Theoretical uncertainty in B->J/ψ K

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SM fit:

$\sin 2\beta = 0.771 \pm 0.036$

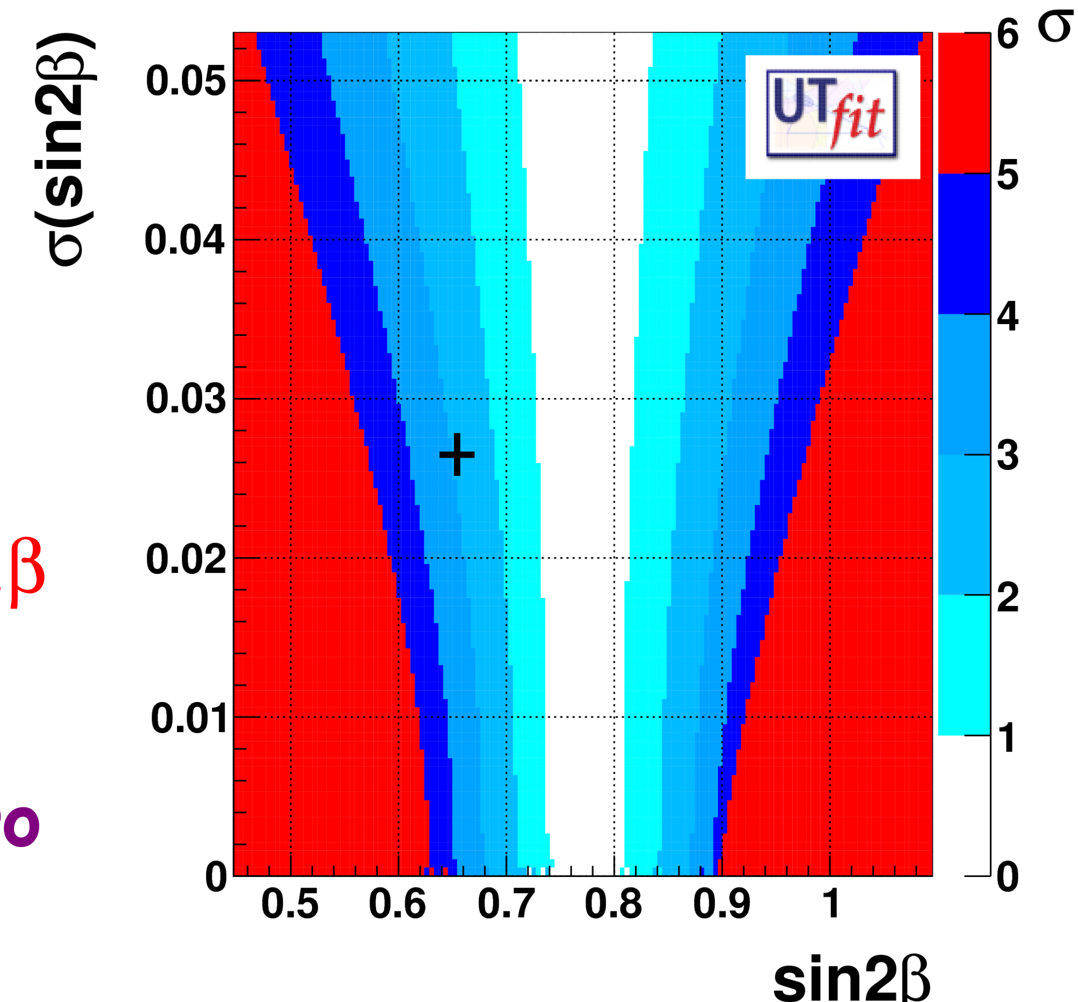
HFAG:

$S(J/\psi K) = 0.654 \pm 0.026$

$\Delta S(J/\psi K) = S(J/\psi K) - \sin 2\beta$

$= -0.117 \pm 0.044$

2.6σ deviation from zero



1-slide sin2β primer

$$\mathcal{A}(B_d \to J/\psi K^0) = \lambda_c^s A_c(B_d, K^0) - \lambda_u^s A_u(B_d, K^0)$$

$$\mathcal{A}(\bar{B}_d \to J/\psi \bar{K}^0) = \lambda_c^{s*} A_c(B_d, K^0) - \lambda_u^{s*} A_u(B_d, K^0)$$

$$\lambda_q^s = V_{qs} V_{qb}^*$$

$$\frac{\Gamma(B_d(t) \to J/\psi K_{S,L}) - \Gamma(\bar{B}_d(t) \to J/\psi K_{S,L})}{\Gamma(B_d(t) \to J/\psi K_{S,L}) + \Gamma(\bar{B}_d(t) \to J/\psi K_{S,L})} = C_{B_d \to J/\psi K_{S,L}} \cos(\Delta m_{B_d} t) - S_{B_d \to J/\psi K_{S,L}} \sin(\Delta m_{B_d} t)$$

$$S_{B_d \to J/\psi K_{S,L}} = \frac{2\mathrm{Im}(\lambda_{B_d \to J/\psi K_{S,L}})}{1 + |\lambda_{B_d \to J/\psi K_{S,L}}|^2}, \qquad C_{B_d \to J/\psi K_{S,L}} = \frac{1 - |\lambda_{B_d \to J/\psi K_{S,L}}|^2}{1 + |\lambda_{B_d \to J/\psi K_{S,L}}|^2}$$

$$\lambda_{B_d \to J/\psi K_{S,L}} = \eta_{K_S, K_L} (q/p)_{B_d} \frac{\mathcal{A}(\bar{B}_d \to J/\psi \bar{K}^0)}{\mathcal{A}(B_d \to J/\psi K^0)} (q/p)_{K^0}^*$$

$$(q/p)_{B_d} = -\frac{V_{tb}^* V_{td}}{V_{tb} V_{td}^*}$$

$$(q/p)_{K^0} = -\frac{V_{cs}^* V_{cd}}{V_{cs} V_{cd}^*}$$

In the limit of vanishing A_u:

$$\lambda_{B_d \to J/\psi K_{S,L}} = \eta_{K_S, K_L} \left(\frac{V_{tb}^* V_{td}}{V_{cb}^* V_{cd}}\right) \left(\frac{V_{cb} V_{cd}^*}{V_{tb} V_{td}^*}\right) = \eta_{K_S, K_L} e^{-2i\beta} \qquad \beta = \arg\left(-\frac{V_{cd} V_{cb}^*}{V_{td} V_{tb}^*}\right)$$

$$S_{B_d \to J/\psi K_{S,L}} = -\eta_{K_S, K_L} \sin 2\beta \quad (\Delta S = 0), \qquad C_{B_d \to J/\psi K_{S,L}} = 0$$

A closer look to the B → J/ψ K amplitude:

$$A(B^0 \to J/\psi K^0) = \overset{\lambda^2}{V^*_{cb} V_{cs}} \underbrace{(E_2 + P_2)}_{A_c} - \overset{\lambda^4}{V^*_{ub} V_{us}} \underbrace{(P_2^{GIM} - P_2)}_{A_u}$$

In B^0 -> J/ψ K^0 :

notation from Buras, Silvestrini, hep-ph/9812392

- A_c is not only tree, but the c-penguin P_2 has the same weak phase as the emission parameter E_2

  may affect the BR, not the extraction of sin2β

- the "penguin pollution" A_u is doubly Cabibbo suppressed w.r.t. the main amplitude A_c
- the "polluting" amplitude $A_u = P_2^{GIM} - P_2$ is a pure u-penguin

  naïve estimate: $V_{cb}^* V_{cs} P / V_{ub}^* V_{us} T \sim \lambda^2 \alpha(m_b)/4\pi \sim 10^{-3}$

How large is really A_u? Can we bound it using the data?

caveat: BR(B^0 -> J/ψ K^0) is not sensitive to A_u

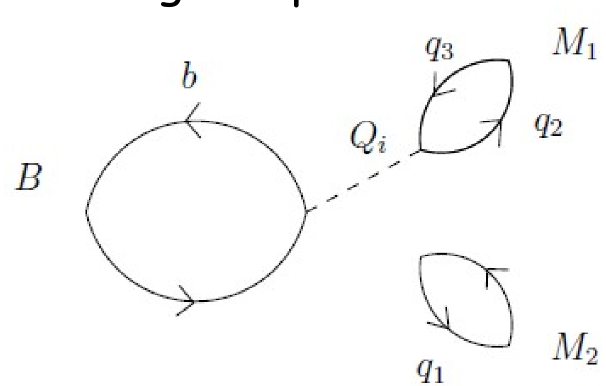
Getting a little help from a (SU3) friend:

$$A(B^0\to J/\psi\pi^0)=\overset{\lambda^2}{V^*_{cb}V_{cd}}\underbrace{(E_2+P_2)}_{A_c}-\overset{\lambda^2}{V^*_{ub}V_{ud}}\underbrace{(P_2^{GIM}-P_2-\cancel{E}A_2)}_{A_u}$$

In $B^0 \to J/\psi\, \pi^0$:

- the amplitudes A_c and A_u has similar flavour couplings
  => can be fitted from the data on BR, S, C
- A_c and A_u are the same amplitudes entering $B^0 \to J/\psi\, K^0$ in the limit of exact flavour SU(3) symmetry as long as EA_2 can be neglected

example of Wick contraction entering the parameter EA_2



The assumption EA_2=0 can be:

- removed by using $B_s \to J/\psi\, \bar{K}$ instead of $B_d \to J/\psi\, \pi^0$ or adding $B_d \to J/\psi\, \eta/\eta'$
- controlled with $BR(B_s \to J/\psi\, \pi^0) \sim |EA_2|^2$

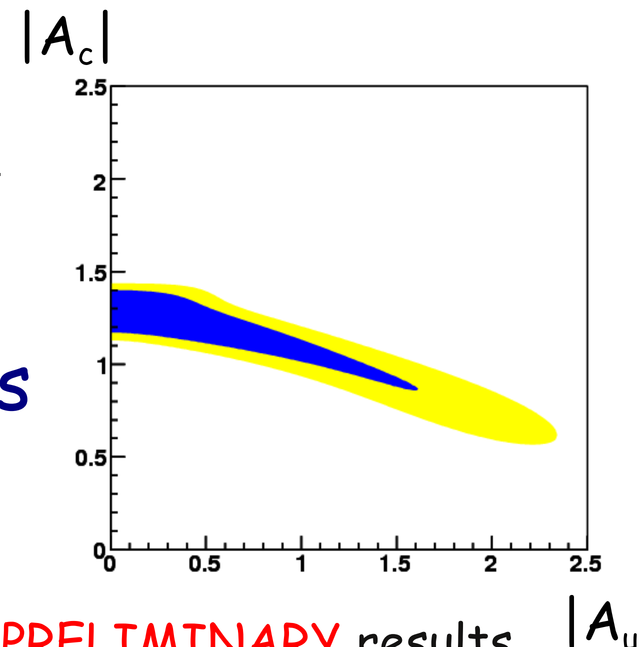
Strategies: (CPS update, in preparation)

1. minimal SU(3) assumption (CPS, hep-ph/0507290)
   i. fix the *range* of $|A_u|$ from $B \to J/\psi\, \pi^0$
   ii. use it to evaluate ΔS in $B \to J/\psi\, K^0$
2. factorized SU(3) breaking (FFJM, arXiv:0809.0842)
   i. take A_u/A_c equal in $B \to J/\psi\, K^0$ & $B \to J/\psi\, \pi^0$
   ii. include factorized SU(3)-breaking in the BRs
   iii. estimate/include additional SU(3)-breaking
3. SU(3) breaking without factorization
   i. relate A_u & A_c in $B \to J/\psi\, K^0$ & $B \to J/\psi\, \pi^0$ including a given amount of SU(3)-breaking
   ii. study the dependence of the results on the size of the SU(3)-breaking

From $B^0 \to J/\psi\, \pi^0$ (weak phase from UTfit w/o sin2β):

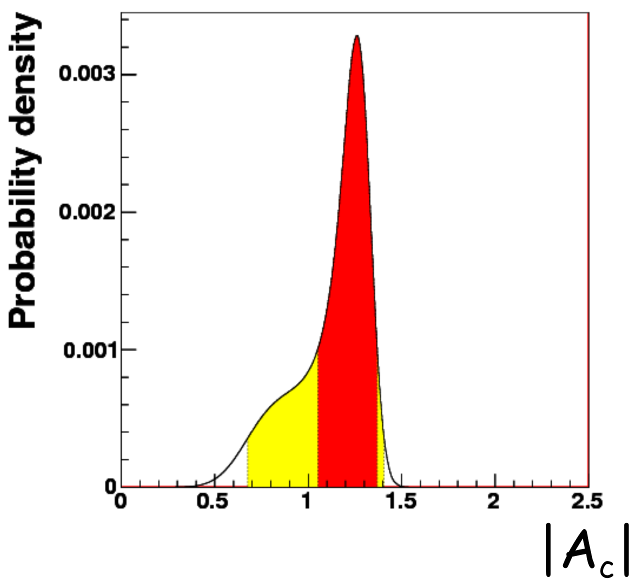
amps in units of factorized E_2

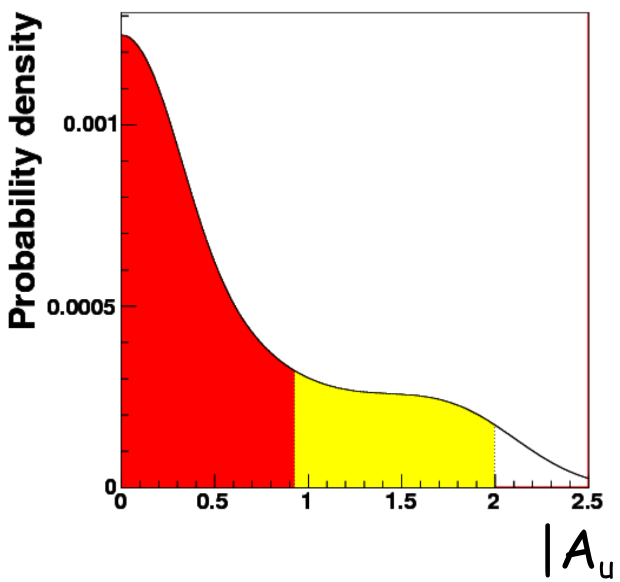
$BR^{\rm exp}$	$(1.74 \pm 0.15)10^{-5}$	$BR^{\rm fit}$	$(1.74 \pm 0.15)10^{-5}$
$\mathcal{C}^{\rm exp}$	-0.1 ± 0.13	$\mathcal{C}^{\rm fit}$	-0.07 ± 0.11
$\mathcal{S}_{\rm CP}^{\rm exp}$	-0.93 ± 0.15	$\mathcal{S}_{\rm CP}^{\rm fit}$	-0.95 ± 0.05
$\lvert A_c \rvert$	1.21 ± 0.16	$\lvert A_u \rvert$	0.46 ± 0.46
δ	$(19 \pm 38)^\circ$		

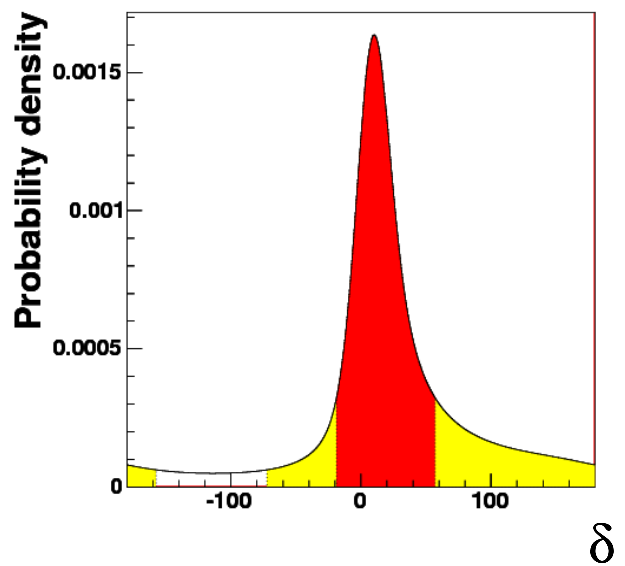


- correlation between A_u & A_d => long tails
- positive values of δ preferred
- factorization off by 20%

CPS update, PRELIMINARY results







Strategy #1: minimal SU(3) assumption

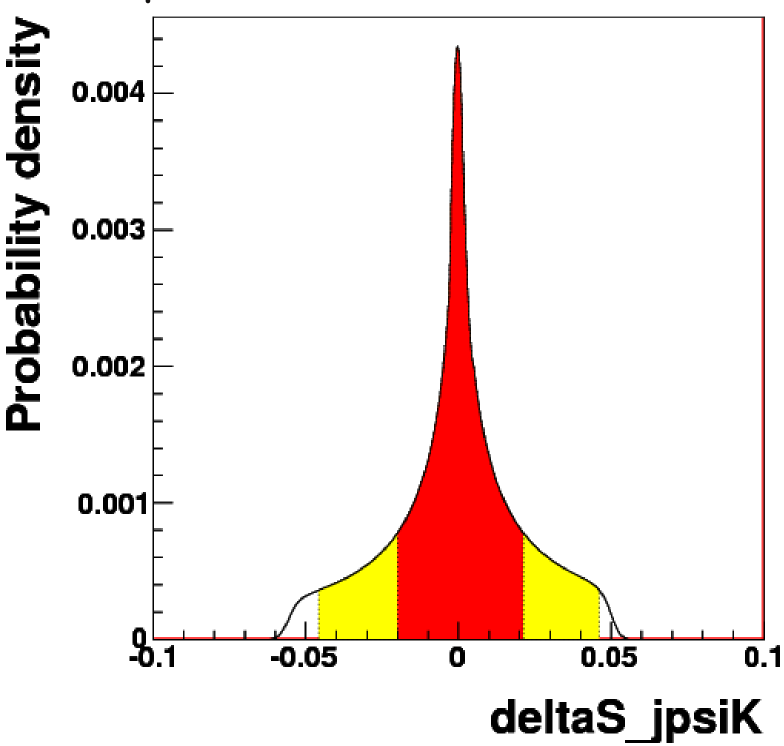
$|A_u| < 2.5$ (99.99% prob. range from $B^0 \to J/\psi\, \pi^0$)

$A_c = 1.24 \pm 0.03$ from the $B^0 \to J/\psi\, K^0$ fit, δ unconstrained

$\Delta S(J/\psi\ K^0)^{SM} = 0.000 \pm 0.021$

[-0.0458, 0.0462]@95% prob.

CPS update, PRELIMINARY results



Back to the discrepancy:
(naïve error combination)

$$\Delta S^{corr} = \Delta S - \Delta S^{SM}$$
$$= -0.117 \pm 0.049$$

$2.6\sigma \to 2.4\sigma$

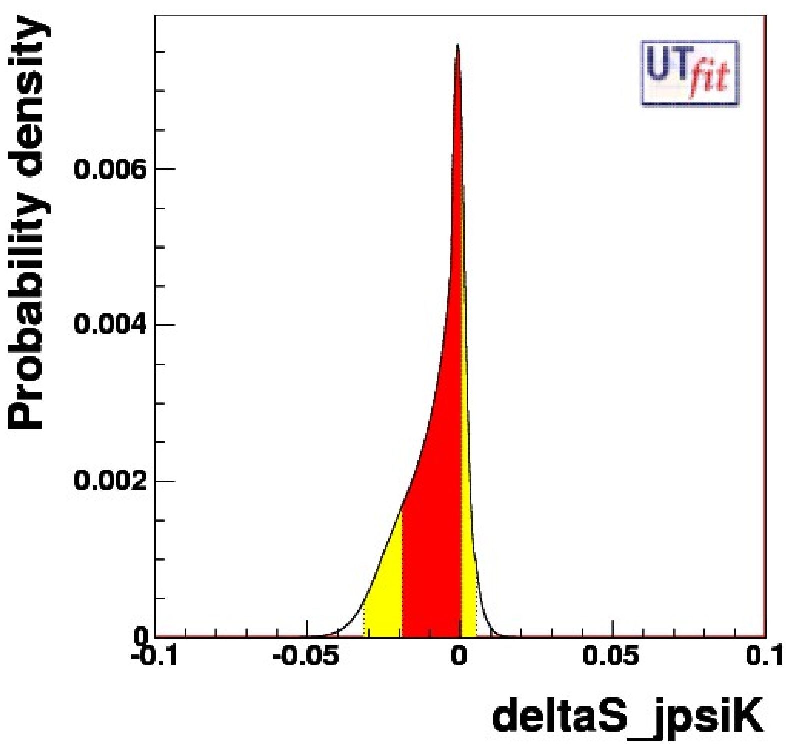
The SU(3) constraint on δ is discarded: no bias on S

Strategy #2: factorized SU(3) breaking

$A_u(J/\psi K^0) = F(B \to K)/F(B \to \pi) \{A_u(J/\psi \pi^0)+|A_u(J/\psi \pi^0)|(x_{SU(3)}+i\, y_{SU(3)}) \}$

$\Delta S(J/\psi K^0)^{SM}$ =

-0.009 ± 0.010 [-0.032, 0.005]@95% p., x,y~30% (i)
-0.012 ± 0.012 [-0.041, 0.005]@95% p., x,y~50% (ii)
-0.013 ± 0.013 [-0.051, 0.006]@95% p., x,y~80% (iii)



In this case: (naïve errors)

ΔS^{corr} = -0.108 ± 0.045 (i)
= -0.105 ± 0.046 (ii)
= -0.104 ± 0.046 (iii)

$2.6\sigma \to 2.4\sigma$ / 2.3σ / 2.3σ

CPS update, PRELIMINARY results

Testing SU(3) breaking with data

In general, it is not possible to fully extract the SU(3) breaking from the data, yet one can check whether SU(3) predictions are compatible with data for a given size of SU(3) breaking

$$6\,\mathrm{BR}(B_d \to J/\psi\eta_8) = \mathrm{BR}(B_s \to J/\psi\bar{K}^0) = 2\,\mathrm{BR}(B_d \to J/\psi\pi^0)\,, \qquad C_{B_d\to J/\psi\eta_8} = C_{B_s\to J/\psi\bar{K}^0} = C_{B_d\to J/\psi\pi^0}$$

$$3\,\mathrm{BR}(B_s \to J/\psi\eta_8) = 2\,\mathrm{BR}(B_d \to J/\psi K^0)\,, \qquad C_{B_s\to J/\psi\eta_8} = C_{B_d\to J/\psi K^0}\,, \qquad S_{B_d\to J/\psi\pi^0} = S_{B_d\to J/\psi\eta_8}\,,$$

$$C_{B_s\to J/\psi\bar{K}^0} = \frac{\mathrm{Im}(\lambda_u^{d*}\lambda_c^d)}{\mathrm{Im}(\lambda_u^{s*}\lambda_c^s)}\frac{\mathrm{BR}(B_d \to J/\psi K^0)}{\mathrm{BR}(B_s \to J/\psi\bar{K}^0)}C_{B_d\to J/\psi K^0}$$

$$a^{\mathrm{CP}}_{B^+\to J/\psi\pi^+} = \frac{\mathrm{Im}(\lambda_u^{d*}\lambda_c^d)}{\mathrm{Im}(\lambda_u^{s*}\lambda_c^s)}\frac{\mathrm{BR}(B^+ \to J/\psi K^+)}{\mathrm{BR}(B^+ \to J/\psi\pi^+)}a^{\mathrm{CP}}_{B^+\to J/\psi K^+}$$

+ relations at the amplitude level

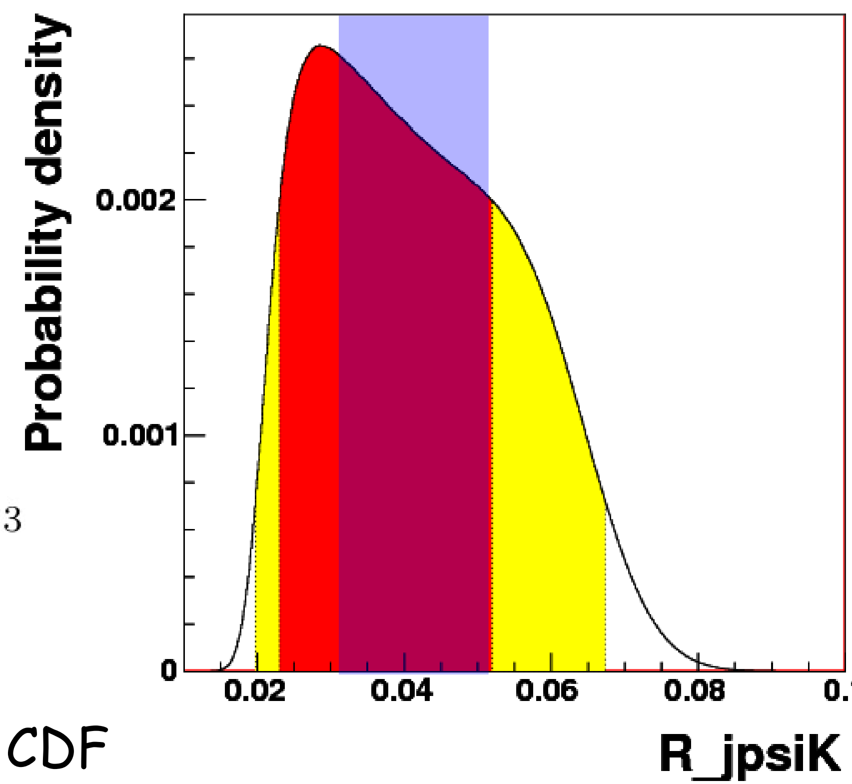
For example:

$$R^{\mathrm{fit}} = \frac{\mathrm{BR}(B_s \to J/\psi K_s)}{\mathrm{BR}(B_d \to J/\psi K_s)} = (37.5 \pm 14.5) \times 10^{-3}$$

$$R^{\mathrm{exp}} = (40.5 \pm 9.5) \times 10^{-3}$$

recently measured by CDF

CPS update, PRELIMINARY results



Strategy #3: SU(3) breaking without factorization

Next workshop...

Can ΔS be used beyond the SM? Yes & No

One can use the experimental information on S(J/ψK) to constrain simultaneously a NP phase in the B_d mixing amplitude and ΔS

$$2\beta \to \phi_d \qquad \phi_d = 2\beta + \phi_d^{\mathrm{NP}}$$

arXiv:0809.0842

This works only if NP is confined to ΔF=2 amplitudes. In the general case, even if NP is assumed to be present in loops only, one expects corrections to the ΔF=1 amplitudes (particularly penguin ones). The method is no longer viable and should not be used for generalized UT fits beyond the SM

Conclusions

I presented (preliminary) updated SM estimates of $\Delta S^{SM}(B_d \to J/\psi K^0)$ using measurements of $B_d \to J/\psi \pi^0$ with the CPS method (+ variations)

$\Delta S^{corr}(B_d \to J/\psi K^0)=\Delta S-\Delta S^{SM}=-0.117\pm0.049$ (2.4σ)

The theoretical assumptions behind the CPS method are:

1. EA_2 is negligible – can be either removed or checked
2. SU(3) symmetry gives reasonable estimates of the range of variation of the related parameters – various implementation of SU(3) breaking to be checked on data

N.B: the accuracy of the method improves with the data on $B_d \to J/\psi \pi^0$. The th. error can be kept smaller than the foreseen exp. systematic error on $\sin 2\beta$ from $B \to J/\psi K^0$

Looking into the future

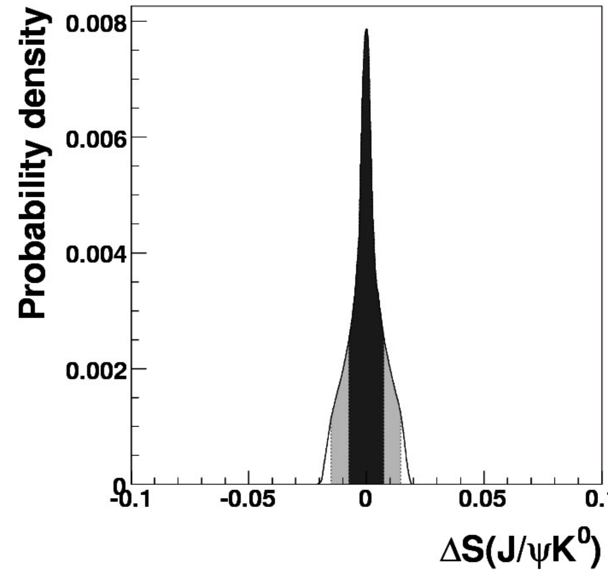
2 ab^{-1} scenario:

$\sigma(S) = 0.08$
$\sigma(C) = 0.08$
} Scaled statistical error
Systematic from $J/\psi\ K^0$

$\sigma(A_{CP}) = 0.032$
} Scaled statistical error
Systematic = smallest now

For BR
same than now (systematic dominated)

$\Delta S = 0.000 \pm 0.007$



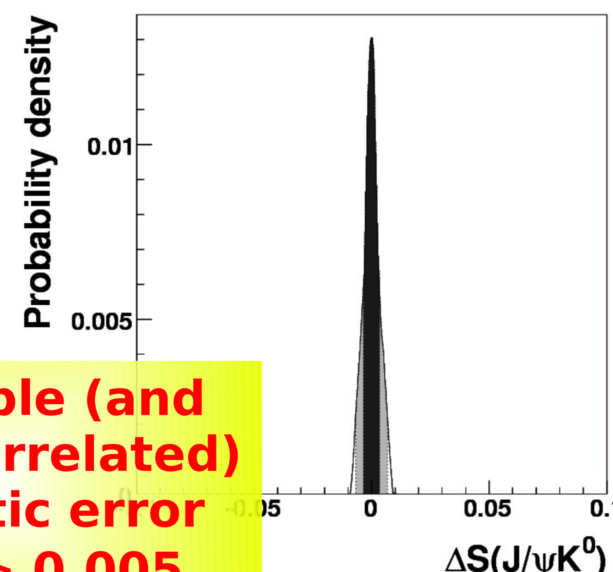
30 ab^{-1} scenario:

$\sigma(S) = 0.024$
$\sigma(C) = 0.030$
} Scaled statistical error
Systematic from $J/\psi\ K^0$

$\sigma(A_{CP}) = 0.011$
} Scaled statistical error
Systematic = smallest now

For BR
same than now (systematic dominated)

$\Delta S = 0.000 \pm 0.003$



irreducible (and largely correlated) systematic error $\sigma^{sys}(S) > 0.005$

thanks to M. Pierini

Inputs

$BR(B_d \to J/\psi\, \pi^0) = (1.74 \pm 0.15)\ 10^{-5}$
$C(B_d \to J/\psi\, \pi^0) = -0.1 \pm 0.13$
$S(B_d \to J/\psi\, \pi^0) = -0.93 \pm 0.15$
$BR(B^+ \to J/\psi\, \pi^+) = (4.8 \pm 0.4)\ 10^{-5}$
$A_{CP}(B^+ \to J/\psi\, \pi^+) = 0.01 \pm 0.07$

$BR(B_d \to J/\psi\, K^0) = (8.63 \pm 0.35)\ 10^{-4}$
$C(B_d \to J/\psi\, K^0) = -0.003 \pm 0.02$;
$S(B_d \to J/\psi\, K^0) = 0.655 \pm 0.0244$;
$BR(B^+ \to J/\psi\, K^+) = (10.26 \pm 0.37)\ 10^{-4}$
$A_{CP}(B^+ \to J/\psi\, \pi^+) = (0.2 \pm 4.1)\ 10^{-3}$

$R = BR(B_s \to J/\psi\, K_s)/BR(B_d \to J/\psi\, K_s)$
$= (40.5 \pm 9.5)\ 10^{-3}$

$F(B_d \to \pi)(m_{J/\psi}^2) = 0.4$
$F(B_d \to K)/F(B_d \to \pi) = 1.2$
$F(B_s \to K)/F(B_d \to \pi) = 0.83$
$f_{J/\psi} = 405$ MeV
$m_B = 5.2795$ GeV
$m_{J/\psi} = 3.097$ GeV
CKM from UTfit w/o $\sin 2\beta$