Introduction to SM th. uncertainties in ΔS

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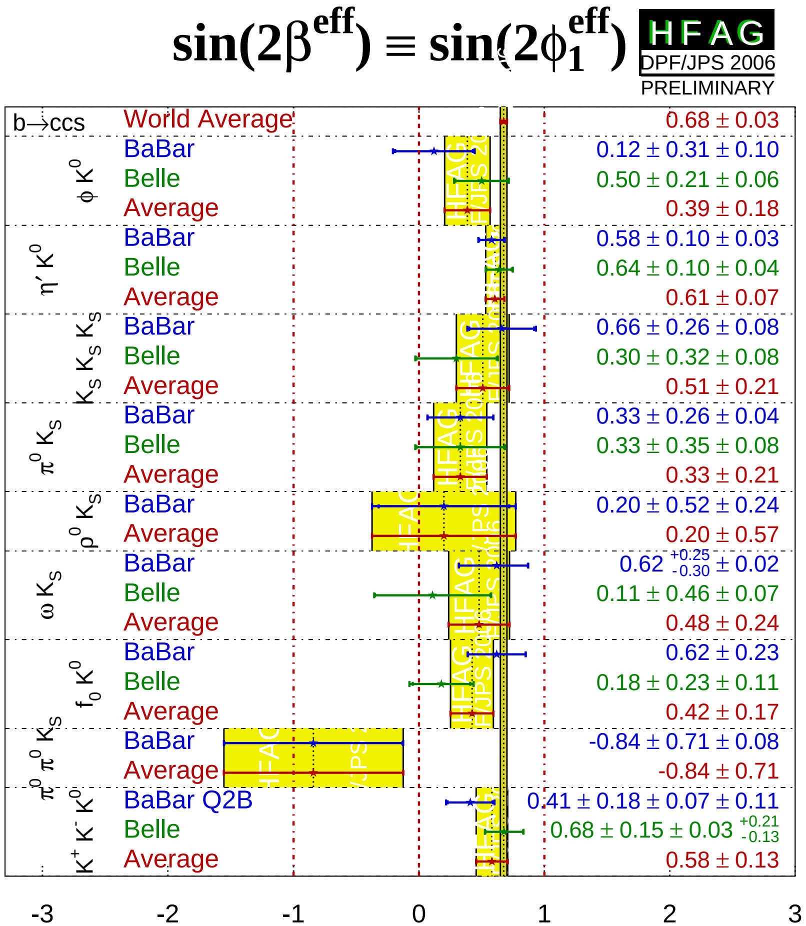
- This talk includes
  SM prediction of ΔS in $b \to s$ penguin dominant channels with two-body final state

- This talk does *not* include
  - SM prediction of ΔS in $b \to s$ penguin dominant channels with three-body final state (☞ see H.Y. Cheng's talk)
  - ΔS in $b \to c\bar{c}s$ dominant channels (☞ see WG5)
  - New physics effect in ΔS (☞ see WG6)

CKM06, 11-16 December 2006 @ Nagoya University

Experimental status of $S_{b\to s}$



Current status of $S_{b\to s}$

- ➤ $b \to s\bar{s}s$ dominant mode
- - $B \to \phi K_S$: 0.39 ± 0.18
- - $B \to \eta' K_S$: 0.61 ± 0.07
- ➤ $b \to s\bar{u}u$ dominant mode
- - $B \to \pi K_S$: 0.33 ± 0.21
- - $B \to \rho K_S$: 0.20 ± 0.57
- - $B \to \omega K_S$: 0.48 ± 0.24

☞ $S_{\phi K_S, \eta' K_S}$ will be measured at a few % precision with $50ab^{-1}$ data.

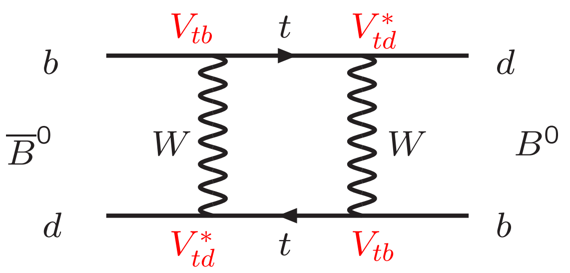
One day, as $S_{b\to s}$ is found to deviate from $S_{J/\psi K_S}$ by a tiny amount, are we going to be able to distinguish between physics beyond SM and SM theoretical uncertainty?

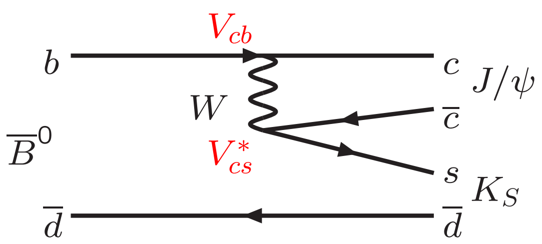
To which extent, $S_{J/\psi K_S} = S_{b\to s}$ in SM?

$$a_f(t) = \frac{\Gamma(\overline{B}\to f)}{\Gamma(B\to f)} = S_f \sin\Delta M_B t - C_f \cos\Delta M_B t$$

$$S_f = \frac{2\,\mathrm{Im}(\pm\frac{q}{p}\overline{\rho})}{|\frac{q}{p}\overline{\rho}|^2+1}, \qquad C_f = \frac{1-|\frac{q}{p}\overline{\rho}|^2}{1+|\frac{q}{p}\overline{\rho}|^2}; \qquad \overline{\rho} = \frac{A(\overline{B}\to f)}{A(B\to f)}$$

$B\to J/\psi K_S$





$\mathrm{Im}(\frac{q}{p}) = \mathrm{Im}(\frac{V_{tb}^*V_{td}}{V_{tb}V_{ts}^*}) = \sin 2\phi_1$ $\quad \mathrm{Im}(\overline{\rho}) = \mathrm{Im}\,\frac{V_{cb}V_{cs}^*}{V_{cb}^*V_{cs}} = 0$

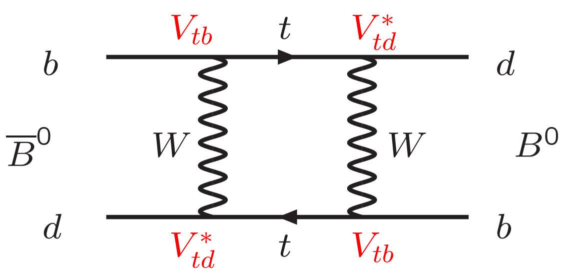
Pollutions

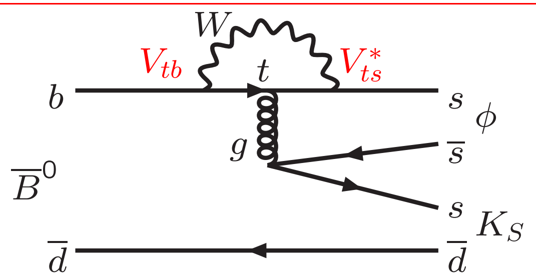
- u-penguins
- u-rescattering

$\mathrm{Im}(\overline{\rho}) = \mathrm{Im}\,\frac{V_{ub}V_{us}^*}{V_{ub}^*V_{us}} = \sin\phi_3$

☞ effect $< 10^{-2} - 10^{-3}$

$B\to s$ dominant





$\mathrm{Im}(\frac{q}{p}) = (\frac{V_{tb}^*V_{td}}{V_{tb}V_{ts}^*}) = \sin 2\phi_1$ $\quad \mathrm{Im}(\overline{\rho}) = \mathrm{Im}\,\frac{V_{cb}V_{cs}^*}{V_{cb}^*V_{cs}} = 0$

Pollutions

- $b\to u\bar{u}s$ trees
- u-penguins
- u-rescattering

$\mathrm{Im}(\overline{\rho}) = \mathrm{Im}\,\frac{V_{ub}V_{us}^*}{V_{ub}^*V_{us}} = \sin\phi_3$

A^u_f/A^c_f dependence of S_f

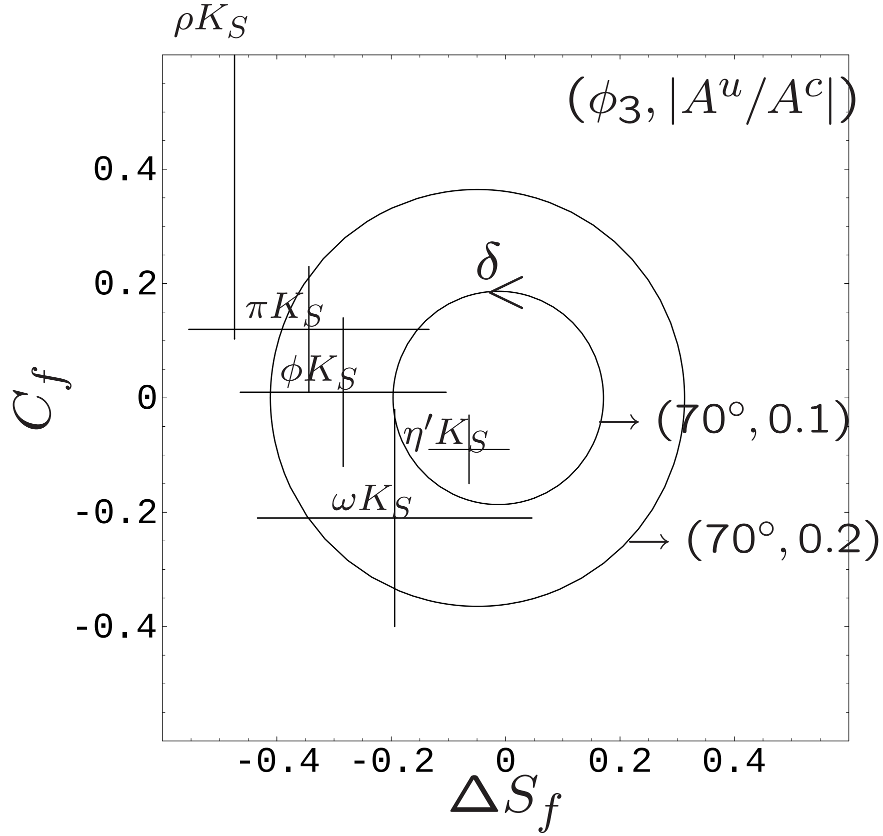
$$A(B\to f) = V^*_{tb}V_{ts}a^t_f + V^*_{cb}V_{cs}a^c_f + V^*_{ub}V_{us}a^u_f$$
$$= V^*_{cb}V_{cs}A^c_f + V^*_{ub}V_{us}A^u_f$$

where $A^c_f = a^c_f - a^t_f$ and $A^u_f = a^u_f - a^t_f$.

$$\bar\rho = \frac{A(\overline{B}\to f)}{A(B\to f)} = 1 - 2i\epsilon_{KM}\frac{A^u_f}{A^c_f}\sin\phi_3 + \mathcal{O}(\epsilon^2_{KM})$$

where $\epsilon_{KM} = \frac{V^*_{ub}V_{us}}{V^*_{cb}V_{cs}} \simeq 0.025$.

☞ figure: $A^u_f/A^c_f = |A^u_f/A^c_f|e^{i\delta}$



Estimate of $\Delta S \equiv S_{b\to s} - S_{J/\psi K_S}$ requires precise information on A^u_f/A^c_f

☞ various theoretical methods have been developed.

$b \to s\bar{s}s$ v.s. $b \to s\bar{u}u$

$$A^c_f = a^c_f - a^t_f, \qquad A^u_f = a^u_f - a^t_f$$

a^t_f = t-penguin

a^c_f = c-penguin, c-rescattering

a^u_f = u-penguin, u-rescattering, $b \to u\bar{u}s$ tree

$b \to s\bar{s}s$ channels ☞ Roughly $\Delta S_{b\to s\bar{s}s} < 3$ %.

$$A^u_f/A^c_f = \underbrace{a^t_f/a^t_f}_{=1} \quad \underbrace{-a^u_f/a^t_f + a^c_f/a^t_f}_{\text{LD}=1/m_b \text{ suppressed (SD tree=0)}} \quad +\mathcal{O}((a^c_f/a^t_f)^2, (a^u_f/a^t_f)^2)$$

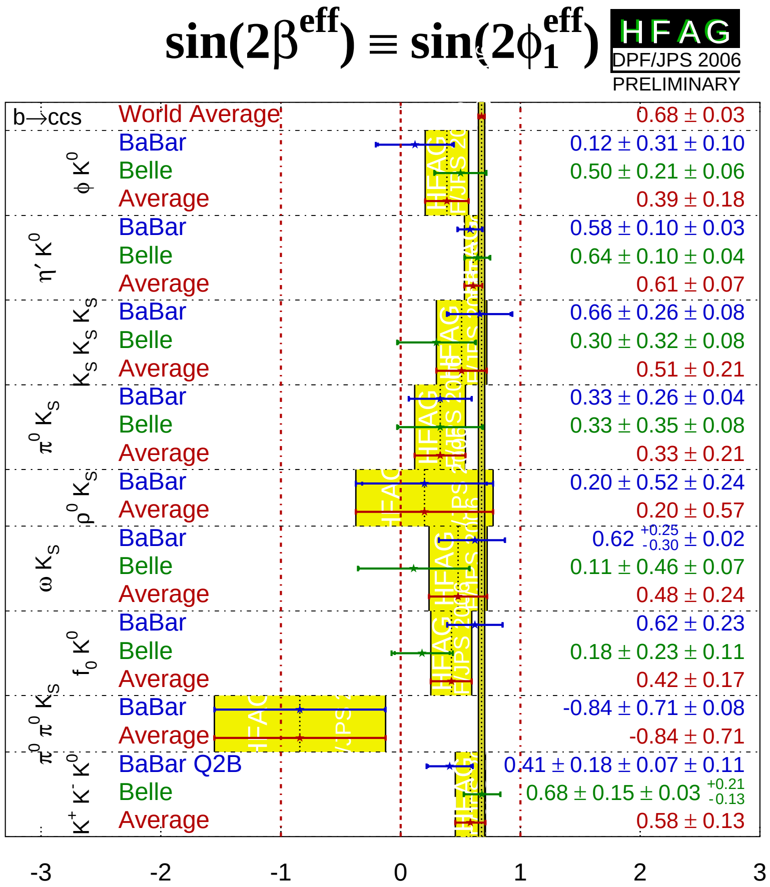
$b \to s\bar{u}u$ channels ☞ Roughly $\Delta S_{b\to s\bar{u}u} < 10$ %.

$$A^u_f/A^c_f = \underbrace{a^u_f/a^t_f}_{\text{SD tree}=1/\alpha_s} \quad \underbrace{-a^t_f/a^t_f}_{=1} +\mathcal{O}((a^c_f/a^t_f), (a^c_f/a^u_f), (a^t_f/a^u_f))$$

The rough estimates of theor. uncertainties are equivalent to or larger than the exp. precision that will be achieved in future. We may need more theor. input to distinguish SM errors from BSM...

Tendency of exp. data is against th.?!

Measured values of $\Delta S_{b\to s}$ are mostly *negative* while many theoretical models predict them *positive*!



In the case of pQCD and QCDF

$$\Delta S \simeq 2\epsilon_{KM} \cos 2\phi_1 \sin\phi_3 \cos\delta \left|\frac{A_f^u}{A_f^c}\right|$$

☞ In perturbative computation, δ is relatively small and $A_f^u/A_f^c \simeq 1 -$ tree/penguin

☞ The sign and size of $-$tree/penguin

$B \to \phi K_S$: zero

$B \to \eta' K_S$: negligible

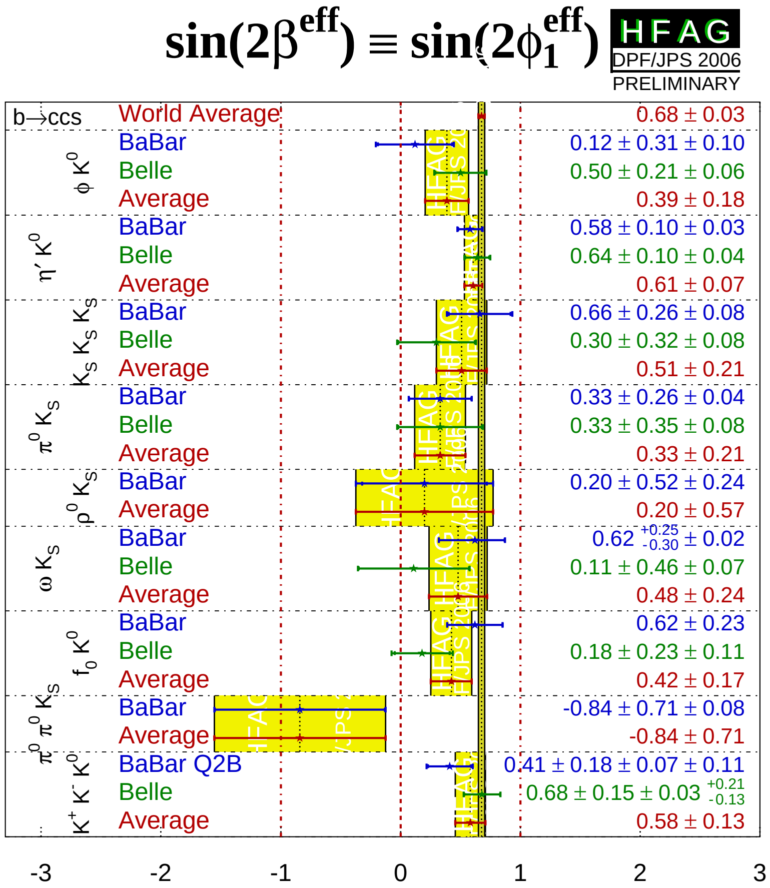
$B \to \pi K_S$: large positive

$B \to \omega K_S$: large positive

$B \to \rho K_S$: large negative

Tendency of exp. data is against th.?!

Measured values of ΔS_f are mostly negative while many theoretical models predict them positive!



Results of pQCD and QCDF

H. Li and, S. Mishima (PRD72 2005, PRD74 2006)

M. Beneke, M. Neubert (NPB 2003)

M Beneke (PLB620 2005)

	pQCD	QCDF
ϕK_S	$0.02^{+0.01}_{-0.01}$	$0.04^{+0.01}_{-0.01}$
$\eta' K_S$	$0.01^{+0.01}_{-0.01}$	
πK_S	$0.07^{+0.05}_{-0.04}$	$0.07^{+0.02}_{-0.03}$
ωK_S	$0.13^{+0.08}_{-0.08}$	$0.17^{+0.03}_{-0.07}$
ρK_S	$-0.08^{+0.08}_{-0.012}$	$-0.17^{+0.01}_{-0.06}$

see also A.R. Williamson, J. Zupan, PRD74 2006

This pattern of ΔS_f must be tested by exp. more precisely in the future

If rescattering is large...

H.Y. Cheng, C.K. Chua, A. Soni (PRD71 2005)

However, a large rescattering effect which produces a large strong phase may break the pattern predicted by perturbative computation.

ΔS_f	SD	SD+LD
ϕK_S	$0.02^{+0.00}_{-0.04}$	$0.03^{+0.01+0.01}_{-0.04-0.01}$
$\eta' K_S$	$0.01^{+0.00}_{-0.04}$	$0.00^{+0.00+0.00}_{-0.04-0.00}$
ηK_S	$0.07^{+0.02}_{-0.04}$	$0.07^{+0.02+0.00}_{-0.05-0.00}$
πK_S	$0.06^{+0.02}_{-0.04}$	$0.04^{+0.02+0.01}_{-0.03-0.01}$
ωK_S	$0.12^{+0.05}_{-0.06}$	$0.01^{+0.02+0.02}_{-0.04-0.01}$
ρK_S	$-0.09^{+0.03}_{-0.07}$	$0.04^{+0.09+0.08}_{-0.10-0.11}$

☞ The pattern of perturbative computation is broken especially in VP channels.

Test of rescattering effect

$$\frac{\Delta S}{-C} = \simeq cos 2\phi_1 \cos\delta$$

☞ $|\Delta S/C| \simeq 1$ in perturbative computation since δ is relatively small.

☞ Prediction with LD effect...

$$\begin{aligned}
\Delta S_{\phi K_S}/(-C_{\phi K_S}) &= -1.3 \\
\Delta S_{\eta' K_S}/(-C_{\eta' K_S}) &= -0.05 \\
\Delta S_{\eta K_S}/(-C_{\eta K_S}) &= -2.0 \\
\Delta S_{\pi K_S}/(-C_{\pi K_S}) &= 1.2 \\
\Delta S_{\omega K_S}/(-C_{\omega K_S}) &= -0.08 \\
\Delta S_{\rho K_S}/(-C_{\rho K_S}) &= -0.08
\end{aligned}$$

Role of branching ratio measurements

- Precise measurements of branching ratios of SU(3) related channels can be used to constrain $|A_f^u/A_f^c|$.

Y. Grossman, Z. Ligeti, Y.Nir, H.R. Quinn, PRD68 2003

M. Gronau, J.L. Rosner, J. Zupan, PLB596 2004, PRD74, 2006

talk by Z. Ligeti in CKM05

✶ see also talk by M. Pierini in CKM05

- Perturbative methods often contain large theoretical uncertainties from the perturbative/non-perturbative input parameters. However, one can constrain many of those by using branching ratio measurements.

Even if we have ambiguity in the strong phase δ, the constraint on ΔS_f may be improved by achieving a high precision determination of $|A_f^u/A_f^c|$ from branching ratios.

Some comments on $S_{\eta' K_S}$ and $S_{\eta K_S}$

- The problem of the large branching ratio of $B \to \eta' K$ can be discussed separately?! (see also Zupan's talk)

  Most of the solutions to this problem (singlet penguin, singlet form factor, U(1) breaking effect etc.) are based on penguin type operator. Thus, this may not increase $\Delta S_{\eta' K_S}$.

- $U(1)$ breaking contributions must be carefully included.

  J.M. Gerard, E.K. PRL 2006

  1) In $\eta - \eta'$ system, U(1) breaking effect is large, larger than SU(3) breaking. SU(3) analysis may contain additional uncertainty from U(1) breaking.
  2) The pseudoscalar mixing angle θ is often fixed at $(-15.7 \pm 1)^\circ$ or -19.5°. However, we must be aware that ηK_S mode shows a strong θ dependence and theoretical error coming from θ must be carefully included.

Conclusions

- In SM, possible deviations of $S_{\phi K_S}$ and $S_{\eta' K_S}$ from $S_{J/\psi K_s}$ are found to be less than a few %.

- Measured values of $\Delta S_{b\to s}$ are mostly *negative* while perturbative computation seems to predict them *positive* for most of decay modes.

- Perturbative computations seem to predict opposite sign for $\Delta S_{\omega K_S}$ and $\Delta S_{\rho K_S}$. However, a large FSI effects may change this pattern. Size of FSI effect must be carefully tested by using both direct and mixing CP asymmetry.

- Precise measurements of various branching ratios are important to further reduce theoretical uncertainties in $\Delta S_{b\to s}$.