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MEASUREMENT OF B MIXING FREQUENCY AND CP VIOLATION PARAMETER $\sin 2\beta$ ($\sin 2\phi_1$) AT B FACTORY EXPERIMENTS

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ABSTRACT

Recent results on B mixing and CP violation from the B-factory experiments, *BABAR* at PEP-II and Belle at KEK-B, are summarized. A discussion of CP violation is then presented which concentrates on the CP parameter $\sin 2\beta$ (also known as $\sin 2\phi_1$). The most recent measurements of this parameter from B-factory data yield

$$\sin 2\beta = 0.741 \pm 0.067 \text{ (stat)} \pm 0.033 \text{ (syst) (BaBar)}$$
$$\sin 2\phi_1 = 0.719 \pm 0.072 \text{ (stat)} \pm 0.035 \text{ (syst) (Belle).}$$

These two B-factory results contribute to the current world average of

$$\sin 2\beta = 0.735 \pm 0.055$$

1 Introduction

In the Standard Model, CP violation is made possible by an irreducible complex phase in the three-generation Cabibbo-Kobayashi-Maskawa(CKM) quark-mixing matrix [1]. CP violation is expected if this complex phase is non-zero. The unitarity of the CKM matrix results in six triangles of equal area in the complex plane (Unitarity Triangles). A non-zero area implies the existence of a CP-violating phase – in other words, *if the inner angles of these Unitary Triangles are found to be non-zero, CP-violation is observed*. For the neutral B-meson system, the angles in question are α, β and γ [1] and are defined by the condition

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

In particular, the measurement of the angle β, defined as

$$\beta \equiv \arg\left[\,-V_{\rm cd}V_{\rm cb}^{*}/V_{\rm td}V_{\rm tb}^{*}\,\right], \qquad (2)$$

is the main focus of this paper.

Observation of CP violation in neutral B decays[2] through the measurement of sin2β was reported in summer 2001 by both the *BABAR* [2] and Belle [3] collaborations employing data luminosities of 29.7 and 29.1 fb^{-1}, respectively. By summer 2002, each experiment's total accumulated luminosity had almost tripled. The more precise sin2β results presented in this paper are based on the full samples obtained for summer 2002: 81 fb^{-1} (88 million $B\overline{B}$ decays) for *BABAR* and 78 fb^{-1} (85 million $B\overline{B}$ decays) for Belle.

2 B-Factory Experiments: *BABAR* and Belle

The *BABAR* and Belle B-factory experiments share similar design concepts. Both experiments center around a high luminosity asymmetric electron-positron collider operating at the $\Upsilon(4S)$ resonance. Each experiment also depends on a high-precision detector designed specifically for high-rate, Lorentz-boosted $B\overline{B}$ production. The PEP-II collider (*BABAR*) counter-circulates an electron beam of 9.0 GeV against a positron beam of 3.1 GeV, resulting in a center-of-mass boost of $\beta\gamma = 0.55$. The KEKB collider (Belle) collides electrons and positrons at 8.0 GeV and 3.5 GeV, respectively, resulting in a boost of $\beta\gamma = 0.425$. B-mesons produced at each collider

[1] BaBar uses notation $\{\alpha, \beta, \gamma\}$ and Belle uses notation $\{\phi_2, \phi_1, \phi_3\}$ to address same three CP angles. In this paper, *BABAR* notation is used except for description of Belle-specific results.

[2] Charge-conjugation is implied throughout this document.

are boosted along the e^- direction because of the asymmetric energies, allowing for the measurement of the decay-time difference of the two Bs.

The primary sub-detectors of *BABAR* include a drift chamber (DCH) and a silicon vertex tracker (SVT), both operating inside a 1.5 T magnetic field provided by a super-conducting solenoid. Surrounding the tracking volume is a detector of internally reflected Čerenkov radiation (DIRC), an electromagnetic calorimeter (EMC) and an instrumented flux return (IFR).

The Belle apparatus consists of a silicon vertex detector (SVD), a central drift chamber (CDC), an array of aerogel threshold Čerenkov counters (ACC), time-of-flight scintillation counters (TOF), and an electromagnetic calorimeter (ECL) located inside a super-conducting solenoid coil that provides a 1.5 T magnetic field. An iron flux-return located outside of the coil is instrumented to detect K_L^0 mesons and to identify muons (KLM).

For the CP and mixing measurements, important detector capabilities include tracking, vertexing and particle identification (PID). Details on how each experiment address these requirements can be found in Ref. [4] and Ref. [5].

3 Overview Of Measurement Technique

3.1 Production of $B^0\overline{B}^0$

As a consequence of Bose-Einstein statistics, the $B^0\overline{B}^0$ pairs produced from the $\Upsilon(4S)$ decays remain in a coherent P-wave state until one of the two B-mesons decays. At the moment of the first decay ($t = 0$), the two B-mesons are in opposite flavor states – knowing the flavor state of one B implies knowledge of the other. Between the first decay and its own decay, the second B-meson's flavor evolves according to a time-dependent oscillatory pattern. If the flavor of one B is known when it decays then the flavor state of the other B at its decay point is solely determined by the proper time between decays (Δt) and mixing frequency Δm_d.

3.2 Exclusive Reconstruction of One B-Meson

Given the large number of B-mesons produced at B-Factories, it is conceivable to exclusively reconstruct one of the two B-mesons into a known decay mode. Excluding from consideration the decay products of this reconstructed B (B_{rec}), the remaining particles in the event then presumably belong to the "other B". Often, the flavor of this "other B" can be determined through an inclusive flavor tagging method (B Flavor-Tagging). For this reason, this inclusively "reconstructed" second B-meson is commonly referred as the (B_{tag}). The B_{rec} and B_{tag} can be individually vertexed, and the distance between the two vertices used to determine the proper-time difference $\Delta t (\equiv t_{rec} - t_{tag})$.

The choice of exclusive decay modes is determined according to physics objectives. For a B-mixing measurement, the B_{rec} has to decay into one of the (self-tagged) flavor eigenstates. The mixing frequency Δm_d is determined by comparing the flavor of the B_{rec} and B_{tag} (both known) in a time-dependent way. For CP measurements, B_{rec}'s are required to be reconstructed in a CP eigenstate, such as $J/\psi K_S^0$, etc.

3.3 B Decay Time Interval

In asymmetric $B\overline{B}$ production, as at *BABAR* and Belle, the large boost causes the B mesons to fly preferentially along the beam direction (conventionally the z-axis). Accordingly, the time interval Δt between the two B decays is calculated, to a good approximation, as

$$\Delta t = \Delta z / (\beta \gamma c), \tag{3}$$

where Δz is the distance between the decay vertices of B_{rec} and B_{tag} along the z-axis. The B_{rec} vertex is determined by using the charged tracks from its exclusive decay products; intermediate vertices, such as those from K_S^0 decay, are also reconstructed. The B_{tag} vertex is obtained by an inclusive fit on charged tracks which do not belong to the exclusive B_{rec}. Constraints from the beam spot locations and B_{rec} momentum are applied when fitting for B_{tag}.

The Δt resolution is affected by the detector resolution for both the B_{rec} and B_{tag} vertices, by a shift on the B_{tag} vertex due to secondary charmed decays, and by kinematic smearing due to the fact that the B flight is not exactly in the z-direction. Accordingly, an empirical resolution function is used to model these effects. In both experiments, the parameters in the resolution functions are determined in data from fits to the neutral and charged B meson lifetime. An average r.m.s. Δt resolution is 1.1ps for *BABAR* and 1.43ps for Belle, both obtained from data.

3.4 Flavor Tagging

The flavor of the B_{tag} is determined through various flavor signatures among its daughter tracks. High momentum (primary) leptons, kaons and soft pions from D^{*+} decay are primary sources for flavor tagging. In addition, Λ baryons and lower

Table 1: Efficiencies ϵ_i, average mistag fractions w_i, mistag fraction differences $\Delta w_i = w_i(B^0) - w_i(\overline{B}^0)$, and Q extracted for each tagging category i from the B_{flav} and B_{CP} sample. This data was collected by the *BABAR* collaboration.

Category	ε (%)	w (%)	Δw (%)	Q (%)
`Lepton`	9.1 ± 0.2	3.3 ± 0.6	-1.5 ± 1.1	7.9 ± 0.3
`Kaon I`	16.7 ± 0.2	10.0 ± 0.7	-1.3 ± 1.1	10.7 ± 0.4
`Kaon II`	19.8 ± 0.3	20.9 ± 0.8	-4.4 ± 1.2	6.7 ± 0.4
`Inclusive`	20.0 ± 0.3	31.5 ± 0.9	-2.4 ± 1.3	2.7 ± 0.3
All	65.6 ± 0.5			28.1 ± 0.7

momentum (secondary) leptons can also be used to assist tagging. To obtain optimal tagging efficiency, both experiments use multivariate algorithms to combine various sources of flavor information in an event. Similar events, judged by their physics content or estimated tagging purity, are usually grouped into tagging categories to aid in the study of tagging-based systematic errors.

The figure of merit for B flavor-tagging is the effective tagging efficiency,

$$Q \equiv \sum_i \varepsilon_i (1 - 2w_i)^2, \tag{4}$$

where i sums over tagging categories. Since the *CP* measurement error and tagging efficiency are related ($\sigma_{asym} \propto 1/\sqrt{Q}$), a higher effective tagging efficiency reduces *CP* measurement error.

At *BABAR*, events are grouped into four hierarchical, mutually exclusive tagging categories based on their physics contents. The `Lepton` category contains events with an identified high momentum lepton. Events with a kaon are assigned to either the `Kaon I` or `Kaon II` category. Among the two, the `Kaon I` category contains events with higher estimated tagging probability, contributed by additional tagging sources such as a soft pion compatible with D^{*+} decay. The `Kaon II` category also contains remaining events with a soft pion. All other events are assigned to the `Inclusive` category except for those that have no useful tagging information (which are excluded from further analysis). A set of neural networks have been developed to classify events and to provide estimated mistag probability. The efficiency and mistag probability for each of the four tagging categories can be obtained from data as shown in table 1. Based on these measured efficiencies and mistag probability, the effective tagging efficiency(Q) is calculated to be 28.1%.

At Belle, events are instead grouped into tagging categories based solely on estimated tagging probability. A quantity r is assigned to each event. An r value of zero signifies no tagging power and an r value of 1 means perfect tagging.

Events are sorted into six intervals of r between 0 and 1, according to flavor purity. The event fraction and mistag probability for each category are determined directly from data as summarized in table 2. The corresponding Q value for Belle is 28.8%, similar to that of *BABAR*'s.

Table 2: The event fractions (ϵ_l) and wrong tag fractions (w_l) for each r interval. The errors include both statistical and systematic uncertainties. The event fractions are obtained from the $J/\psi K_S^0$ simulation. This data was collected by the Belle collaboration.

$Category(l)$	r	ϵ_l	w_l
1	$0.000 - 0.250$	0.399	0.458 ± 0.006
2	$0.250 - 0.500$	0.146	0.336 ± 0.009
3	$0.500 - 0.625$	0.104	$0.229\ ^{+0.010}_{-0.011}$
4	$0.625 - 0.750$	0.122	0.159 ± 0.009
5	$0.750 - 0.875$	0.094	0.111 ± 0.009
6	$0.875 - 1.000$	0.137	$0.020\ ^{+0.007}_{-0.006}$

4 Measurement Of $B^0\overline{B}^0$ Oscillation Frequency

To measure the B^0 mixing parameter Δm_d, the flavors of both the B_{rec} and B_{tag} need to be determined. The mixing frequency is extracted from the time evolution of opposite-flavor ("unmixed") and same-flavor ("mixed") B-decays. The physics probability density function (PDF), before accounting for detector and background effects, is:

$$\mathrm{f}(\Delta t) \quad = \quad \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}}[1 \pm \cos(\Delta m_d \Delta t)], \tag{5}$$

where τ_{B^0} is the B^0 lifetime, and "$\pm$" denotes "$+$" for unmixed events and "$-$" for mixed events.

Samples that can be used for the mixing measurement include:

1. "Fully Hadronic", where B_{rec} is completely reconstructed to the exclusive hadronic decays $D^{(*)-}h$ (where $h = \pi^+, \rho^+, a_1^+$), $J/\psi K^{*0}(K^{*0} \to K^+\pi^-)$.
2. "Semileptonic", where B_{rec} is reconstructed to $D^{*-}l^+\nu$.
3. "Partial $D^*\pi$", where B_{rec} is partially reconstructed to $D^{*-}\pi^+$ ($D^{*-} \to D^0\pi^-$).
4. "Dilepton", where instead of attempting to reconstruct one of the B decays, events with two high momentum leptons are used.

For the first three samples above, the flavor of the B_{rec} is determined by the charge of its daughters and the flavor of the B_{tag} is provided by flavor tagging.

The time-difference Δt is determined using the B_{rec} and B_{tag} vertices. For dilepton samples, the charges of the two leptons (which are presumed to be from semileptonic B decays) indicate the flavor of the B-mesons. Proper-time information is obtained using the impact parameters of the two leptons.
BaBar has reported results from three measurements [7]:

- $\Delta m_d = 0.516 \pm 0.016(\text{stat}) \pm 0.010(\text{syst})\,\text{ps}^{-1}$ ("Hadronic" , 30 fb^{-1})
- $\Delta m_d = 0.492 \pm 0.018(\text{stat}) \pm 0.013(\text{syst})\,\text{ps}^{-1}$ ("Semileptonic", 21 fb^{-1})
- $\Delta m_d = 0.493 \pm 0.012(\text{stat}) \pm 0.009(\text{syst})\,\text{ps}^{-1}$ ("Dilepton", 21 fb^{-1})

Belle has reported results from four measurements [8]:

- $\Delta m_d = 0.528 \pm 0.017(\text{stat}) \pm 0.011(\text{syst})\,\text{ps}^{-1}$ ("Hadronic", 29 fb^{-1})
- $\Delta m_d = 0.494 \pm 0.012(\text{stat}) \pm 0.015(\text{syst})\,\text{ps}^{-1}$ ("Semileptonic", 29 fb^{-1})
- $\Delta m_d = 0.505 \pm 0.017(\text{stat}) \pm 0.020(\text{syst})\,\text{ps}^{-1}$ ("Partial $D^*\pi$" , 29 fb^{-1})
- $\Delta m_d = 0.503 \pm 0.008(\text{stat}) \pm 0.009(\text{syst})\,\text{ps}^{-1}$ ("Dilepton", 29 fb^{-1})

Combining *BABAR* and Belle results yields $\Delta m_d = 0.503 \pm 0.007\,\text{ps}^{-1}$, as compared with combined non B-factory results $\Delta m_d = 0.498 \pm 0.013\,\text{ps}^{-1}$ (LEP+SLD+CDF).
If all results are combined, a world average Δm_d value of $0.503 \pm 0.006\,\text{ps}^{-1}$ is obtained.

5 CP Violation Measurement With Charmonium Final States

For the measurement of CP asymmetries, the B_{rec} needs to be reconstructed in a CP eigenstate (B_{CP}) with eigenvalue $\eta_f = -1$ or $+1$. For events where $B_{rec}= B_{CP}$ and the flavor of B_{tag} is known to be $B^0(\overline{B}^0)$, the decay rate $f_+(f_-)$ is given by

$$f_\pm(\Delta t) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}}\left[1 \pm \frac{2\,\mathcal{I}m\,\lambda}{1+|\lambda|^2}\sin(\Delta m_d \Delta t) \mp \frac{1-|\lambda|^2}{1+|\lambda|^2}\cos(\Delta m_d \Delta t)\right], \qquad (6)$$

where λ is a complex parameter that depends on both the B^0-$\overline{B}^0$ oscillation amplitude and the amplitudes describing $\overline{B}^0$ and B^0 decays to a common *CP* final state. *CP* violation arises if λ is not unity. In other words, *CP* violation is manifested with a non vanishing sine or cosine term in the equation. Experimentally, *CP* violation can be observed as a difference between the Δt distributions of B^0- and $\overline{B}^0$-tagged events or as an asymmetry with respect to $\Delta t = 0$ for either flavor tag.

Among many possible CP modes, $b \to c\bar{c}s$ (charmonium) decays offer the best opportunity for CP violation measurement [9]. These modes include the CP-odd ($\eta_f = -1$) final states $J/\psi K^0_S$, $\psi(2S)K^0_S$, $\chi_{c1}K^0_S$, and $\eta_c K^0_S$, and CP-even ($\eta_f = +1$)

state $J/\psi\, K^0_L$. In addition, a CP-mixed state $J/\psi\, K^{*0}$, where K^{*0} decays to $K^0_S\pi^0$, can also be used after its CP composition is measured through an angular analysis. For this CP-mixed $J/\psi\, K^{*0}$ decay, *BABAR* and Belle find the CP-odd fraction to be $16.0 \pm 3.5\%$ and $19 \pm 2(\mathrm{stat}) \pm 3(\mathrm{syst})\%$, respectively. This fraction can be used to compute an effective η_f (~ 0.65) for use in the CP extraction.

Table 3: Number of signal events $N_{\rm tag}$ after tagging and vertexing requirements, signal purity P, and results of fitting for *CP* asymmetries in the B_{CP} sample and in various sub-samples, as well as in the $B_{\rm flav}$ and charged B control samples. Errors are statistical only. (*BABAR* experiment)

Sample	$N_{\rm tag}$	$P(\%)$	$\sin2\beta$
$J/\psi\, K^0_S$,$\psi(2S)K^0_S$,$\chi_{c1}K^0_S$,$\eta_c K^0_S$	1506	94	0.76 ± 0.07
$J/\psi\, K^0_L$ ($\eta_f = +1$)	988	55	0.72 ± 0.16
$J/\psi\, K^{*0}(K^{*0} \to K^0_S\pi^0)$	147	81	0.22 ± 0.52
$J/\psi\, K^0_S$ ($K^0_S \to \pi^+\pi^-$)	974	97	0.82 ± 0.08
$J/\psi\, K^0_S$ ($K^0_S \to \pi^0\pi^0$)	170	89	0.39 ± 0.24
$\psi(2S)K^0_S$ ($K^0_S \to \pi^+\pi^-$)	150	97	0.69 ± 0.24
$\chi_{c1}K^0_S$	80	95	1.01 ± 0.40
$\eta_c K^0_S$	132	73	0.59 ± 0.32
`Lepton` category	220	98	0.79 ± 0.11
`Kaon I` category	400	93	0.78 ± 0.12
`Kaon II` category	444	93	0.73 ± 0.17
`Inclusive` category	442	92	0.45 ± 0.28
B^0 tags	740	94	0.76 ± 0.10
$\overline{B}^0$ tags	766	93	0.75 ± 0.10
$B_{\rm flav}$ sample	25375	85	0.02 ± 0.02
charged B sample	22160	89	0.02 ± 0.02
Full *CP* sample	2641	78	0.74 ± 0.07

In the Standard Model, λ is expected to be $\eta_f e^{-2i\beta}$ ($|\lambda| = 1$, $Im(\lambda) = -\eta_f \sin2\beta$) for these charmonium decays. Thus, a measurement with the time dependent decay rates in equation 6 directly reveals the CP parameter $\sin2\beta$ with little ambiguity.

Both *BABAR* and Belle reconstruct these charmonium modes for use in their $\sin2\beta$ measurements [12, 13]. Yields on each signal mode are summarized in table 3 for BaBar [3] and in table 4 for Belle. Shown also in these two tables are measured $\sin2\beta$ ($\sin2\phi_1$) value for each sub-sample (see text below).

After the flavor of the B_{tag} and time-difference Δt are determined for each event in the CP sample, the whole sample is used to construct a likelihood function

[3] Only events with a flavor tag are included, total Tagging efficiency is $65.6 \pm 0.5\%$.

Table 4: The numbers of reconstructed $B \to f_{CP}$ candidates before flavor tagging and vertex reconstruction ($N_{\rm rec}$), the numbers of events used for the $\sin 2\phi_1$ determination ($N_{\rm ev}$), and the estimated signal purity for each f_{CP} mode. (Belle experiment.)

Sample	$N_{\rm rec}$	$N_{\rm ev}$	Purity	sin2ϕ_1
$J/\psi\,(\ell^+\ell^-)K_S^0(\pi^+\pi^-)$	1285	1116	0.98	0.73 ± 0.10
$J/\psi\,(\ell^+\ell^-)K_S^0(\pi^0\pi^0)$	188	162	0.82	
$\psi(2S)(\ell^+\ell^-)K_S^0(\pi^+\pi^-)$	91	76	0.96	
$\psi(2S)(J/\psi\,\pi^+\pi^-)K_S^0(\pi^+\pi^-)$	112	96	0.91	
$\chi_{c1}(J/\psi\,\gamma)K_S^0(\pi^+\pi^-)$	77	67	0.96	0.67 ± 0.17
$\eta_c(K_S^0K^-\pi^+)K_S^0(\pi^+\pi^-)$	72	63	0.65	
$\eta_c(K^+K^-\pi^0)K_S^0(\pi^+\pi^-)$	49	44	0.72	
$\eta_c(p\overline{p})K_S^0(\pi^+\pi^-)$	21	15	0.94	
$J/\psi\,(\ell^+\ell^-)K^{*0}(K_S^0\pi^0)$	101	89	0.92	0.04 ± 0.63
$J/\psi\,(\ell^+\ell^-)K_L^0$	1330	1230	0.63	0.78 ± 0.17
All CP Sample	3326	2958	0.81	0.72 ± 0.07

based on the PDF

$$\mathrm{f}(\Delta t) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}}[1 - \eta_f q(1-2w)\sin 2\beta \sin(\Delta m_d \Delta t)] \tag{7}$$

where $q = +1(-1)$ when B_{tag} is tagged as B^0 ($\overline{B}^0$) and w is the estimated mistag probability for the tagging category to which the event belongs. As mentioned earlier, both *BABAR* and Belle obtain w from data. The CP-parameter sin2β in the PDF serves as a free parameter and is to be extracted from a fit on the data employing the PDF.

The above physics PDF has to be modified to take into account the time resolution function and background time distribution. Details of time resolution treatment and fitting procedure can be found in [10] for *BABAR* and in [11] for Belle.

The value of sin2β is determined by an unbinned maximum-likelihood fit to the observed Δt distribution. For all CP modes combined, the fitted sin2β (sin2ϕ_1) values are:

$$\begin{aligned} \sin 2\beta &= 0.741 \pm 0.067\ (\mathrm{stat}) \pm 0.033\ (\mathrm{syst}).\ (\mathrm{BaBar}) \\ \sin 2\phi_1 &= 0.719 \pm 0.074\ (\mathrm{stat}) \pm 0.035\ (\mathrm{syst}).\ (\mathrm{Belle}) \end{aligned}$$

Fitted sin2β values for various sub-samples are included in table 3 for *BABAR* and table 4 for Belle. No inconsistency between the samples is observed.

Combining these latest two sin2β results from *BABAR* and Belle with earlier (non B-factory) results, namely $(0.84^{+0.82}_{-1.04} \pm 0.16)$ from Aleph, $(0.79^{+0.41}_{-0.44})$ from CDF and $(3.20^{+1.8}_{-2.0} \pm 0.5)$ from OPAL, a world average of $\sin 2\beta = 0.735 \pm 0.055$ is obtained.

This world average value on (directly measured) sin2β can be compared with the Standard Model constraints in the $\overline{\rho} - \overline{\eta}$ plane, as shown in figure 1. The indirect constraints are realized from measurements on $|V_{ub}/V_{cb}|$, Δm_d, Δm_s and CP-violation in the kaon system. Within the current measurement uncertainties, good agreement is observed. Measurements with improved precision and, in particular, measurements of other CP angles are necessary to provide a more stringent test on the Standard Model CKM theory of CP-violation.

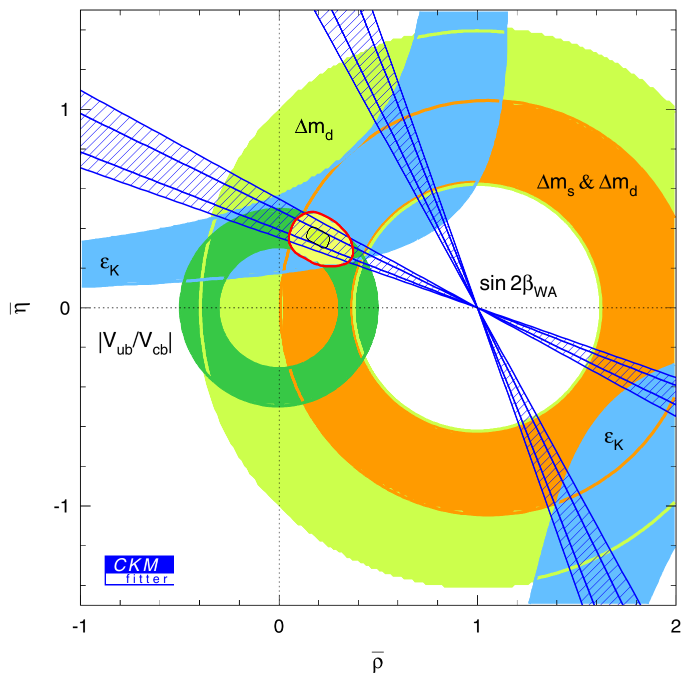

Figure 1: Directly measured sin2β result shown as straight lines in the CKM $\overline{\eta}$-$\overline{\rho}$ plane. Contours near $\overline{\eta} = 0.3$ *and* $\overline{\rho} = 0.2$ are Standard Model prediction fitted with constraints from other measurements.

The sin2β measurements discussed so far are performed with the assumption $|\lambda| = 1$, as is predicted by the Standard Model for the $b \to c\bar{c}s$ decays. To test this assumption, a more general physics PDF, shown earlier in equation 6, can instead be used. A fitting based on this generalized PDF gives [4]

$$|\lambda| \;=\; 0.948 \pm 0.051 \text{ (stat)} \pm 0.017 \text{ (syst)} \text{ (BaBar)}$$

[4]Belle uses all *CP* modes in this generalized fit while *BABAR* fits only on *CP*-odd modes.

$$|\lambda| = 0.950 \pm 0.049 \text{ (stat)} \pm 0.026 \text{ (syst) (Belle)}$$

The coefficient of $\sin(\Delta m_d \Delta t)$ term is simultaneously fitted to be 0.759 ± 0.074 (stat) at *BABAR* and 0.720 ± 0.074 (stat) at Belle, respectively. These results are consistent with the original assumption of $|\lambda| = 1$.

6 CP Violation Measurement With Other Modes

In addition to the $b \to c\bar{c}s$ charmonium modes, *CP* violation measurement can be performed with many other *CP* decays. In this section, *CP* results measured from two classes of $\sin2\beta$ [5] sensitive samples, the Cabibbo-suppressed $b \to c\bar{c}d$ decays and the penguin dominated $b \to s\bar{s}s$ decays, are briefly summarized. More details can be found in [14, 15].

Unlike the theoretically clean $b \to c\bar{c}s$ decays with which $\sin2\beta$ can be directly measured, these additional modes may be affected by more than one *CP*-violating phases. The Standard Model assumption $\lambda = \eta_f e^{-2i\beta}$ can not always be applied; often, a generic form of physics PDF as defined in equation 6 has to be used. With this generic PDF, *CP* asymmetry coefficients $S_f (\equiv \frac{2\mathcal{I}m\,\lambda}{1+|\lambda|^2})$ and $C_f (\equiv \frac{1-|\lambda|^2}{1+|\lambda|^2})$ can be extracted and compared with theoretical predictions. In the limit that only one weak phase contributes, the coefficient S_f should be equal to $-\eta_f \sin2\beta$, where η_f is the eigen value of the corresponding *CP* mode, and the coefficient C_f should be equal to zero.

6.1 Time Dependent CP Asymmetries With $b \to c\bar{c}d$ Decays

One useful $b \to c\bar{c}d$ mode is the $B^0 \to J/\psi\,\pi^0$ decay where a *CP* even ($\eta_f = +1$) final state is produced. The decay process receives both tree and penguin contributions. The Cabibbo-suppressed tree contribution has the same weak phase as the $b \to c\bar{c}s$ modes but the penguin contribution of comparable strength may bring in a different weak phase. Both *BABAR* and Belle have reconstructed events in this mode; the measured *CP* asymmetry coefficients are:

$$\begin{aligned} S_{J/\psi\,\pi^0} &= 0.05 \pm 0.49 \text{ (stat)} \pm 0.16 \text{ (syst) } (BABAR) \\ C_{J/\psi\,\pi^0} &= 0.38 \pm 0.41 \text{ (stat)} \pm 0.09 \text{ (syst) } (BABAR) \\ S_{J/\psi\,\pi^0} &= 0.93 \pm 0.49 \text{ (stat)} \pm 0.08 \text{ (syst) (Belle)} \\ C_{J/\psi\,\pi^0} &= -0.25 \pm 0.39 \text{ (stat)} \pm 0.06 \text{ (syst) (Belle).} \end{aligned}$$

[5] Results on $\sin2\alpha$ are summarized in a separate article in this proceedings.

In addition to $B^0 \to J/\psi\,\pi^0$, *BABAR* has also constructed the $B^0 \to D^{*+}D^{*-}$ decay. This decay is also a $b \to c\bar{c}d$ process but the final state $D^{*+}D^{*-}$ is not a *CP* eigenstate – an angular analysis is necessary to determine the *CP* composition. With their $D^{*+}D^{*-}$ sample, *BABAR* has measured a *CP*-odd fraction of 0.096 ± 0.060(stat) and extracted the effective *CP* asymmetry parameters as:

$$\begin{aligned} Im(\lambda) &= 0.31 \pm 0.43 \text{ (stat)} \pm 0.13 \text{ (syst)} \\ |\lambda| &= 0.98 \pm 0.25 \text{ (stat)} \pm 0.09 \text{ (syst)} \end{aligned}$$

If the $B^0 \to D^{*+}D^{*-}$ decay is a tree-only process, $Im(\lambda) = -\sin 2\beta$ and $|\lambda| = 1$ are expected. In the Standard Model, penguin-induced correction is predicted to be small ($< 2\%$) compared to this tree-only *CP* asymmetry.

6.2 Time Dependent CP Asymmetries With $b \to s\bar{s}s$ Decays

The penguin dominated $b \to s\bar{s}s$ process is also sensitive to $\sin 2\beta$. If only the Standard Model weak phase contributes, the *CP* coefficients S_f and C_f are expected to be $-\eta_f \sin 2\beta (\sin 2\phi_1)$ and zero, respectively. Significant deviations to these expected value probe for new physics (in the penguin loops, for example).

BABAR has reported *CP* results from the *CP*-odd $B^0 \to \phi K^0_S$ decays. The effective $\sin 2\beta$ value is found to be $-0.19^{+0.52}_{-0.50}$(stat) $\pm$ 0.09(syst).

Belle has presented results with two *CP*-odd, $B^0 \to \phi K^0_S$ and $B^0 to \eta' K^0_S$ modes, and a *CP* mixed mode[6] $B^0 \to K^+K^-K^0_S$ as well. The "$\sin 2\phi_1$" ($\equiv -\eta_f S_f$) values measured from these three decays are 0.76 ± 0.36(stat)$^{+0.05}_{-0.06}$(syst), -0.73 ± 0.64(stat) $\pm$ 0.18(syst), and 0.52 ± 0.46(stat) $\pm$ 0.11(syst), respectively [7]. In the meantime, *CP* asymmetry parameter C_f is also measured with each mode and found to be consistent with zero.

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[6] For this *CP* mixed mode, Belle has measured its *CP* composition to be 97% *CP*-odd and 3% *CP*-even.

[7] The systematic error for the $K^+K^-K^0_S$ mode is subject to an additional $^{0.27}_{0.03}$ contribution from the uncertainty in the fraction of the *CP*-odd component

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