f \), and \( \Phi_M \) and \( \Phi_D \) are the mixing and decay phases, respectively. If there is no contribution other than the Standard Model to \( B_d \leftrightarrow \bar{B}_d \) mixing, then \( \Phi_M = 2\beta \). Experiments usually assume \( A_{CP}^{dir} = 0 \) and quote the error on \( A_{CP}^{mix} \) as a measure of their CP reach.

Since tagging is imperfect, the observed \( A_{mix}^{obs} \) will be the product of the dilution \( D \) and \( A_{CP}^{mix} \). Therefore, contrary to the oscillation studies, one needs to know the magnitude of the dilution from independent measurements in order to extract the true value of \( A_{CP}^{mix} \). Experiments always assume that the backgrounds have no CP asymmetry and are treated as an additional dilution to \( A_{CP}^{mix} \). Although this assumption would be valid for combinatoric backgrounds, it is not correct for 2–body background under the \( B_d \rightarrow \pi^+\pi^- \) which might have its own CP asymmetry.

The Angle \( \beta \): Everybody’s favourite decay mode for measuring the angle \( \beta \) is \( B_d \rightarrow J/\psi K^0 \). In this decay mode, the dominant decay diagram is the \( b \rightarrow c\bar{c}s \) tree transition with \( \Phi_D = 0 \) (the penguin contributions are expected to be small and have the same phase as the tree amplitude), yielding to good approximation:

\[
A_{CP}^{dir} = 0 \quad \text{and} \quad A_{CP}^{mix} = -\sin(2\beta)
\]
The Angle $\alpha$: The preferred method of measuring the angle $\alpha$ is through the decay mode, $B_d \rightarrow \pi^+\pi^-$. In fact, this decay mode measures the sum of the angles $\gamma$ and $\beta$.

Again if one totally ignores the penguin pollution, since the phase contributed by the dominant $b \rightarrow u\bar{u}d$ decay is $\Phi_D = -2\gamma$, $A_{CP}^{mix} = \sin(2(\gamma + \beta)) = -\sin(2\alpha)$

Here we used the triangular relation $\alpha = \pi - \gamma - \beta$.

The presence of QCD penguins with phases different than the leading tree contribution in this decay mode leads to direct CP violations, $A_{CP}^{dir} \neq 0$. In this case

$$A_{CP}^{dir} = 2 \frac{|P|}{T} \sin(\Delta) \sin(\alpha)$$
$$A_{CP}^{mix} = -\sin(2\alpha) - 2 \frac{|P|}{T} \cos(\Delta) \cos(2\alpha) \sin(\alpha)$$

where $|P|/T$ is the ratio of penguin to tree contributions and $\Delta$ is the strong phase difference between the penguin and tree diagrams. Even if direct CP violation turns out to be too small to observe, the correction to the simple assumption, $A_{CP}^{mix} = -\sin(2\alpha)$, could be very large.

In principle, the effect of penguin pollution could be eliminated by measuring the branching ratios of $BR(B^+ \rightarrow \pi^+\pi^0)$, $BR(B_d \rightarrow \pi^0\pi^0)$ and their charge conjugate channels [5]. But, due to the small $BR(B_d \rightarrow \pi^0\pi^0)$, this method would be difficult to realize from the experimental point of view.

If $|P|/T$ is known, $\alpha$ and $\Delta$ can be extracted from the observed asymmetry.

The Angle $\gamma$ Method–1: One way to measure the angle $\gamma$ is to use $B_s$ decays into $D^\pm K^\mp$ [6]. Here, the decay time distributions depend on both the weak phase, $\gamma$ and the strong phase, $\delta$. $\sin(\gamma + \delta)$ and $\sin(\gamma - \delta)$ can be obtained by fitting to four decay time distributions of $B_s$ and $B_{s\bar{s}}$, with and without oscillations. Here we assume that $V_{ts}$ is real. In fact, the weak phase measured with this method is $\gamma - 2\delta'$, where $\delta'$ is the phase of $V_{ts}$. The estimated error on the angle $\gamma$ depends on the values of $x_s, \gamma$ and $\delta$.

The Angle $\gamma$ Method–2: A second method of measuring $\gamma$ [7] consists of measuring the exclusive decay rates in the following 3 channels: $B^+ \rightarrow D_{CP}^0 K^+, B^+ \rightarrow \bar{D}^o K^+$ and $B^+ \rightarrow D^o K^+$ and their charge–conjugate states,
where $D_{\text{CP}}^0 = (D^0 + \bar{D}^0)/\sqrt{2}$. The angle, $\gamma$, is then extracted by forming two triangles using these six amplitudes in the complex plane, as shown in Fig. 4. Unfortunately, these triangles are very flat; therefore, this method is experimentally very challenging.

Analogous channels exist for $B^0$ decays where the corresponding triangles are not as flat as for charged $B$'s.

### 2.3 Tagging strategies

As explained above, many $B$ physics studies require knowledge of the flavor of the neutral $B$–meson at its time of creation. This information is usually obtained by examining the decay products of the accompanying $B^+$ meson. Since flavor tagging is not always correct, the purity of the tag, as well as its efficiency, plays an important role in extracting the interesting physics quantities from the decay time distributions. A figure of tagging merit is the product of the tagging efficiency, $\epsilon$, and the square of the dilution, $D$. The most common tagging methods are:

- **High–$p_t$ leptons from semileptonic $B$ meson decays.** This type of tagging uses the correlation between the charge of the lepton and the flavor of the $b$ quark. Selection of high–$p_t$ leptons decreases the contamination from charm and $K/\pi$ decays. Although in this mode the tag is very pure, due to the small branching ratio of semileptonic $B$ decays, this tag is relatively inefficient. Nevertheless, high–$p_t$ leptons constitute the main tagging particles for hadronic $B$ final states which are triggered by the tagging lepton.

- **Charged kaons from $b \rightarrow c \rightarrow s$ transitions.** This method relies on the correlation of the kaon charge with the $b$ quark flavor. In order to enhance the purity of kaons from $b$ decays, a large impact parameter to the primary vertex or association of the kaon to a secondary vertex is required. This tag is relatively efficient, but it suffers from the badly measured (multiple scattered) kaons along with the wrong–sign kaons from $D_s$ decays. The rapid oscillations of $B_s$’s make the kaons and leptons from these decays useless.

- **Jet–charge tags.** This method relies on the correlation between the $b$ quark flavor and its charge which is inferred from the total charge of
the b–jet. Since it is relatively hard to associate which of the primary tracks belongs to a b–jet, the jet charge is calculated as a weighted sum of all track charges inside a cone around the B meson. This type of tagging has been successfully employed at LEP \[9\] and could be applied both to the jet containing the constructed B meson (same–side) and the accompanying \(\overline{b}\)-jet (away-side).

• Fragmentation tags. Figure 3 demonstrates the correlation between the nearby particle’s charge, produced in the fragmentation process, and the \(\overline{b}\) quark flavor. During the fragmentation of \(\overline{b}\) quarks to \(B_d\), a \(d\) quark is picked up from the vacuum, leaving a \(\overline{d}\) in the vicinity of the \(B_d\) meson. If this \(\overline{d}\) forms a charged pion, in this case a \(B_d\) is always associated with a \(\pi^+\). Similarly, \(B_u\) is always associated with a \(\pi^-\). Therefore, in principle, the flavor of the B meson could be tagged by studying the charge of the pion close to the reconstructed B meson. Since the charge–flavor correlation for the \(B_d\) and \(B_u\) mesons are opposite, in order for this tag to function with high purity, the charge of the B meson should be correctly identified. This method is less attractive for semileptonic decays, since it is very easy to miss a slow pion and misidentify the B meson charge, hence dirty introducing large dilutions. This type of tagging is employed by the CDF collaboration in their oscillation analysis \[10\].

Similar correlations exist between the \(B_s\) flavor and the charge of a nearby kaon from the primary vertex \[11\].

3 New results

While we await the discovery of CP violation in B mesons decays, a wealth of new information on other B physics topics is coming from CLEO, CDF, DØ and the LEP experiments. Here I summarize some of these results presented at this meeting which have direct effects on our understanding and expectations from the future B experiments.

• Many measurements of the \(B_d\) oscillation frequency from the LEP, CLEO and ARGUS experiments yield the world average \[9\]:

\[
\Delta m_d = 0.463 \pm 0.018 \text{ ps}^{-1}
\]
• CDF presented\cite{10}: $\Delta m_d = 0.474 \pm 0.029 \pm 0.026 \text{ ps}^{-1}$, which is consistent with the weighted average from the $e^+e^-$ experiments. The CDF error is comparable to the measurement errors of the individual $e^+e^-$ measurements, thus demonstrating that precise B physics measurements can be carried out in a “dirty” hadron environment.

• The combined results on $B_s$ oscillations from LEP\cite{9} yield a lower limit for $\Delta m_s$.

$$\Delta m_s > 10.2 \text{ ps}^{-1} \text{ at 95\% C.L.}$$

LEP will not be taking new data at the $Z^0$ mass, but the $\Delta m_s$ sensitivity could still be improved with new analysis techniques of the existing data. SLD is also expected to have an impact with their precise vertex detector. The combined $\Delta m_s$ sensitivity could probably lie in the range $15$–$20 \text{ ps}^{-1}$\cite{9}. The existing lower limit already narrows the discovery window of the $B_s$ oscillations at the 1st–generation hadron B experiments\cite{9}. On the other hand, if $\Delta m_s > 15 \text{ ps}^{-1}$, it would be possible to observe the lifetime differences between the heavy and light $B_s$’s directly.

• Both CDF and DØ reported that the $b\bar{b}$ cross sections are significantly larger than one expects from NLO QCD calculations, although the shape of the $p_t$ spectrum is in reasonable agreement with the theory. However, the $s$–dependence of the cross section agrees with the QCD predictions \cite{10,12}. Although this is good news for the future LHC B–experiments (larger production rate), it also points out a deficiency in our understanding of heavy quark production.

• In the Flavor–Changing–Neutral–Current sector, CDF reported new upper limits for $BR(B_d \to \mu^+\mu^-) < 6.9 \times 10^{-7}$ and $BR(B_s \to \mu^+\mu^-) < 2.1 \times 10^{-6}$\cite{10}. These limits are two orders–of–magnitude larger than Standard Model expectations.

• Many new branching ratios and/or upper limits for several classes of rare decays are reported by the CLEO collaboration\cite{13}. From these, $BR(B_d \to K^+\pi^-) = (1.5^{+0.5}_{-0.4} \pm 0.1) \times 10^{-5}$ and $BR(B^+ \to K^0\pi^+) = (2.3^{+1.3}_{-1.0} \pm 0.2) \times 10^{-5}$ already generated considerable excitement since,\footnote{No $B_s$’s are produced at $e^+e^-$ machines operating at the $\Upsilon_{4S}$.}
in principle, such measurements (with smaller errors) will place constraints on possible values of the angle, $\gamma$.

- Even though CLEO only reports an upper limit for $BR(B_d \to \pi^+\pi^-) < 1.5 \times 10^{-5}$, using the ratio of $N_{\pi\pi}/N_{K\pi}$ from their combined maximum-likelihood fits to $B \to hh$, one could calculate $BR(B_d \to \pi^+\pi^-) = 7 \times 10^{-6}$. If confirmed, this would make the observation of CP violation in the $B_d \to \pi^+\pi^-$ decay mode very unlikely at the 1st-generation experiments.

4 First generation CP–violation B–experiments

In the five experiments preparing to study CP violation in B decay, there are three distinctly different pioneering approaches.

- Experiments in asymmetric $e^+e^-$ machines: BABAR [14, 15] and BELLE [16, 17],
- General purpose high-$p_t$ (central) experiments: CDF [18] and DØ [19],
- A fixed–target experiment at a proton storage ring: HERA-B [20, 21].

While all these experiments have similar CP–reach in the “gold–plated” channel, $B_d \to J/\psi K^*$, the three approaches forms a complementary set with their different systematic uncertainties and various strengths.

4.1 Asymmetric $e^+e^-$ experiments: BABAR & BELLE

Figures 5 and 6 shows the detector layouts of the $e^+e^-$ experiments under construction, BABAR at SLAC and BELLE at KEK, respectively. Both experiments are very similar in their detector designs, differing mainly in their approach to particle identification. While the BELLE experiment uses a combination of time–of–flight detectors and Aerogel Cherenkov counters, the BABAR experiment relies on a new type of Ring–Imaging–Cherenkov counter, DIRC [22]. The DIRC detector uses quartz bars as a radiation medium; the produced Cherenkov light is transported using internal reflections in the radiators, to photon detectors located outside the magnetic volume. The construction of both detectors are proceeding according to sched-
ule; they are both expected to become operational in the second half of 1999 [14, 16].

4.2 General purpose high–$p_t$ experiments: CDF & DØ

The existing central high–$p_t$ experiments, CDF and DØ, at the Tevatron collider are undergoing major upgrades to prepare for RUN–II. Although the main purpose of the upgrades is to prepare the detectors for the luminosity increase with the new Main Injector, many of the improvements will also increase the B–physics reach of the experiments. Of course, the B program also benefits from the increased luminosity of RUN II.

Figure 7 shows half of the CDF II detector layout (after upgrade). A new Silicon–Micro–Vertex detector of CDF II will increase its vertex acceptance and resolution. In addition, a new second level trigger will allow CDF II to trigger on hadronic B decays, opening up the possibility of using decay modes other than ones containing $J/\psi$, as has been done until now.

The DØ upgrade is more like a rebuild. Although they will retain their excellent calorimetry, they are adding a solenoid magnetic field and a silicon microvertex detector along with an entirely new tracking system. Figure 8 shows the layout of their new tracking system and the magnet.

Both experiments will start data taking again in 2000 [18, 19].

4.3 Fixed–target experiment: HERA-B

Hera-B is a fixed–target experiment which uses the stored 820 GeV HERA proton beam and a non–invasive internal fixed–target consisting of 8 wires. Figure 9 shows the layout of the HERA-B spectrometer with the proton beam pipe going through the detector. Wire targets are placed in the same conical vacuum tank which houses the silicon vertex detector. The RICH detector behind the magnet provides kaon identification over the full momentum range. The main Level–1 trigger of HERA-B is a pair of high–$p_t$ leptons or hadrons with cuts on the invariant mass of the pair ($J/\psi$ mass in case of dilepton trigger and B mass in case of high–$p_t$ dihadron trigger).

The rather small $b\bar{b}$ cross section not far above $B^0\bar{B}^0$ threshold implies that the HERA-B detector has to operate with interactions rates of 40 MHz.

\footnote{There are plans to increase the beam energy above 900 GeV.}
corresponding to 4 superimposed interactions per proton bunch crossing. The HERA-B detector has to cope with the correspondingly high particle densities and the data acquisition system has to handle high data flows, similar to those in the LHC experiments.

The experiment had successful engineering runs in 1996 and 1997, with prototype and/or final detector modules of each subsystem. During the 1997 run, the wire targets routinely operated with 40 MHz interaction rates and all detectors were read out simultaneously through the common data acquisition system.

Operational problems in the harsh high-rate hadron environment encountered in the (inner tracker) Micro–Strip–Gas Chambers (see discussion of solution in Sec. 6.1) and the (outer tracker) honeycomb drift chambers has delayed the startup of full HERA-B operation. Major efforts are underway to find a solution to the use of honeycomb drift chambers in the HERA-B environment and to complete as much as possible of the tracking system for the 1999 running period [20]. Independently, a back-up scenario for the outer tracker[20], based on (ATLAS TRT) straw tubes of the type used in the HERA–B transition radiation detector[26] which has survived HERA–B high-rate runs without problems, is being worked out.

4.4 Symmetric $e^+e^-$ experiment: CLEO upgrade

The CLEO experiment is preparing for the next luminosity upgrade of the CESR $e^+e^-$ storage ring, where the luminosity of $\mathcal{L} = 2 \cdot 10^{33} \text{cm}^{-2}\text{s}^{-1}$ will be reached. In addition to changes to the inner tracking volume to house the new machine elements, four new layers will be added to the silicon vertex detector. The most important addition will be the RICH detector module with LiF radiator. The new RICH detector will provide the critical K/$\pi$ separation needed for rare 2–body B decays [27].

5 Future B–experiments
5.1 General purpose high–p$_t$ experiments: ATLAS & CMS

The two general purpose high–p$_t$ experiments, ATLAS [28] and CMS [29], planned for the LHC at CERN also have extensive B physics programs which exploit the large b$ar{b}$ cross section at these energies.

The excellent muon systems [30, 31] and electromagnetic calorimeters [32] of ATLAS and CMS will allow them to trigger on and study B mesons containing $J/\psi$ or leptons in the final state. The pixel detectors in the most inner part of the tracking systems of ATLAS [33, 34] and CMS [35, 36], have a very good vertex resolution which are critical for B physics. Due to the difficulty of reconstruction and tagging of B mesons in the presence of multiple interactions in the same bunch crossing, most of the B physics program in these experiments will be limited to the early days of the LHC when the machine luminosity will be about $10^{33}$ cm$^{-2}$ s$^{-1}$.

The main trigger for these experiments is a high–p$_t$ lepton(s). Even if one learns to do B physics with multiple interactions, the limited bandwidth of the Level–1 trigger output will force them to run with even higher than the already high p$_t$ thresholds (except for the dimuon trigger), thus limiting the usefulness of the higher luminosities available at LHC for B physics.

Most of the Technical Design Reports from both experiments are already approved and construction of the various subsystems is starting [37, 38].

5.2 The ultimate B experiments: BTeV & LHCb

It is generally accepted that an experiment optimized to exploit the large b$ar{b}$ cross sections in the forward directions at hadron colliders will be the ultimate B experiment in any foreseeable future. Both the BTeV proposal [38, 39] for the Tevatron and the LHCb proposal [40, 41] for LHC are in this class.

Due to the forward peaking of b$ar{b}$ production, both experiments have a forward geometry [42] similar to fixed–target experiments. Both experiments could use similar designs and technologies in many of their subsystems. The fundamental differences are limited to their magnetic configurations, silicon vertex detectors and trigger strategies.

Figure 10 shows the layout of the proposed LHCb spectrometer. The LHCb detector is a single–arm spectrometer with a 4.2 Tm dipole magnet centered at 4m from the interaction region. In contrast, BTeV is a 2–arm
spectrometer with a single dipole magnet over the interaction point, as shown in Fig. 1. The second spectrometer of the BTeV is there to give them a factor of two in event yield, which is needed to partially compensate for the lower $b\bar{b}$ cross section at the Tevatron.

The LHCb detector will have a planar geometry silicon vertex detector with $r-\phi$ strips. The Level–1 trigger of the LHCb will be high-$p_t$ lepton(s) or hadron(s), while Level–2 incorporates vertex topology and track triggers. In contrast, The BTeV collaboration plans to use silicon pixel detectors in their vertex detectors (also with a planar geometry) and relies on a vertex–topology trigger in Level–1.

Both experiments will have RICH particle identification systems, giving them a clear advantage over the general purpose detectors, ATLAS and CMS.

The LHCb collaboration submitted its Technical Proposal in March 1998, while BTeV was recently approved as an R&D project to prepare a Technical Proposal. Since the proposed BTeV pixel and trigger designs are technically very challenging, an intensive R&D program on these topics is the highest priority of the BTeV collaboration.

6 R&D projects

The B experiments presently being constructed or undergoing upgrades and the future, next generation experiments all require major R&D efforts, for all sub–systems from vertex detectors to trackers, to trigger and data acquisition. There were many reports from these efforts at this conference, all reporting positive results. I will mention only a few of them, where the results are relevant for more than one experiment. Readers should consult the individual contributions in these Proceedings for more details.

6.1 Micro–Strip–Gas–Chambers

During the last few years, Micro–Strip–Gas–Chambers (MSGC) have become a promising tracking device for high–rate, high–occupancy HEP experiments. They have been selected as the "baseline solution" for CMS and HERA-B and are being considered by LHCb.
The initial R&D on MSGC concentrated on aging problems which were solved by the application of a thin diamond–like coating on the glass substrate \[48\] and using clean materials for the assembly and clean gas systems. The main problem of the last two years was the so called “Sparking Problem”, in which strips are destroyed by gas discharges induced by heavily ionizing particles \[49\]. This problem was first reported by the HERA-B inner tracker collaboration at the Beauty96 conference at Rome \[50\]. Since then, extensive R&D on this subject was carried out by the CMS and HERA-B collaborations and two solutions were presented in this conference:

- CMS opted for “advanced passivation” \[51\], in which a thin layer of polyimid is applied to the cathode edges to prevent field extraction of electrons, and a lower voltage is used to achieve a gas gain of around 1000 \[36\].

- In HERA-B, higher gas gains are needed because the MSGC are used in the trigger. The HERA-B solution, the GEM–MSGC \[52\], is an alternative design based on the Gas Electron Multiplier (GEM) \[53\]. The GEM foil acts as an internal pre–amplifier and provides a second region of gas amplification. This allows the operation of GEM–MSGCs with gas gains of 4000 or more, while both regions of gas amplification are still in a non–critical mode for gas discharge \[54\].

### 6.2 Silicon microVertex detectors

In order to minimize extrapolation distances and impact parameter errors, MicroVertex detectors of the forward geometry spectrometers are positioned inside the beam pipe close to circulating beams. The P238 test–experiment \[55\] demonstrated that such detectors could be reliably operated a few mm from the circulating beams. At high interaction rates, radiation damage limits how close these detectors can approach the beams. However, in the future, advances in radiation hardness of silicon detectors or the use of new radiation–hard materials may improve the vertex resolution of the forward spectrometers by allowing them to run closer to the circulating beams. The vertex resolution of the forward detectors could also be improved by minimizing the multiple scattering of tracks. There are two classes of dead materials which contribute to this problem:
• When detectors are placed inside the beam pipes, it is now a general practice to enclose them in thin (≈ 100 µ) aluminium pockets to shield them from RF pick up from the circulating beams [55, 50, 23].

• The large vertex vacuum vessels used in forward geometry detectors introduces abrupt changes to beam pipe cross sections which effect the impedance of the storage ring and introduce beam instabilities. In HERA-B, the thin metal ribbons or wires are placed around the beams inside the vertex vacuum vessels [50] to carry the image charge.

Both of these additional materials increase multiple scattering in the vertex detectors. Additional R&D, involving both accelerator and detector physicists, is needed to determine if the aluminum RF shields around the silicon detectors can be eliminated or at least further reduced in thickness, to minimize their impact.

6.3 Triggering trends in B experiments

$B^0\bar{B}^0$ events look very much like minimum bias events, apart from having detached secondary and possibly tertiary vertices and a somewhat higher transverse momentum of the B hadron decay products. Moreover, because the “interesting” final states are a small fraction of the $B^0\bar{B}^0$ events produced, hadron experiments are required to run with interaction rates of tens of megahertz. The common strategy is to use multi-level trigger schemes where at each stage more time, more data and more intelligence is introduced for the trigger calculations. The general trend in multi-level B triggers is to use high-$p_t$ lepton and hadron triggers and store the data in pipeline buffers (on the detectors) during the Level–1 calculations. In the large general purpose experiments, triggers based on tracking and event topology are usually introduced in Level–2, while HERA-B employs tracking in Level–1 and BTeV plans to trigger on event topology in Level–1. The Level–1 trigger calculations are performed with custom hardware; general purpose processors are employed as early as Level–2 [25]. The final trigger level performs full event construction. All experiments aim for archival rates of about 100 Hz.

Detailed algorithms for early trigger levels were developed and their expected performance were extensively studied with Monte Carlo event generators. The same is not true for the higher trigger levels where only some general ideas exist. More effort is needed in this area.
There is a problem in hadron experiments which I call a “dilemma of riches”. Assuming all background from minimum bias could be eliminated at the trigger level, 100 Hz archival rates are barely sufficient for archiving all reconstructable B events. This will force collaborations to select (trigger on) only certain B decay modes. Thus, the so-called ”inclusive B experiments” will be not quite inclusive.

6.4 A ”true” B–factory

On the last day of the conference, Gerry Jackson talked on “A Dedicated Hadronic B Factory” [57]. He pointed out that the Very Large Hadron Collider (VLHC) project, under study at Fermilab with a new superconducting transmission–line super–ferric magnet technology, will require a 3 TeV injector to allow the VLHC to reach 50 to 60 TeV beam energies. The estimated cost of the 3 TeV machine is ≈370 M$. He then went on to say that this 3 TeV accelerator could be operated as a 3 TeV pp collider (the magnets provide two dipole fields with opposite polarity). The machine parameters and the interaction region beam optics would be optimized to match the requirements of a dedicated B physics experiment.

The 3 TeV machine would also be a highly valuable accelerator demonstration of the new magnet technology and the cost savings of the magnets and of modern tunneling techniques. This new machine would have a diameter of 34 km (somewhat outside the FNAL site) and would be filled by the Main Injector.

Such a facility would be a true ”B–factory” with 60 kHz $b\bar{b}$ production rate at $\mathcal{L} = 2 \cdot 10^{32} \text{ cm}^{-2}\text{s}^{-1}$, compared to 3.6 Hz at the asymmetric $e^+e^-$ machines. Although the $b\bar{b}$ cross section at $\sqrt{s} = 6$ TeV is about a factor of two lower than at LHC, optimizing the machine for B physics and being the ”prime user” should more than compensate for this factor. For example, when the LHC luminosity becomes $\mathcal{L} = 10^{34} \text{ cm}^{-2}\text{s}^{-1}$, the beams in the LHCb interaction region have to be “blown–up” to decrease the LHCb luminosity to $\mathcal{L} = 2.0 \cdot 10^{32} \text{ cm}^{-2}\text{s}^{-1}$. Having a very narrow bunch–crossing would allow B mesons to decay outside of the beam envelope which would be beneficial for triggering and eliminating combinatoric backgrounds.


7 Comparison of present and future B experiments

Tables 2 and 3 compare the physics capabilities of the 1st and 2nd–generation experiments, respectively, in measuring the three angles of the Unitarity Triangle. Even though the CLEO experiment could observe indirect CP–violation and obtain a constraint on the angle γ, it is not included in the tables, since it is not likely that they will measure these angles directly. The numbers from the BABAR and CDF experiments are given in Table 2 as representatives of asymmetric e+e− and central hadron collider experiments, respectively; the physics reach of BABAR and BELLE, and of CDF and DØ are expected to be very similar [60]. The first row shows the nominal start up year with full detector set up. The b\bar b production rates are calculated with the design luminosities given in the third row. In the remainder of the tables, values were calculated for one “Snowmass year”, 10^7 sec. and using each experiment’s “design” luminosity[6].

The next two rows in the tables compare different experiments based on their expected errors in the so called, “mixing–induced CP Asymmetry, A_{CP}^{mix}”. For the angle β, the Bd → J/ψ K^0 decay channel is used and therefore the error on A_{CP}^{mix} is equivalent to δ(sin(2β)).

Only the decay channel Bd → π^+π^- is considered for the angle, α, and the experimental errors were scaled with a new assumed branching ratio of BR(Bd → π^+π^-) = 7×10^{-6}. The low branching ratio effects both the number of signal events and the ratio of signal to background and therefore has a more detrimental effect on the central high–pt experiments which have large backgrounds from the 2–body hadronic decays. For this decay mode, the quoted errors on A_{CP}^{mix} ignore penguin pollution and assume A_{CP}^{dir} = 0.

With this assumption, δ(A_{CP}^{mix}) = δ(sin(2α)).

No error on the angle γ is given in the tables[6] since the experiments could use more than one method to extract this angle and usually the error on the angle, γ, depends on other quantities such as x_s, the strong phase, etc.

The next row shows the limits on x_s where the Bs oscillations could be

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5“Luminosity leveling” planned for Run–II at Tevatron and also possible for the LHCb experiment will result in a better integrated Luminosity than assumed here.

6The details of the angle γ measurements and the expected errors are discussed in Ref. [40] and [28].
observed. And finally, the last row identifies the experiments which are capable of observing significant signals in the $B_s \to \mu^+\mu^-$ decay mode with the expected Standard Model branching ratio of $BR(B_s \to \mu^+\mu^-) = 4 \times 10^{-9}$ \cite{61}.

All 1st–generation experiments have sufficient sensitivity to observe CP violation in the $B_d \to J/\psi K^o$ decay mode and measure $\sin(2\beta)$. The measurement of angle $\alpha$ is already difficult given the fact that the $B_d \to \pi^+\pi^-$ decay mode suffers from penguin pollution. But even if penguin pollution could be kept under control, if the branching ratio of $B_d \to \pi^+\pi^-$ turns out to be small as assumed in these tables, the measurement of angle, $\alpha$, may be exceedingly difficult at the 1st–generation experiments. On the other hand, the BABAR and BELLE experiments could measure angle $\alpha$ using other channels, such as $B_d \to \rho \pi$. These possibilities have not been fully studied in the hadron experiments.

Since the central high–pt experiments have very limited or no particle identification capability, the $B_d \to \pi^+\pi^-$ decay mode will suffer from large backgrounds from the $B_d \to K^+\pi^-$, $B_s \to K^-\pi^+$ and $B_s \to K^+K^-$ decay modes. In calculating the error on $A_{CP}^{\text{mix}}$, backgrounds from these 2–body decay modes are assumed to have no CP asymmetry. Although CDF and DØ may observe CP asymmetry in this topology, due to the presence of these backgrounds it will probably be impossible for them to extract $\alpha$ from their measurements.

Although $e^+e^-$ experiments could observe “direct CP violation” and set constraints on the angle $\gamma$, none of the 1st–generation experiments measure $\gamma$ using $B_s$ decay modes. Similarly, $x_s$ limits at hadron machines are also limited by the detector resolution and event rates not much above the present LEP limit. $e^+e^-$ experiments could not contribute to $B_s$ physics, since they will presumably be running at the $\Upsilon_{4S}$, at least in the first few years.

Table 3 shows a similar comparison for the 2nd–generation experiments using the latest information available at the time of the writing this paper. Since the Beauty97 conference, the BTeV collaboration introduced improvements to their silicon vertex detector geometry and studied the response of their proposed topology trigger algorithm to multiple interactions; they reported that the algorithm is still functional at luminosities $\mathcal{L} = 2 \cdot 10^{32}$ cm$^{-2}$s$^{-1}$. Most of the improvement in $x_s$ is due to use of a different decay mode than in the original study and an improved silicon vertex design \cite{38}.

The new LHCb numbers are from their Technical Proposal and include
the increase in event yields due to their new trigger implementation and the higher running luminosity [1].

In the 2nd–generation experiments, due to the larger $b\bar{b}$ production rate and/or more efficient triggers, the errors on $\sin(2\beta)$ and $\sin(2\alpha)$ (only for the dedicated B experiments) decrease to the level where stringent tests of the Standard Model could be made. The small differences between the ATLAS and CMS errors are due to the electron identification at lower momenta in ATLAS with their Transition–Radiation–Detector tracker. Both ATLAS and CMS suffer from the lack of particle identification for hadrons. Here again, asymmetry measurements by the general purpose high–$p_t$ experiments using the $B_d \to \pi^+\pi^-$ decay mode will have limited use, due to the large 2–body B decay background. On the other hand, the dedicated B experiments, BTeV and LHCb, will not have this type of background. The only limitation on $\alpha$ from these experiments is the penguin pollution.

The BTeV and LHCb experiments, with their good particle identification capabilities, are the only experiments which have access to the angle $\gamma$ using $B_s$ decay.

All 2nd–generation experiments could observe $B_s$ oscillations at much larger values of $x_s$ than could the 1st–generation experiments. They could also see a significant signal in $B_s \to \mu^+\mu^-$ with the Standard Model branching ratio in a few years.

Of course the B physics programs of the 1st and 2nd–generation experiments are much richer and not limited to these decay modes. There are many other decay modes which could be used in the determination of the angles or to look for New Physics effects. Initially, measurements in different decay modes could be combined to decrease the errors on the CP–asymmetries. Eventually, these may provide additional tests of the Standard Model.

The Standard Model prediction of CP violation in $B_s \to J/\psi \phi$ is very small, $A_{CP}^{mix} = 2\lambda^2\eta$. A measurement of the very small asymmetry with good precision would therefore lead to a determination of $\eta$. On the other hand, the observation of a large CP asymmetry in this channel could only result from New Physics.

The very large heavy flavor data samples at hadron machines will be used to investigate the spectroscopy of open flavor states such as $B_c$ and beauty–flavored baryons and hidden flavor $b\bar{b}$–onium states. The ability of $e^+e^-$ experiments to construct final states containing $\pi^0$’s, i.e. $B_d \to \pi^0\pi^0$, is one of their strong points.
8 Conclusions

Despite the usual unforeseen problems in some experiments, all projects are moving ahead with full speed to observe CP violation in the decay, $B_d \rightarrow J/\psi K^0$, at the turn of the century. However, the actual discovery time will depend on a few critical issues. For example, when will the HERA-B tracking system be complete and when will the $e^+e^-$ machines and the Tevatron collider reach their design luminosities?

If the branching ratio of $B_d \rightarrow \pi^+\pi^-$ turns out to be small as hinted by the recent CLEO data, the measurements of $\sin(2\alpha)$ might take several years. In this case, experiments might observe “Direct” CP violation in charged B decays before measuring $\sin(2\alpha)$, thus providing direct evidence for a non-zero value of the angle $\gamma$.

It looks like we will have to wait for the 2nd–generation dedicated B experiments for the determination of all the angles. Even then there are discrete sign ambiguities to resolve. It is very important to measure these angles using a variety of decay modes. This will increase the chance of observing New Physics effects, which otherwise could be missed.

Since there are many theoretical assumptions in the methods used to extract the angles, the complete determination of the Unitarity Triangle and stringent testing of the Standard Model will require independent determination of these parameters by a variety of methods using different decay modes. In this regard, rare kaon decay experiments on $K^0 \rightarrow \pi^0\nu\bar{\nu}$ and $K^+ \rightarrow \pi^+\nu\bar{\nu}$ will also contribute greatly.

There will be difficulties in the determination of the dilution factors, the production asymmetries and the fake asymmetries possibly introduced by the detector acceptance, triggers or reconstruction. All these problems can be overcome by studying large numbers of different final states. Although experiments always quote their CP–reach for $10^7$ secs, it certainly will take more than one year to understand the systematics of these measurements.

Finally, the present experimental programs have studied their B physics capabilities with only a few analysis methods using a handful of decay modes. As data from the new experiments become available, new analysis methods will be cooked up and ways found to reconstruct decay modes which were thought to be very hard or impossible. There is no better creative stimulation than having real data to play with.

When all the work is done, there are the following possible outcomes:
• The CKM phase is zero and the Unitarity Triangle is flat. This is not very likely; although the present data does not rule out $\eta = 0$, it is at the edge of the allowed region.

• All measurements agree with the Standard Model description of CP violation and the angles, $\alpha, \beta$ and $\gamma$ sum to $\pi$. Thus, there is no sign of New Physics. This would be very “boring”.

• The Unitarity Triangle is not unitary, or it can not explain all the observed CP violation effects. Hence, we have signs of New Physics. This would be very exciting.

• However, the most exciting thing would be to find something totally unexpected which challenges all known theories.

During the last decade, discussing (and calculating) the merits of different ways to do B physics in our cyber experiments dominated our activities.

1. Asymmetric $e^+e^-$ vs. hadron machines?

2. Fixed–target (Gas jet, wire targets, extracted beams) vs. collider?

3. Forward vs. central?

One of the aims of this series of Beauty conferences was to find the answers to these questions. The other was to create a forum to discuss developments in the critical detector, trigger and data acquisition R&D issues. Items 2 and 3 have been resolved in favor of forward collider experiments. The community is slowly realizing that hadronic B–experiments will play a more and more dominant role in the B physics area. Soon real data will be available and the real fun will begin.

The next decade will be even more exciting if, as has happened before, data leads the theory, rather than following and confirming theoretical predictions.

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I think I reflect the sentiments of all the participants when I thank our hosts, Peter Schlein and Jim Kolonko, for organizing a very smooth and pleasant workshop and making this conference a very enjoyable experience for all of us.
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### TABLES

Table 1: List of B physics experiments planned or under construction. Next generation hadron experiment are preparing technical design reports of their detector sub-systems (TDR) or technical proposals (TP).

| Exp.      | Lab.  | Accelerator     | date | Status            |
|-----------|-------|-----------------|------|-------------------|
| CLEO III  | Cornell | Sysm. $e^+e^-$ | 1999 | Upgrade           |
| BABAR     | SLAC  | Asym. $e^+e^-$  | 1999 | Construction      |
| BELLE     | KEK   | Asym. $e^+e^-$  | 1999 | Construction      |
| HERA-B    | HERA  | wire target     | 1999 | Construction      |
| CDF       | FNAL  | Tevatron        | 2000 | Upgrade           |
| DØ        | FNAL  | Tevatron        | 2000 | Upgrade           |
| BTeV      | FNAL  | Tevatron        | ∼2003| Approved R&D for TP |
| ATLAS     | CERN  | LHC             | 2005 | TDRs are partially approved |
| CMS       | CERN  | LHC             | 2005 | TDRs are partially approved |
| LHCb      | CERN  | LHC             | 2005 | Submitted TP, March 1998 |
Table 2: Physics comparison of the 1st–generation B experiments for $10^7$ s, as discussed in the text.

|                  | HERA-B | BABAR | BELLE | CDF |
|------------------|--------|-------|-------|-----|
| **Year**         | 1999   | 1999  | 2000  |     |
| **b$\bar{b}$ rate** | 40 Hz  | 3.6 Hz| 2 kHz |     |
| **$\mathcal{L}$ cm$^{-2}$s$^{-1}$** | $3 \cdot 10^{33}$ | $2 \cdot 10^{33}$ | |
| Ang($\beta$)     | 0.13   | 0.16  | 0.08  |     |
| Ang($\alpha$)    | 0.24   | 0.26  | 0.26  |     |
| Ang($\gamma$)    | No     | No    | No    |     |
| $x_s$            | 17     | No    | 20    |     |
| FCNC ($B_s \rightarrow \mu^+\mu^-$) | No    | No    | No    |     |

Table 3: Physics comparison of the 2nd–generation B experiments for $10^7$ s, as discussed in the text. All numbers given in this Table are the latest values received from the collaborations [58, 41, 59] (March 1998).

|                  | B-TeV | LHCb | ATLAS | CMS |
|------------------|-------|------|-------|-----|
| **Year**         | ~ 2003| 2005 | 2005  | 2005|
| **b$\bar{b}$ rate** | 20 kHz| 100 kHz| 500 kHz| 500 kHz|
| **$\mathcal{L}$ cm$^{-2}$s$^{-1}$** | $2 \cdot 10^{32}$ | $2 \cdot 10^{32}$ | $1 \cdot 10^{33}$ | $1 \cdot 10^{33}$ |
| Ang($\beta$)     | 0.016 | 0.011| 0.017 | 0.021|
| Ang($\alpha$)    | 0.04  | 0.05 | 0.18  | 0.17 |
| Ang($\gamma$)    | Yes   | Yes  | No    | No  |
| $x_s$            | 70    | 75   | 38    | 38  |
| FCNC ($B_s \rightarrow \mu^+\mu^-$) | Yes   | Yes  | Yes   | Yes |
\[ \bar{\rho} = \rho \left(1 - \frac{\lambda^2}{2}\right) \]
\[ \bar{\eta} = \eta \left(1 - \frac{\lambda^2}{2}\right) \]

Figure 1: Unitarity Triangle in \( \bar{\rho}, \bar{\eta} \) plane defining the angles \( \alpha, \beta \) and \( \gamma \). The preferred decay channels used to extract the parameters of the Unitarity Triangle is also shown.
Figure 2: Expected decay time distribution for oscillated $B_s$ decays ($B_s \rightarrow \bar{B}_s \rightarrow X$) for $x_s = 25$ and 50. Solid curves are the ideal (no dilution and perfect vertex (time) resolution) decay time distributions. Shaded curves show the effect of a vertex resolution ($\sigma_t = 0.04 ps$).
Figure 3: Flavor diagram showing the correlation between the flavor and charge of the B meson and the charge of near by $\pi$ or $K$ produced in the fragmentation.

Figure 4: Triangular relation between the decay amplitudes of $B^+ \rightarrow D^0_{\text{CP}} K^+$, $B^+ \rightarrow \bar{D}^0 K^+$ and $B^+ \rightarrow D^0 K^+$ and their charge-conjugate states, where $D^0_{\text{CP}} = (D^0 + \bar{D}^0)/\sqrt{2}$. 

31
Figure 5: Overall view of the BABAR spectrometer.
Figure 6: Overall view of the BELLE spectrometer.
Figure 7: Elevation view of half of CDF II detector.
Figure 8: The schematic view of the DØ tracker system and the new solenoid magnet.
Figure 9: Plan and elevation views of the HERA-B spectrometer.
Figure 10: Layout of the LHCb spectrometer.

Figure 11: Layout of the BTeV two-arm spectrometer.