CP Asymmetries in $B \to f_0 K_S$ *Decays*

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Rupak Dutta and SG, arXiv:0805.1963, PRD 78, 034021 (2008).

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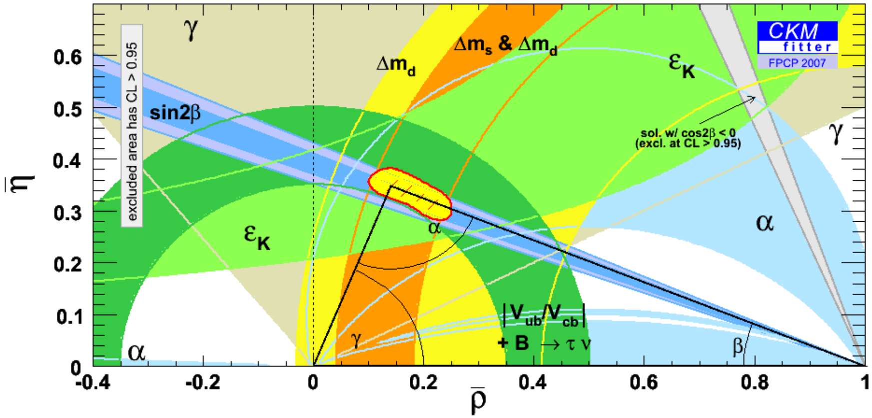
Context



[CKMfitter: hep-ph/0104062, hep-ph/0406184 ; http://ckmfitter.in2p3.fr – June, 2007 update]

We now **know** the mechanism of CP violation in Nature to a precision of $\mathcal{O}(10\%)$. [N.B. SuperB CDR, March, 2007]

A Continuing Mission...

One can find evidence for physics BSM by observing

i) processes which are highly forbidden in the SM...

— and/or —

ii) decided failures of "Unitarity Triangle" tests

We focus on ii) and ask
"Is the value of $\sin(2\beta)$ universal?"
Even in the Standard Model this is true only to some limited precision.

The energy reach can be limited by the "irreducible" hadronic uncertainty....

Is the value of $\sin(2\beta)$ *universal?*

- $b \to sc\bar{c}$

  Probed in $B \to J/\psi K_S$ and related $c\bar{c}$ modes. Currently [HFAG, Summer 2008]

  $$\sin(2\beta) = 0.671 \pm 0.024 \text{ (WA) } [J/\psi K_S ...]$$

  S_f yields $\sin(2\beta)$ as "wrong phase" penguin is $\mathcal{O}(\lambda^2)$ suppressed.

  i.e., $\Delta S = -\eta_f S_f - \sin 2\beta \approx -(2.16 \pm 2.23) \cdot 10^{-4}$ [Boos, Mannel, Reuter, hep-ph/0403085]

  With penguin effects this becomes $\mathcal{O}(10^{-3})$. [Li, Mishima, 2007]

  Under flavor-based assumptions, $B \to J/\psi\pi$ data [Ciuchini, Pierini, Silvestrini, 2005] and $B_s \to J/\psi K_S$ data [Fleischer, 1999] can help control the corrections.

  The error in $\sin(2\beta)$ will be dominated by expt'l uncertainties for some time to come!

- $b \to sq\bar{q}$ ($q \in u, d, s$)

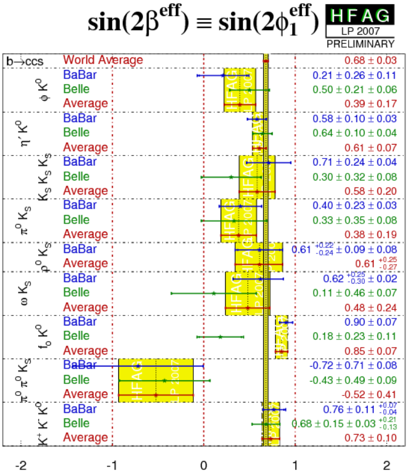
  Penguin modes probed in $B \to (\phi, \eta', \eta, f_0, \pi^0, \rho^0, ...)K_S$.

  Sensitive to effects from virtual new particles, which may result in deviations of $-\eta_f S_f$ from $\sin(2\beta)$.

  [Grossman, Worah, hep-ph/9612269]

An Intriguing Discrepancy?

In the SM the charmless $b \to s$ modes measure $\sin(2\beta)$, up to small corrections. [Grossman, Worah (1996)] How large are they?



Analyzing CP Violation in B-Meson Decay

$$A_f(t) = \frac{\mathrm{Br}(\bar{B}^0(t) \to f) - \mathrm{Br}(B^0(t) \to f)}{\mathrm{Br}(\bar{B}^0(t) \to f) + \mathrm{Br}(B^0(t) \to f)} \equiv S_f \sin(\Delta M_B\, t) - C_f \cos(\Delta M_B\, t)\,,$$

$$S_f = \frac{2\,\mathrm{Im}\xi_f}{1 + |\xi_f|^2} \quad ; \quad C_f = \frac{1 - |\xi_f|^2}{1 + |\xi_f|^2}\,, \qquad \xi_f = \left(\frac{q}{p}\right) \frac{A(\bar{B}^0 \to f)}{A(B^0 \to f)}$$

Now in $b \to sq\bar{q}$ [Beneke, 2005]

$$A(\bar{B} \to f) = \lambda_c\, a_f^c + \lambda_u\, a_f^u \propto (1 + e^{-i\gamma}\, d_f)\,, \;\; d_f = |\lambda_u/\lambda_c|(a_f^u/a_f^c)\,, \;\; \lambda_q = V_{qb}\, V_{qs}^*$$

$$\begin{aligned} \Delta S_f &= -\eta_f\, S_f - \sin(2\beta) \\ &= \frac{2\,\mathrm{Re}(d_f)\cos(2\beta)\sin\gamma + |d_f|^2\,(\sin(2\beta + 2\gamma) - \sin(2\beta))}{1 + 2\,\mathrm{Re}(d_f)\cos\gamma + |d_f|^2}\,, \end{aligned}$$

$$C_f = -\frac{2\,\mathrm{Im}(d_f)\sin\gamma}{1 + 2\,\mathrm{Re}(d_f)\cos\gamma + |d_f|^2}\,,$$

We compute d_f in the QCD factorization approach.

[Beneke, Buchalla, Neubert, and Sachrajda, 1999, 2001; Beneke, Neubert, 2003; Cheng, Yang, 2006]

ΔS in Charmless $b \to s$ Decays

Theory (QCD$_f$) [M. Beneke, 2005] vs. Experiment.[HFAG summer 2008]

Mode	ΔS_f (Theory)	ΔS_f [Range]	$\sin(2\beta^{eff})$(Expt.)
$\pi^0 K_S$	$0.07^{+0.05}_{-0.04}$	$[+0.02, 0.15]$	0.57 ± 0.17
$\rho^0 K_S$	$-0.08^{+0.08}_{-0.12}$	$[-0.29, 0.02]$	$0.63^{+0.17}_{-0.21}$
$\eta' K_S$	$0.01^{+0.01}_{-0.01}$	$[+0.00, 0.03]$	0.59 ± 0.07
ηK_S	$0.10^{+0.11}_{-0.07}$	$[-1.67, 0.27]$	—
ϕK_S	$0.02^{+0.01}_{-0.01}$	$[+0.01, 0.05]$	$0.44^{+0.17}_{-0.18}$
ωK_S	$0.13^{+0.08}_{-0.08}$	$[+0.01, 0.21]$	0.45 ± 0.24
$f_0 K_S$	—	—	$0.62^{+0.11}_{-0.13}$

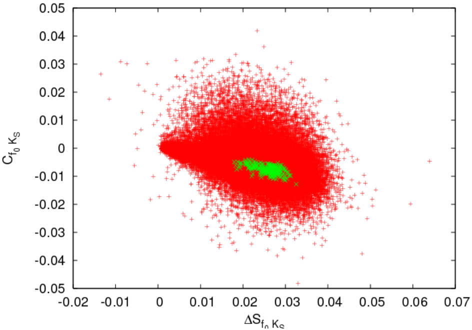
Mode	QCDF [43]	pQCD [8, 44]	SCET [34]
$\pi^0 K_S$	$0.07^{+0.05}_{-0.04}$	$0.053^{+0.02}_{-0.03}$	0.077 ± 0.030
$\rho^0 K_S$	$-0.08^{+0.08}_{-0.12}$	$-0.187^{+0.10}_{-0.06}$	–
ωK_S	0.13 ± 0.08	$0.153^{+0.03}_{-0.07}$	–

ΔS in $B \to f_0 K_S$ Decay

We employ QCD$_f$ to compute ΔS. [Cheng, Yang, 2006]

ΔS in this decay mode has no tree-level contribution irrespective of the structure of the f_0!

Scanning over theory space at one and three sigma, with the empirical branching ratio as a constraint:



There is little correlation between C and ΔS as d_f is small.

Summary

Our scans of theory space (in the SM) yield

$\Delta S_{f_0 K_S} \in [0.018, 0.033]$ at 1σ $\Delta S_{f_0 K_S} \in [-0.019, 0.064]$ at 3σ

- Large excursions in ΔS come from small charm penguin amplitudes; they are controlled by imposing the experimental branching ratio as a constraint.
- The largest excursion in ΔS comes from the uncertainty associated with the B meson distribution amplitude λ_B; these are also controlled once we impose the branching ratio constraint.
- ΔS is not sensitive to the $B \to f_0$ form factor and the f_0 scalar decay constant as the $B \to f_0 K_S$ decay amplitude is driven by s quark component of the f_0.

ΔS in $B \to f_0 K_S$ decay is comparably small to that in $B \to \phi K_S$.
We have another "clean" decay mode, of differing quantum numbers, to study!

Outlook

The pattern of CP violation in Nature can be described by a single parameter in the quark mixing (CKM) matrix to the $\mathcal{O}(10\%)$ level. No new sources of CP violation beyond the SM have as yet been found.

Future insight will come from either higher precision studies or from bettered constraints on highly forbidden processes or both.

We possess sufficient theoretical control to interpret improved experimental results.

The future is rich in promise!