RESULTS ON THE CKM ANGLE ϕ_1 (β)

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I review results related to the CKM angle $\phi_1(\beta)$. These results include recent measurements of CP-violation from the BaBar and Belle experiments in $b \to c\bar{c}s$, $b \to c\bar{c}d$ and $b \to sq\bar{q}$ processes.

1. Introduction

1.1. *The B Physics Program*

The B physics program addresses several fundamental questions. Is the irreducible phase in the Cabibbo-Kobayashi-Maskawa (CKM) matrix the source of all CP-violating phenomena in the B system?[1] Or is CP-violation, the first manifestation of physics beyond the Standard Model? A related question is whether there are new CP-violating phases from physics beyond the Standard Model.[2]

The unitarity of the CKM matrix implies the existence of three measurable phases. In the convention favored at KEK and Belle, these are denoted

$$\phi_1 \equiv arg\left(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right) \quad (1)$$

$$\phi_2 \equiv arg\left(-\frac{V_{ud}V_{ub}^*}{V_{td}V_{tb}^*}\right) \quad (2)$$

$$\phi_3 \equiv arg\left(-\frac{V_{cd}V_{cb}^*}{V_{ud}V_{ub}^*}\right). \quad (3)$$

while at SLAC and at BaBar these angles are usually referred to as β, α and γ, respectively.

As first noted by Bigi, Carter and Sanda,[3] there are large measurable CP-asymmetries in the decays of neutral B mesons to CP-eigenstates. In the decay chain $\Upsilon(4S) \to B^0\bar{B}^0 \to f_{CP}f_{\rm tag}$, where one of the B mesons decays at time t_{CP} to a final state f_{CP} and the other decays at time $t_{\rm tag}$ to a final state $f_{\rm tag}$ that distinguishes between B^0 and $\bar{B}^0$, the decay rate has a time dependence given by[3]

$$\frac{e^{-\frac{|\Delta t|}{\tau_{B^0}}}}{4\tau_{B^0}}\left\{1 + q\cdot\Big[\mathcal{S}\sin(\Delta m_d\Delta t) + \mathcal{A}\cos(\Delta m_d\Delta t)\Big]\right\},$$

where τ_{B^0} is the B^0 lifetime, Δm_d is the mass difference between the two B^0 mass eigenstates, $\Delta t = t_{CP} - t_{\rm tag}$, and the b-flavor charge $q = +1$ (-1) when the tagging B meson is a B^0 ($\bar{B}^0$). The CP-violation parameters $\mathcal{S}$ and $\mathcal{A}$ are given by

$$\mathcal{S} \equiv \frac{2\mathcal{I}m(\lambda)}{|\lambda|^2+1}, \qquad \mathcal{A} \equiv \frac{|\lambda|^2-1}{|\lambda|^2+1}, \quad (4)$$

where λ is a complex parameter that depends on both the $B^0\bar{B}^0$ mixing and on the amplitudes for B^0 and $\bar{B}^0$ to decay to f_{CP}. To a good approximation, the SM predicts $\mathcal{S} = -\xi_f \sin 2\phi_1$, where $\xi_f = +1(-1)$ corresponds to CP-even (-odd) final states. Direct CP-violation, $\mathcal{A} = 0$ (or equivalently $|\lambda| = 1$), is expected for both $b \to c\bar{c}s$ and $b \to s\bar{s}s$ transitions.

1.2. *Accelerators and Detectors*

The B-factory accelerators, PEPII[4] and KEKB[5] were commissioned with remarkable speed starting in late 1998. The experiments, BaBar[6] and Belle,[7] started physics data taking in 1999. In the summer of 2001, the two experiments announced the observation of the first statistically significant signals for CP-violation outside of the kaon system.[8,9]

Due to the extraordinary performance of the two accelerators, the most recent results reported in the summer of 2003 at the Lepton-Photon Symposium are based on very large data samples. BaBar has integrated 113 fb^{-1} on the $\Upsilon(4S)$ resonance while Belle has integrated a sample of 140 fb^{-1}. KEK-B also passed a critical milestone for e^+e^- storage rings and achieved a peak luminosity above 1×10^{34} cm$^{-2}s^{-1}$.

1.3. *The Principle of the Measurement*

The measurement of time-dependent CP-asymmetry requires:

- A large sample of $\Upsilon(4S)$ decays into $B^0\bar{B}^0$ pairs. To boost the $\Upsilon(4S)$ decay frame so that the B mesons' flight length can be measured with solid-state vertex detector technology, both the KEKB and PEP-II accelerators use asymmetric energy beams with energies of 8.0 and 3.5 GeV or 9.0 and 3.1 GeV, respectively.

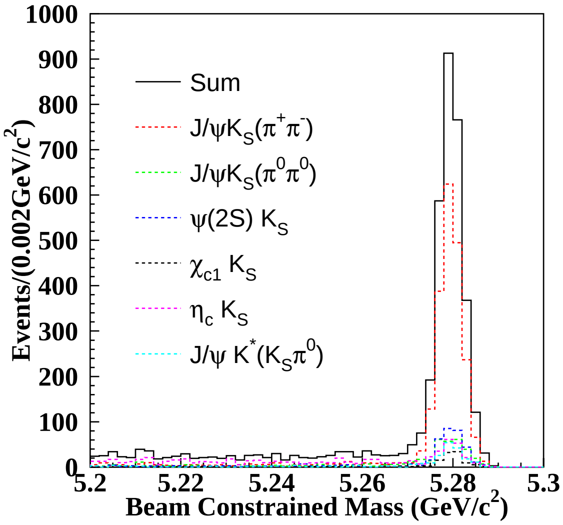

Figure 1. The fully reconstructed CP-eigenstate sample used by Belle. This sample is obtained from a data sample with an integrated luminosity of 140 fb^{-1}.

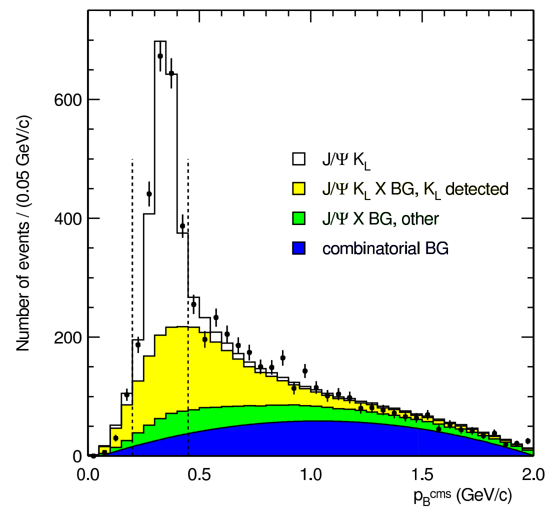

Figure 2. The p_B^* (B momentum in the CM frame) distribution for the $B \to J/\psi K_L$ sample used by Belle. This sample is obtained from a data sample with an integrated luminosity of 140 fb^{-1}. The shaded portions show the contributions of different background components. The vertical dashed lines indicate the signal region.

- Efficient reconstruction of $B \to X_{c\bar{c}} K^0$ decays. This implies accurate measurements of momenta and energies of neutrals using CsI(Tl) crystal calorimeters in addition to good charged particle tracking in small cell drift chambers and efficient identification of leptons and K_S^0 as well as K_L^0 mesons.

- A measurement of Δt. This is related to the measurement of Δz, the spatial distance between the decay vertices and achieved at both experiments by using double-sided silicon strip detectors situated at small radii close to the interaction point.

- A determination of the flavor of the accompanying B ("tagging"); this is based on the identification of electrons, muons and charged kaons and the measurement of their charge.

More detailed descriptions of the detectors[6,7] and the experimental analysis procedure are available elsewhere.[10]

2. Status of CP-Violation in $b \to c\bar{c}s$ Processes

Belle and BaBar reconstruct B^0 decays to the following $b \to c\bar{c}s$ CP-eigenstates: $J/\psi K_S$, $\psi(2S)K_S$, $\chi_{c1}K_S$, $\eta_c K_S$ for $\xi_f = -1$ and $J/\psi K_L$ for $\xi_f = +1$.[11] The two classes ($\xi_f = \pm 1$) should have CP-asymmetries that are opposite in sign.

Both experiments also use $B^0 \to J/\psi K^{*0}$ decays where $K^{*0} \to K_S \pi^0$. Here the final state is a mixture of even and odd CP. The CP content can, however, be determined from an angular analysis of other ψK^* decays. The CP-odd fraction is found to be small (i.e. $(19 \pm 4)\%$ ($(16 \pm 3.5)\%$) in the Belle (BaBar) analysis).

The most recent BaBar analysis is based on a data sample with an integrated luminosity of 81 fb^{-1} and was first presented in 2002.[9] There is a corresponding published Belle result also shown in 2002 with 78 fb^{-1}.[8] At this Symposium, Belle provided a new preliminary result for their 140 fb^{-1} sample.[12]

The data sample used for the recent Belle measurement is shown in Fig. 1 and Fig. 2. Table 1 lists the numbers of candidates, N_{ev}, and the estimated signal purity for each f_{CP} mode. It is clear that the CP-eigenstate samples that are used for the CP-violation measurements in $b \to c\bar{c}s$ are large and clean.

In the summer of 2001, the first statistically significant measurements of the CP-violating parameter $\sin 2\phi_1$ were reported by Belle and BaBar. Belle

Table 1. The yields from Belle for reconstructed $B \to f_{CP}$ candidates after flavor tagging and vertex reconstruction, $N_{\rm ev}$, and the estimated signal purity, p, in the signal region for each f_{CP} mode. J/ψ mesons are reconstructed in $J/\psi \to \mu^+\mu^-$ or e^+e^- decays. Candidate K_S^0 mesons are reconstructed in $K_S^0 \to \pi^+\pi^-$ decays unless otherwise written explicitly.

Mode	ξ_f	$N_{\rm ev}$	p
$J/\psi K_S^0$	-1	1997	0.976 ± 0.001
$J/\psi K_S^0(\pi^0\pi^0)$	-1	288	0.82 ± 0.02
$\psi(2S)(\ell^+\ell^-)K_S^0$	-1	145	0.93 ± 0.01
$\psi(2S)(J/\psi\pi^+\pi^-)K_S^0$	-1	163	0.88 ± 0.01
$\chi_{c1}(J/\psi\gamma)K_S^0$	-1	101	0.92 ± 0.01
$\eta_c(K_S^0K^-\pi^+)K_S^0$	-1	123	0.72 ± 0.03
$\eta_c(K^+K^-\pi^0)K_S^0$	-1	74	0.70 ± 0.04
$\eta_c(p\bar{p})K_S^0$	-1	20	0.91 ± 0.02
All with $\xi_f = -1$	-1	2911	0.933 ± 0.002
$J/\psi K^{*0}(K_S^0\pi^0)$	$+1(81\%)$	174	0.93 ± 0.01
$J/\psi K_L^0$	$+1$	2332	0.60 ± 0.03

found

$$\sin 2\phi_1 = 0.99 \pm 0.14 \pm 0.06 \tag{5}$$

while BaBar obtained

$$\sin 2\phi_1 = 0.59 \pm 0.14 \pm 0.05. \tag{6}$$

The results were based on data samples of comparable size (31 million and 32 million $B\bar{B}$ pairs, respectively).

The new Belle data are shown in Fig. 3. This figure shows the Δt distributions where a clear shift between B^0 and $\bar{B}^0$ tags is visible as well as the raw asymmetry plots in two bins of the flavor tagging quality variable r. For low-quality tags ($0 < r < 0.5$), which have a large background dilution, only a modest asymmetry is visble while in the subsample with high quality tags ($0.5 < r < 1.0$), a very clear asymmetry with a sine-like time modulation is present. The final results are extracted from an unbinned maximum-likelihood fit to the Δt distributions that takes into account resolution, mistagging and background dilution. The new Belle result with 140 fb^{-1} (152 million $B\bar{B}$ pairs) is

$$\sin 2\phi_1 = 0.733 \pm 0.057 \pm 0.028. \tag{7}$$

The new Belle result may be compared to the BaBar result with 78 fb^{-1} of

$$\sin 2\phi_1 = 0.741 \pm 0.067 \pm 0.03. \tag{8}$$

Both experiments are now in very good agreement. A new world average can be calculated from these results,

$$\sin 2\phi_1 = 0.736 \pm 0.049. \tag{9}$$

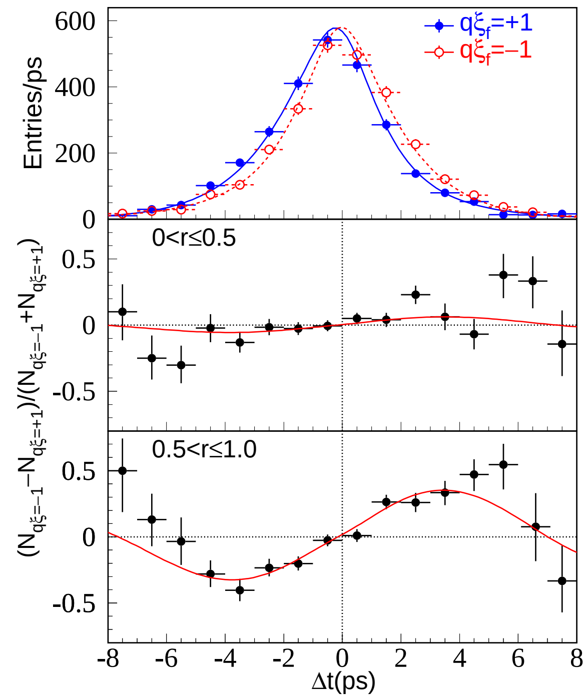

Figure 3. Belle data from 2003: (a) Δt distributions for B^0 and $\bar{B}^0$ tags (b) raw asymmetry for low-quality tags and (c) raw asymmetry for high-quality tags. The smooth curves are projections of the unbinned likelihood fit.

This world average can be interpreted as a constraint on the CKM angle ϕ_1. This constraint can be compared to the indirect determinations on the unitarity triangle.[13] This comparison is shown in Fig. 4 and is consistent with the hypothesis that the Kobayashi-Maskawa phase is the source of CP-violation.

The measurement of $\sin(2\phi_1)$ in $b \to c\bar{c}s$ modes, although still statistically limited, is becoming a precision measurement. The systematics are small and well-understood. Recently, BaBar physicists discovered a new small source of systematic uncertainty due to CP-violation in $b \to c\bar{u}d$ decays on the tagging side.[14]

The presence of an asymmetry with a cosine dependence ($|\lambda| \neq 1$) would indicate direct CP-violation. In order to test for this possibility in $b \to c\bar{c}s$ modes, Belle also performed a fit with $a_{CP} \equiv -\xi_f {\rm Im}\lambda/|\lambda|$ and $|\lambda|$ as free parameters, keeping everything else the same. They obtain

$$|\lambda| = 1.007 \pm 0.041({\rm stat}) \tag{10}$$
$$a_{CP} = 0.733 \pm 0.057({\rm stat}),$$

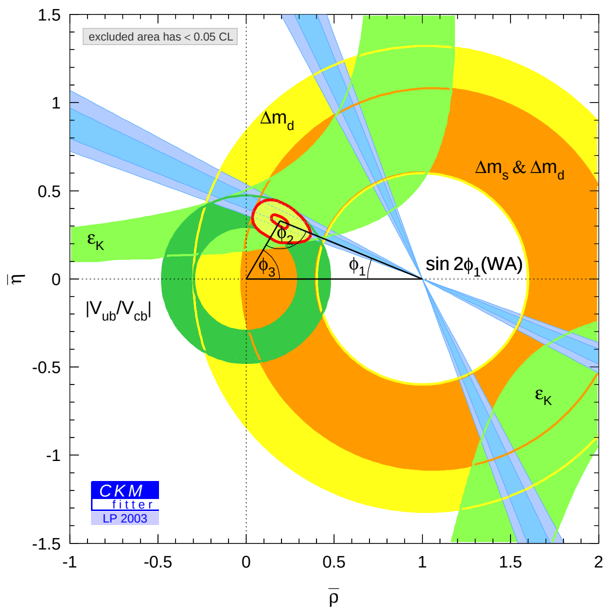

Figure 4. Indirect constraints on the angles of the CKM triangle compared to the most recent direct measurements of ϕ_1 from Belle and BaBar. The theoretical uncertainties in the indirect constraints are conservatively estimated by the CKM fitter group.

for all the $b \to c\bar{c}s$ CP modes combined. This result is consistent with the assumption used in their primary analysis.

3. Studies of CP-Violation in $b \to c\bar{c}d$ Processes

Neutral B decays to CP-eigenstates that proceed by $b \to c\bar{c}d$ processes are expected to have the same CP-violation as $b \to c\bar{c}s$ since both are sensitive to the phase of $B - \bar{B}$ mixing. A small deviation from this expectation is possible because of the contribution of $b \to d$ penguin diagrams (a.k.a. "penguin pollution") in the decay modes that are examined. Penguin pollution may also give rise to direct CP-violation and a CP-violating term with a $\cos(\Delta m_d \Delta t)$ dependence.

The $b \to c\bar{c}d$ decay modes that have been used so far for CP-violation studies are $B \to D^{*+}D^{*-}$, $B \to D^{*+}D^-$, and $B \to J/\psi\pi^0$.[15−18] The effect of penguin pollution might be expected to be the largest in $B \to J/\psi\pi^0$ because the penguin contribution is not color-suppressed in that mode.

For $B \to \psi\pi^0$, with 81 fb^{-1} BaBar has a signal of 40 ± 7 events[15] and finds

$$\sin 2\phi_{1eff}(B \to \psi\pi^0) = 0.05 \pm 0.45 \pm 0.16. \quad (11)$$

The corresponding result from Belle is based on 140 fb^{-1} and uses 89 ± 10 events.[16] They obtain

$$\sin 2\phi_{1eff}(B \to \psi\pi^0) = 0.72^{+0.37}_{-0.42} \pm 0.08. \quad (12)$$

In both cases, the systematic error includes the possibility of CP-violation in a small component of the background that peaks under the signal.

The $b \to c\bar{c}d$ mode $B \to D^{*+}D^{*-}$ has a vector-vector final state and requires special treatment since it includes contributions from both CP-even and odd components. To extract the CP-odd fraction, one fits the angular distribution in the transversity basis. The result from BaBar based on a sample with 156 ± 14 signal events is,

$$R_\perp = 0.063 \pm 0.055 \pm 0.009, \quad (13)$$

where the quantity $R_\perp$ is the fraction of the CP-odd component. The measurement indicates that $B^0 \to D^{*+}D^{*-}$ is mostly CP-even.

The time distributions from BaBar for $B \to D^{*+}D^{*-}$ are shown in Fig. 5. BaBar finds

$$\sin 2\phi_{1eff}(B \to D^{*+}D^{*-}) = -0.05 \pm 0.29 \pm 0.10, \quad (14)$$

which is about 2.5σ from the result in $b \to c\bar{c}s$ modes. This may be a statistical fluctuation or could be an indication that the Standard Model $b \to d$ penguin contribution is large. The fit includes the possibility of direct CP-violation. The parameter λ is found to be $0.75 \pm 0.19 \pm 0.02$, which is consistent with unity, as expected for no direct CP-violation.

Since $B^0 \to D^{*+}D^-$ and its charge conjugate are not CP-eigenstates, a modified treatment is required. There are four rather than two CP-violating observables that are determined from a time-dependent fit to the different D^*D charge states.

BaBar finds,

$$S_{+-} = -0.82 \pm 0.75 \pm 0.14, \quad (15)$$
$$S_{-+} = -0.24 \pm 0.69 \pm 0.12, \quad (16)$$
$$A_{+-} = +0.47 \pm 0.40 \pm 0.12, \quad (17)$$
$$A_{-+} = +0.22 \pm 0.37 \pm 0.10. \quad (18)$$

In the limit of no penguins and assuming factorization in these hadronic decays, $S_{-+} = S_{+-} = -\sin 2\phi_1$ and $A_{+-} = A_{-+} = 0$. The above results for CPV in $B \to D^*D$ decays are consistent with this limit.

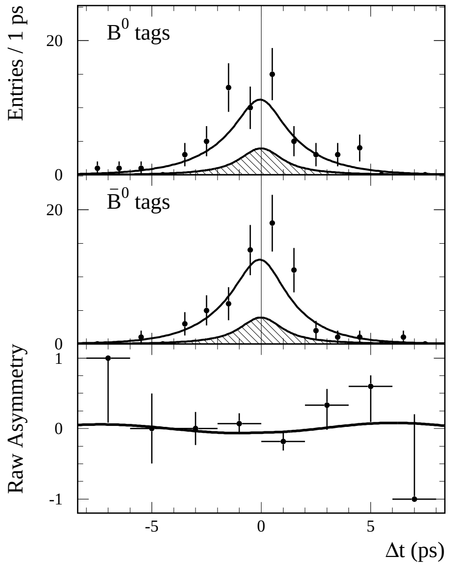

Figure 5. BaBar results on CP-violation in $B \to D^{*+}D^{*-}$. The top two figures show the Δt distributions for B^0 and $\bar{B}^0$ tags. The third plot shows the raw time asymmetry distribution.

Observation of the CP-eigenstate mode $B \to D^+D^-$ was reported by Belle at this conference. With 140 fb^{-1}, the 5σ signal contains 24.3 ± 6.0 events. In the future, this mode can also be used for time-dependent measurements of CPV in $b \to c\bar{c}d$ processes.

The results of CP-violation measurements for $b \to c\bar{c}d$ decays are summarized in Fig. 6. The measurements are not yet precise enough to definitively demonstrate the presence of penguin pollution.

4. Status of CP-Violation in $b \to sq\bar{q}$ Penguin Processes

In addition to the program of measuring the other remaining angles of the unitarity triangle that is discussed in the contribution by Jawahery,[19] there is also the question of whether there are additional CP-violating phases from new interactions or physics beyond the Standard Model. At the moment, such new phases are poorly constrained.

One way to attack this question is to measure the time-dependent CP-asymmetry in penguin-dominated modes such as $B^0 \to \phi K^0_S$, $B^0 \to \eta' K^0_S$ or $B^0 \to K^0_S\pi^0$, where heavy new particles may contribute inside the loop, and compare it to the asymmetry in $B^0 \to J/\psi K^0_S$ and related $b \to c\bar{c}s$ charmonium modes.

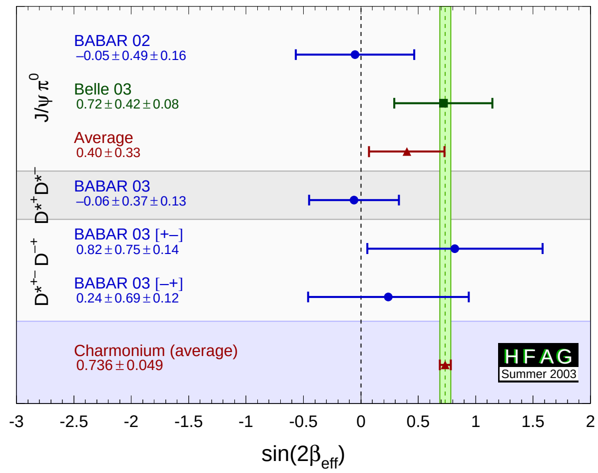

Figure 6. Summary plot of results on CP-violation in $b \to c\bar{c}d$ modes.

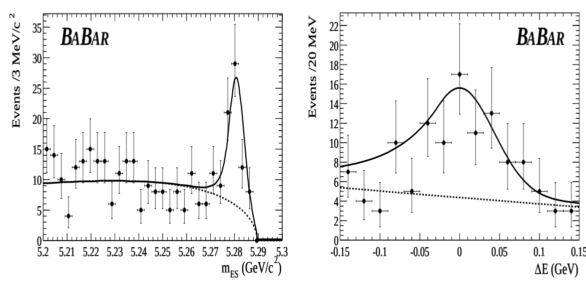

Figure 7. Beam constrained mass and ΔE distributions for $B \to K^0_S\pi^0$ from BaBar.

The mode $B \to K_S\pi^0$ proceeds through a $b \to sd\bar{d}$ transition. The BaBar data on $B \to K^0_S\pi^0$ are shown in Fig. 7. To be useful for time-dependent CPV studies at least one of charged pions from the K^0_S must be detected in the BaBar silicon vertex detector.[20] There are 123 ± 16 events of this type that are then used to obtain

$$\sin 2\phi_{1eff}(B \to K^0_S\pi^0) = 0.48^{+0.38}_{-0.47} \pm 0.11. \quad (19)$$

The time distributions are shown in Fig. 8. The direct CP-violation parameter is $A = -0.40^{+0.28}_{-0.27} \pm 0.10$.[20] When A is fixed to zero, the value of $S = \sin(2\phi_{1eff})$ shifts slightly to $0.41^{+0.41}_{-0.48} \pm 0.11$. The results for $B \to K_S\pi^0$ are consistent with the value from the $b \to c\bar{c}s$ modes, $\sin 2\phi_1 = 0.736 \pm 0.049$.

The mode $B \to \eta' K^0_S$ is expected to include contributions from $b \to s\bar{u}u$ and $b \to s\bar{d}d$ penguin processes. The beam constrained mass distribution for the $B \to \eta' K^0_S$ sample used by Belle is shown in

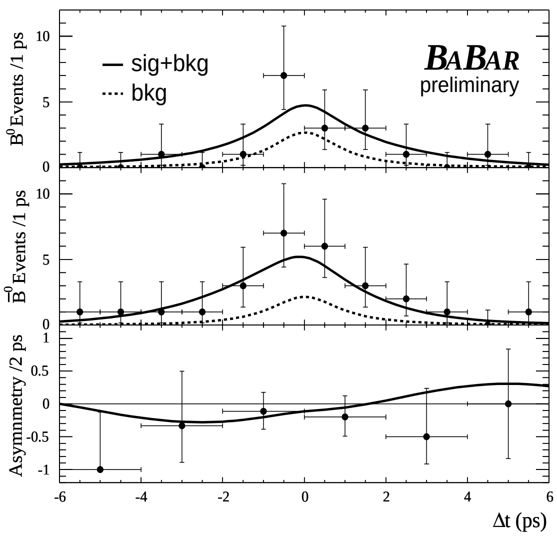

Figure 8. BaBar data on $B \to K^0_S \pi^0$. The top two figures show the Δt distributions for B^0 and $\bar{B}^0$ tags, separately. The third plot shows the raw time asymmetry distribution.

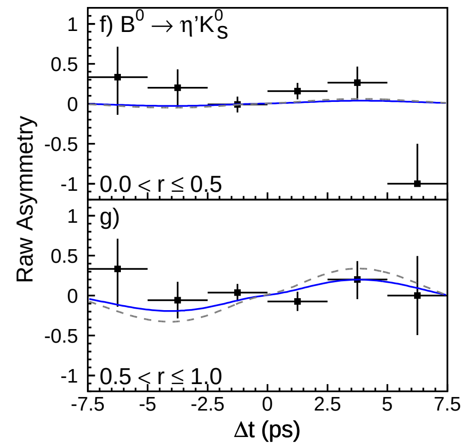

Figure 10. Belle data for the raw asymmetry in $B^0 \to \eta' K^0_S$. The upper plot shows the data for low-quality tags while the lower plot shows the higher quality tags. The dashed curves are the expectations from the Standard Model.

Fig. 9 and contains 244 ± 21 signal events.[21] Belle finds (Fig. 10),

$$\sin 2\phi_{1eff}(B \to \eta' K^0_S) = 0.43 \pm 0.27 \pm 0.05 \quad (20)$$

The BaBar data is shown in Fig. 11. They obtain,

$$\sin 2\phi_{1eff}(B \to \eta' K^0_S) = 0.02 \pm 0.34 \pm 0.03 \quad (21)$$

The average of these two results for $B \to \eta' K^0_S$ is about 2.2σ from the $b \to c\bar{c}s$ measurement, which is the Standard Model expectation.

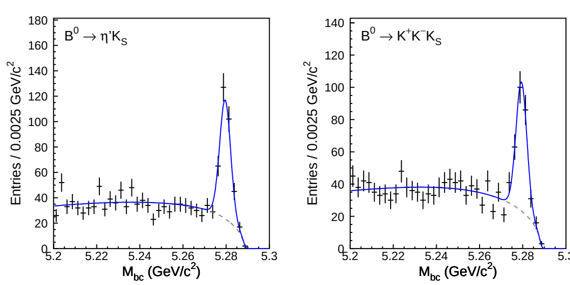

Figure 9. Beam constrained mass distributions for $B \to \eta' K^0_S$ (left) and $B \to K^+K^-K^0_S$ (right).

The decay mode $B \to K^+K^-K^0_S$, where K^+K^- combinations consistent with the ϕ have been removed, is found by Belle to be dominately CP-odd[22] and thus can be treated as a CP-eigenstate and used for studies of time-dependent CP-violation in $b \to sq\bar{q}$ processes. The beam constrained mass distribution for the $B \to K^+K^-K^0_S$ sample used by Belle is shown in Fig. 9. There are 199 ± 18 signal events. Belle obtains,

$$\sin 2\phi_{1eff}(B \to K^+K^-K^0_S) = 0.51 \pm 0.26 \pm 0.05^{+0.18}_{-0.00}, \quad (22)$$

where the third error is due to the uncertainty in the CP content of this final state.[22] The results for $B \to K^+K^-K^0_S$ are also consistent with $b \to c\bar{c}s$ decays. However, in this decay there is also the possibility of "tree-pollution", the contribution of the $b \to u\bar{u}s$ tree amplitude that may complicate the interpretation of the results.[23]

The $B^0 \to \phi K^0_S$ decay, which is dominated by the $b \to s\bar{s}s$ transition, is an especially unambiguous and sensitive probe of new CP-violating phases from physics beyond the SM.[24] The SM predicts that measurements of CP-violation in this mode should yield $\sin 2\phi_1$ to a very good approximation.[25,23] A significant deviation in the time-dependent CP-asymmetry in this mode from what is observed in $b \to c\bar{c}s$ decays would be evidence for a new CP-violating phase.

The $B \to \phi K^0_S$ sample used by BaBar is shown in Fig. 12. The signal, obtained from a sample with an integrated luminosity of 110 fb^{-1}, contains 70 ± 9 events.[20] The time distributions for the BaBar data are shown in Fig. 13. They obtain

$$\sin 2\phi_{1eff}(B \to \phi K^0_S) = 0.45 \pm 0.43 \pm 0.07. \quad (23)$$

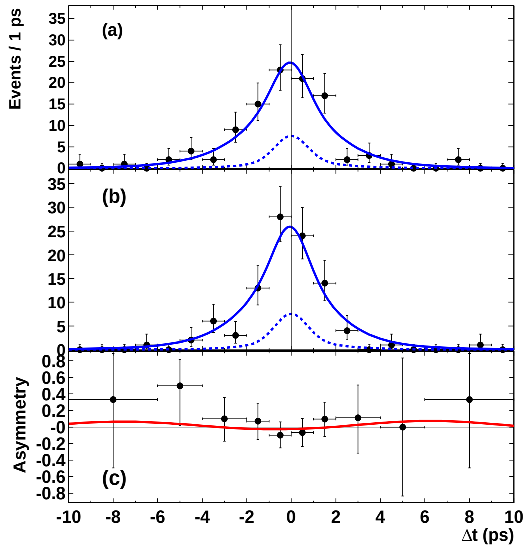

Figure 11. BaBar data on $B \to \eta' K^0_S$. The top two figures show the Δt distributions for B^0 and $\bar{B}^0$ tags, separately. The third plot shows the raw time asymmetry distribution.

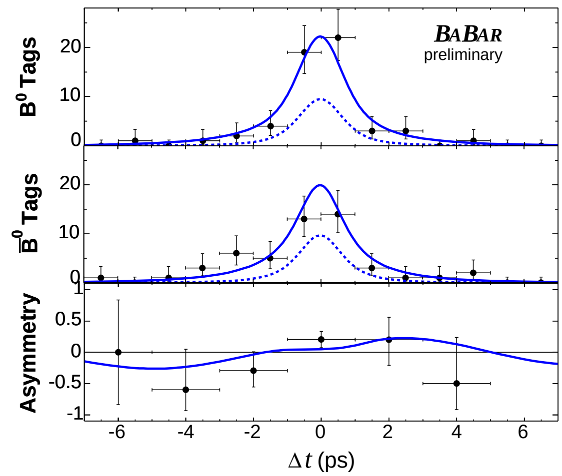

Figure 13. BaBar time difference and asymmetry data distributions in $B \to \phi K^0_S$. The top two figures show the Δt distributions for B^0 and $\bar{B}^0$ tags, separately. The third plot shows the raw time asymmetry distribution.

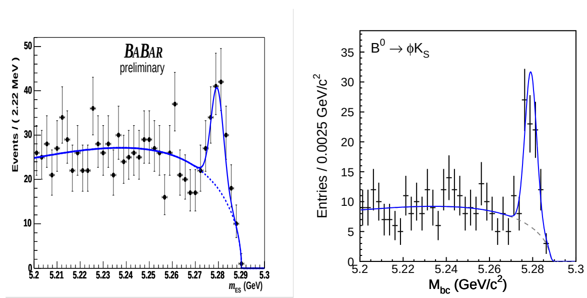

Figure 12. Beam constrained mass distributions for $B \to \phi K^0_S$ from BaBar (left) and Belle(right).

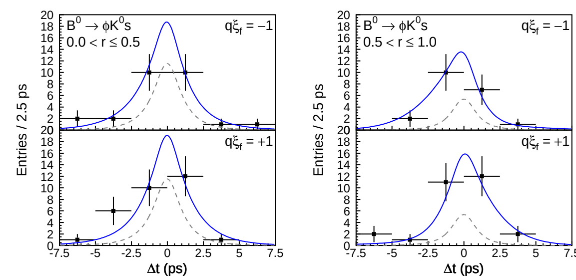

Figure 14. Belle data: (left) Δt distributions for low-quality tags and (right) for high-quality tags. The dashed curves show the background contributions.

This value is consistent with the Standard Model expectation, but is somewhat different from the value obtained with the 81 fb^{-1} sample, which was $\sin 2\phi_{1eff} = -0.18 \pm 0.51 \pm 0.09$. The new result includes more data and a reprocessing of the old data sample. After extensive checks with data and Toy Monte Carlo studies, the large change in the central value is attributed to a 1σ statistical fluctuation.[26]

The $B \to \phi K^0_S$ sample used by Belle is shown in the right panel of Fig. 12. The selection criteria are described in detail elsewhere.[27,28] The signal contains 68 ± 11 events. Figure 15 shows the raw asymmetries from Belle in two regions of the flavor-tagging parameter r. While the numbers of events in the two regions are similar, the effective tagging efficiency is much larger and the background dilution is smaller in the region $0.5 < r \leq 1.0$. The solid curves show the results of the unbinned maximum-likelihood fit to the Δt distribution.

The observed CP-asymmetry for $B^0 \to \phi K^0_S$ in the region $0.5 < r \leq 1.0$ (Fig. 15 (lower panel)) indicates the difference from the SM expectation (dashed curve). Note that these projections onto the Δt axis do not take into account event-by-event information (such as the signal fraction, the wrong tag fraction and the vertex resolution) that is used in the unbinned maximum likelihood fit.

The contamination of $K^+K^-K^0_S$ events in the ϕK^0_S sample ($7.2 \pm 1.7\%$) is small. Finally, backgrounds from the $B^0 \to f_0(980)K^0_S$ decay, which has the opposite CP-eigenvalue to ϕK^0_S, are found to be

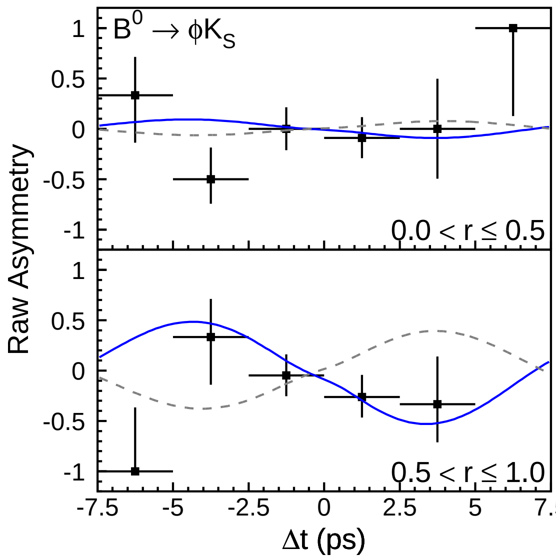

Figure 15. Belle data for the raw asymmetry in $B^0 \to \phi K^0_s$. The upper plot shows the data for low-quality tags while the lower plot shows the higher quality tags. The dashed line is the expectation from the Standard Model.

small ($1.6^{+1.9}_{-1.5}\%$). The influence of these backgrounds is treated as a source of systematic uncertainty.

Belle obtains

$$\sin 2\phi_{1eff}(B \to \phi K^0_S) = -0.96 \pm 0.5^{+0.09}_{-0.11} \qquad (24)$$

from their likelihood fit to the ϕK^0_S data. The likelihood function is parabolic and well-behaved. An evaluation of the significance of the result using the Feldman-Cousins method and allowing for systematic uncertainties shows that this result deviates by 3.5σ from the Standard Model expectation.[28]

The Belle group performed a number of validation checks for their $B \to \phi K^0_S$ CP-violation result. Fits to the same samples with the direct CP-violation parameter $\mathcal{A}$ fixed at zero yield $sin2\phi_{1eff} = -0.99 \pm 0.50(\text{stat})$ for $B^0 \to \phi K^0_S$. As a consistency check for the $\mathcal{S}$ term, the same fit procedure is applied to the charged B meson decays $B^+ \to \phi K^+$. The result is $\mathcal{S} = -0.09 \pm 0.26(\text{stat})$, $\mathcal{A} = +0.18 \pm 0.20(\text{stat})$ for $B^+ \to \phi K^+$ decay. The results for the $\mathcal{S}$ term is consistent with no CP-asymmetry, as expected. The asymmetry distribution is shown in Fig. 16. In addition, the ϕK^0_S sideband has been examined as shown in Fig. 16. No asymmetry is found in that sample.

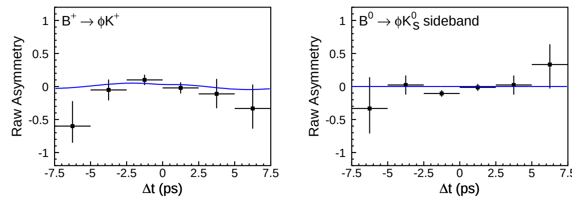

Figure 16. Belle data: consistency checks of the $B \to \phi K^0_S$ analysis. The asymmetries in (a) the $B^{\pm} \to \phi K^{\pm}$ sample and (b) the $B \to \phi K^0_S$ sideband sample.

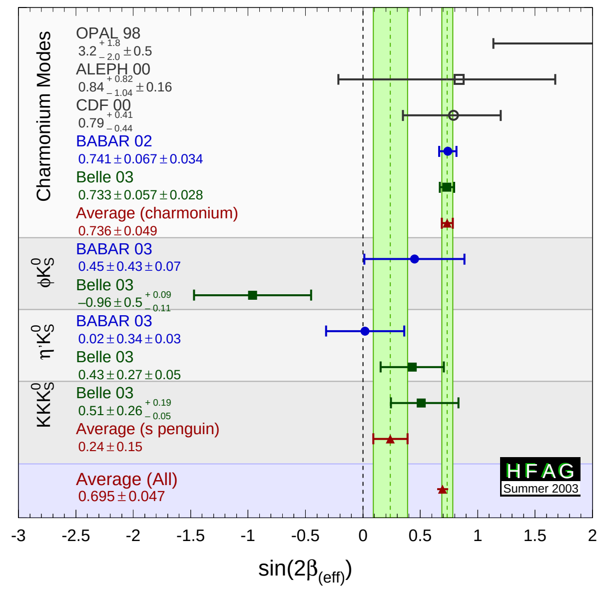

Figure 17. Summary plot of results on $\sin 2\phi_1$ and $\sin 2\phi_{1eff}$ in $b \to c\bar{c}s$ and $b \to s\bar{q}q$ modes.

5. Conclusion

Belle presented a new measurement of time-dependent CP-violation in $b \to c\bar{c}s$ CP-eigenstates. This result and previous results from BaBar are in good agreement with each other and with the hypothesis that the Kobayashi-Maskawa phase is the source of CP-violation.

Studies of CP-violation in $b \to c\bar{c}d$ modes are progressing. In $B \to D^{*+}D^{*-}$ decays, BaBar observes a 2.5σ hint for penguin pollution. More data and measurements are needed to clarify whether penguin pollution is present in this class of decays.

In $B \to \phi K^0_S$ decays there was a surprise. With 140 fb^{-1} Belle observed a 3.5σ deviation from the Standard Model expectation. This could be an indication of new physics from heavy particles in the

$b \to s\bar{s}$ penguin loop. However, BaBar's value moved closer to the Standard Model with the addition of new data and reprocessing. More precise measurements of the other $b \to sq\bar{q}$ modes can further constrain phases from new physics. For example, new physics may contribute differently to pseudoscalar-vector and pseudoscalar-pseudoscalar modes.[2]

The results of CP-violation measurements for $b \to sq\bar{q}$ penguin decays are summarized in Fig. 17. The world average for all $b \to s$ penguin decays (shown by the dotted line) appears to be displaced from the average for $b \to c\bar{c}s$ modes. The high energy physics community will require that this experimental issue be resolved conclusively in the future. This will require large data samples with integrated luminosities of at least 1 ab^{-1} or 1000 fb^{-1}.

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DISCUSSION

Stefan Spanier (University of Tennessee):

1) Unfortunately, the plenary session gives the audience only a limited chance to help you to establish the results by asking detailed questions.

2) Knowing the previous value of $S = -0.7 \pm 0.6$ from Belle, the newly added statistics must lead to an unphysical value of $S < -1.4$ leading typically to large correlations in S and C (pathological behavior) in this new sample. How probable is the value in the new sample?

3) How strong is the CP-asymmetry in the background?

Tom Browder:

1) A special breakout session is planned later in the Symposium.

2) For a true value near $S = -1$, the values in the new sample are quite consistent with Toy Monte Carlo studies. There is no statistically pathological behaviour in either old or new data samples. The observed errors are actually slightly larger than expected.

3) The background from $B \rightarrow f_0 K^0_S$ and $B \rightarrow K^+ K^- K^0_S$ decays is small and the CP-asymmetry from these backgrounds is included in the systematic error.

Alex Kagan (Cincinnati): Can you show the raw BaBar data for $S(\phi K^0_S)$ again?

Tom Browder: Yes. Note that a figure with this data was included in the talk and appears in the Proceedings.

Hitoshi Murayama (Berkeley): On the ϕK^0_S mode, the change in the BaBar result was attributed to a statistical fluctuation. They have added only 40% more data. How is that possible? Do you have a breakdown of the asymmetry between the previous and new data samples?

Tom Browder: Not only was more data added, but the old BaBar data sample was also reprocessed. After reprocessing, a small number of events changed from B^0 tags to $\bar{B}^0$ tags (or vice versa). This accounts for the shift in the central value.