The Measurement of $\sin 2\beta_{\mathrm{eff}}$ in Loop-Dominated *B* Decays

Experimental summary and outlook

Andreas Höcker

Laboratoire de l'Accélérateur Linéaire, Orsay

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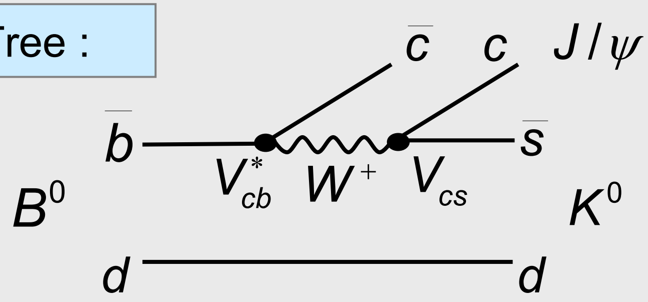
hoecker@lal.in2p3.fr

Confronting Loop and Tree Decays

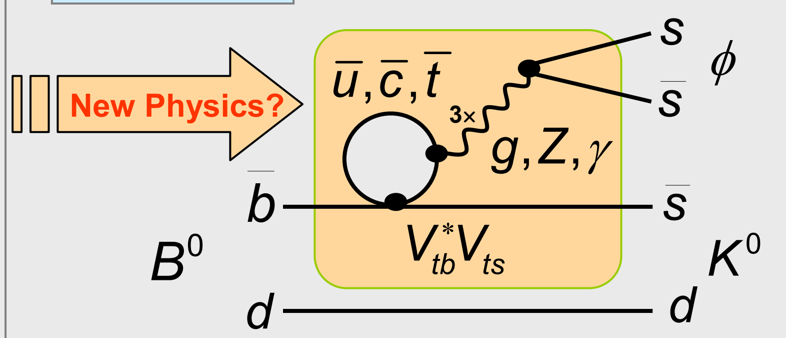
- $b \to c\bar{c}s$ decays are tree and penguin diagrams, with equal dominant weak phases
- $b \to s\bar{s}s$ decays are pure "internal" and "flavor-singlet" penguin diagrams
  - ➡ High virtual mass scales involved: believed to be sensitive to New Physics

Both decays dominated by single weak phase

Tree :



Penguin :



$b \to c\bar{c}s$

$$\lambda_{J/\psi K^0_{S,L}} = \eta_{J/\psi K^0_{S,L}} \left(\frac{q}{p}\right)_B \cdot \left(\frac{V_{cb}V_{cs}^*}{V_{cb}^*V_{cs}}\right) \cdot \left(\frac{q}{p}\right)_K = \eta_{J/\psi K^0_{S,L}} e^{-2i\beta}$$

$b \to s\bar{s}s$

$$\lambda_{\phi K^0_{S,L}} = \eta_{\phi K^0_{S,L}} \left(\frac{q}{p}\right)_B \cdot \left(\frac{V_{tb}V_{ts}^*}{V_{tb}^*V_{ts}}\right) \cdot \left(\frac{q}{p}\right)_K \sim \eta_{\phi K^0_{S,L}} e^{-2i\beta}$$

$\sin 2\beta$ [charmonium] $\stackrel{?}{=}$ $\sin 2\beta$ [*s*-penguin]

(~7000 tagged events) (~1500 tagged events)

Confronting Loop and Tree Decays

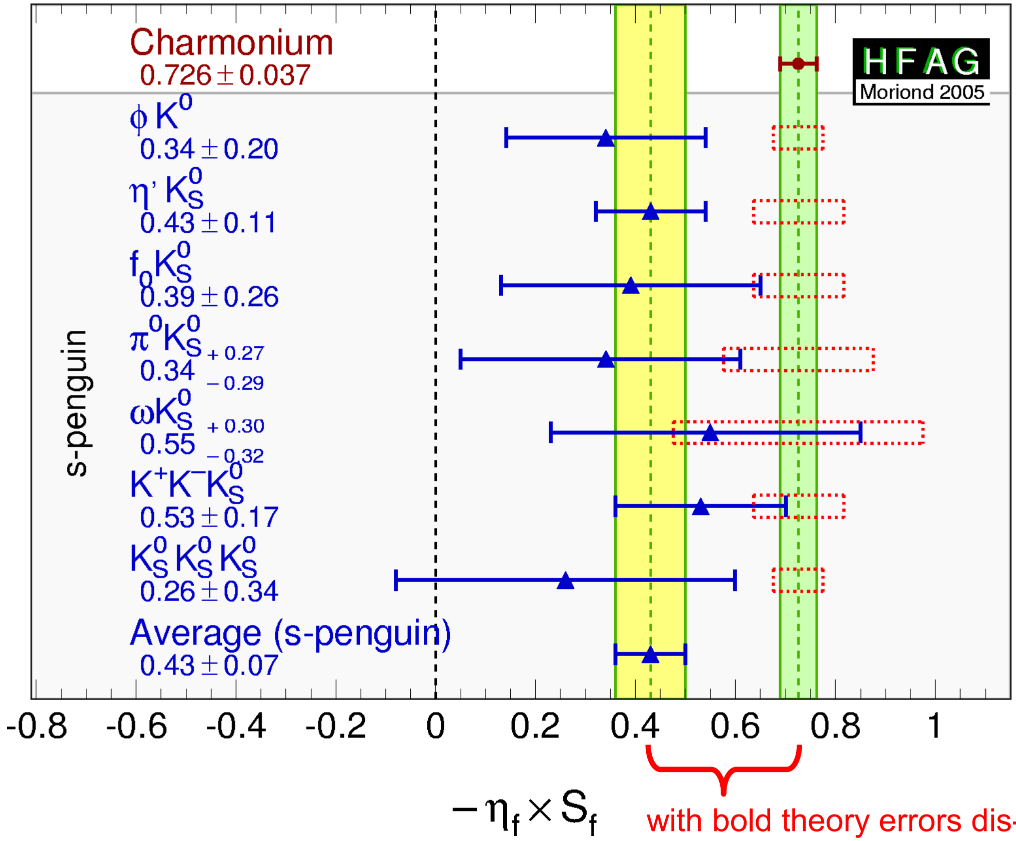
- The charmonium measurement: $\sin 2\beta = 0.725 \pm \underbrace{0.037}_{0.033[\text{stat-only}]}$ HFAG, Winter 2005
  - Theory uncertainty ? Mannel at CKM 2005

$$\Delta S_{[c\bar{c}]} \equiv \sin 2\beta_{\text{eff}} - \sin 2\beta = (-2.2 \pm 2.2) \times 10^{-4}$$

- Conflict with $\sin 2\beta_{\text{eff}}$ from *s*-penguin modes ?

$$\left\langle \sin 2\beta_{[s\text{-peng}]} \right\rangle - \sin 2\beta_{[c\bar{c}]} = \underbrace{-0.30 \pm 0.08}_{3.7\sigma}$$

$$\left\langle \sin 2\beta_{[\phi/\eta'/2K_S]} \right\rangle - \sin 2\beta_{[c\bar{c}]} = \underbrace{-0.33 \pm 0.10}_{3.3\sigma}$$



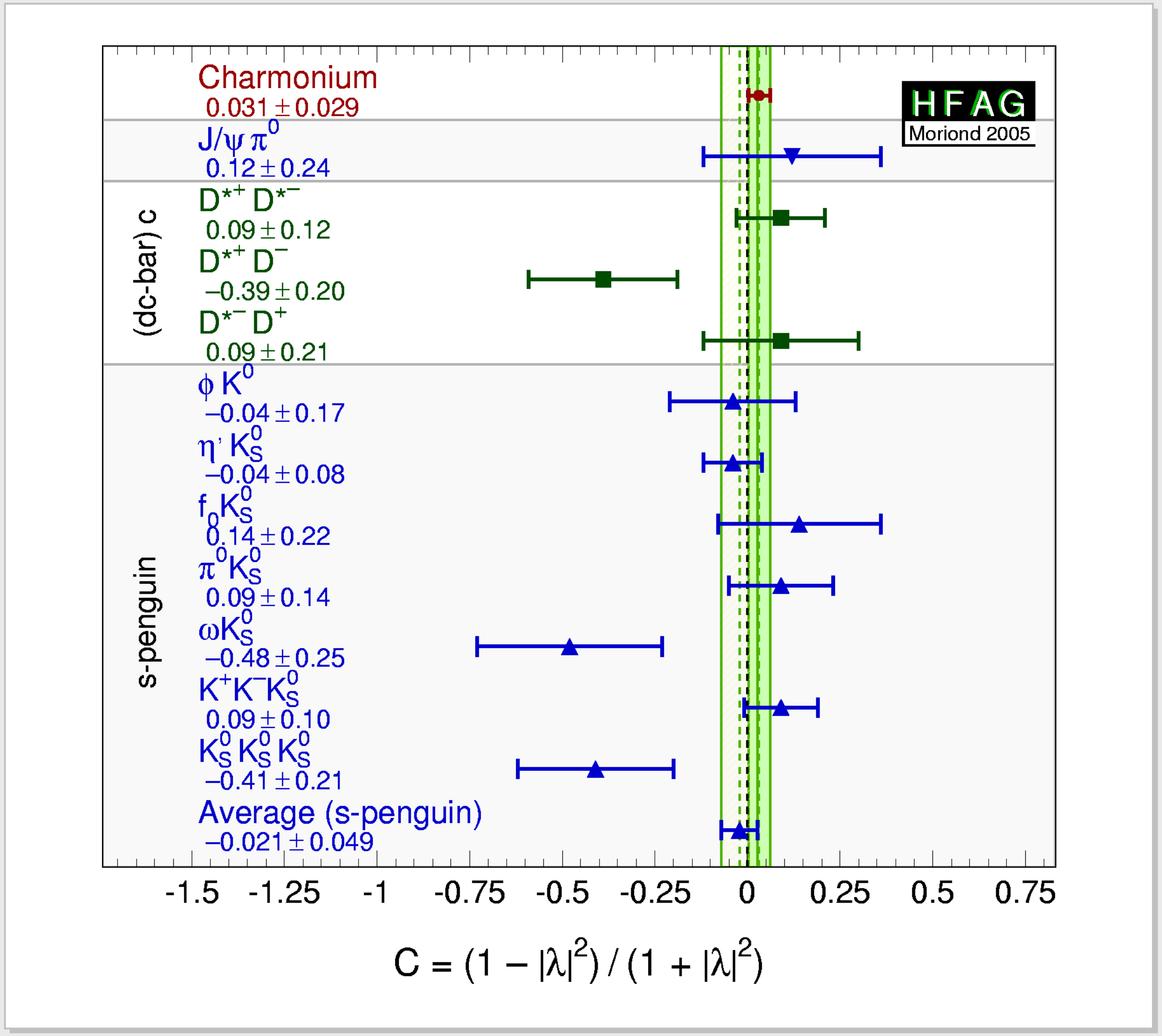
with bold theory errors discrepancy reduces to ~ 3σ

  - Theory uncertainty ?

what is $\Delta S_{[s\text{-peng}]}$? positive ?

WG4 at CKM 2005 and today's discussion

Direct *CP* Violation ?

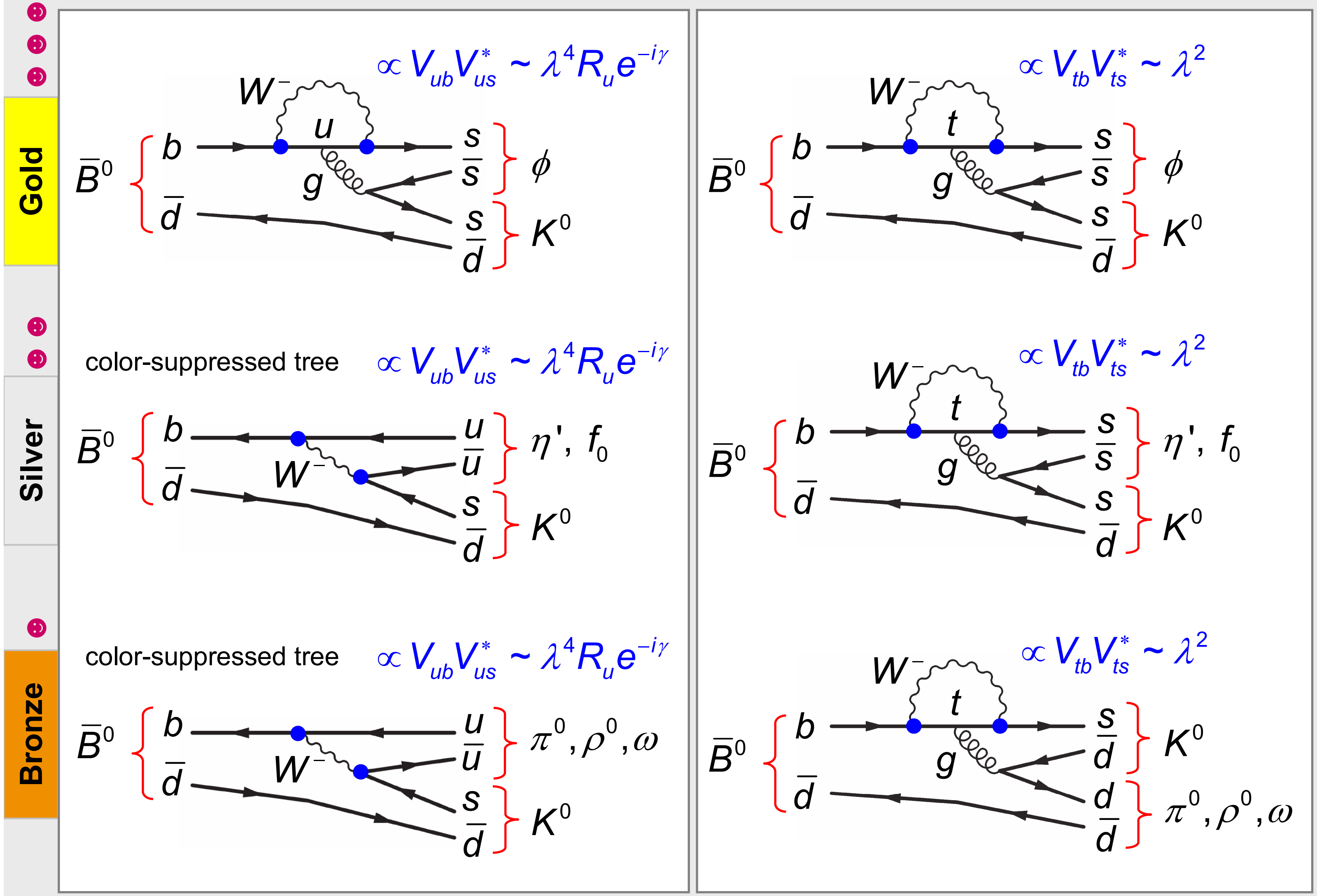


… none.

Naïve Classification of the penguins

- Can we identify golden, silver and bronze-plated *s*-penguin modes ?

Naïve (dimensional) uncertainties on sin2β



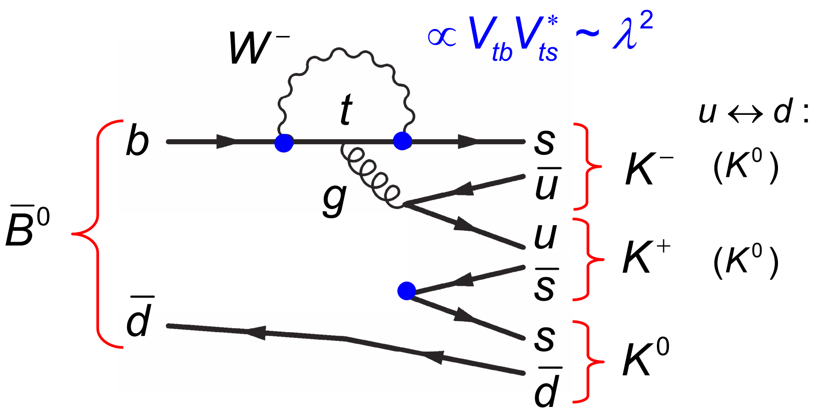
Gold: $O(\lambda^2)$ ~ 5%

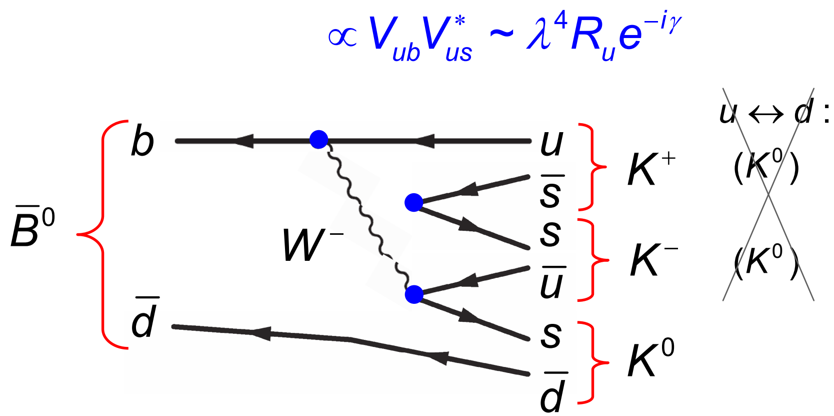
Silver: $O(\lambda^2(1+f_{q\bar{q}}/\bar{\lambda}))$ ~ 10%

Bronze: $O(\lambda^2/\bar{\lambda})$ ~ 20%

KKK^0 Modes

- How about $B^0 \to K^+K^-K^0$ and $B^0 \to K_S\, K_S\, K_S$?





$B^0 \to K^+K^-K^0$ bronze and $B^0 \to K_S\, K_S\, K_S$ seems to be a new golden mode !

but : « *popup* » *ss*-bar dynamically disvafored with respect to *popup uu*-bar

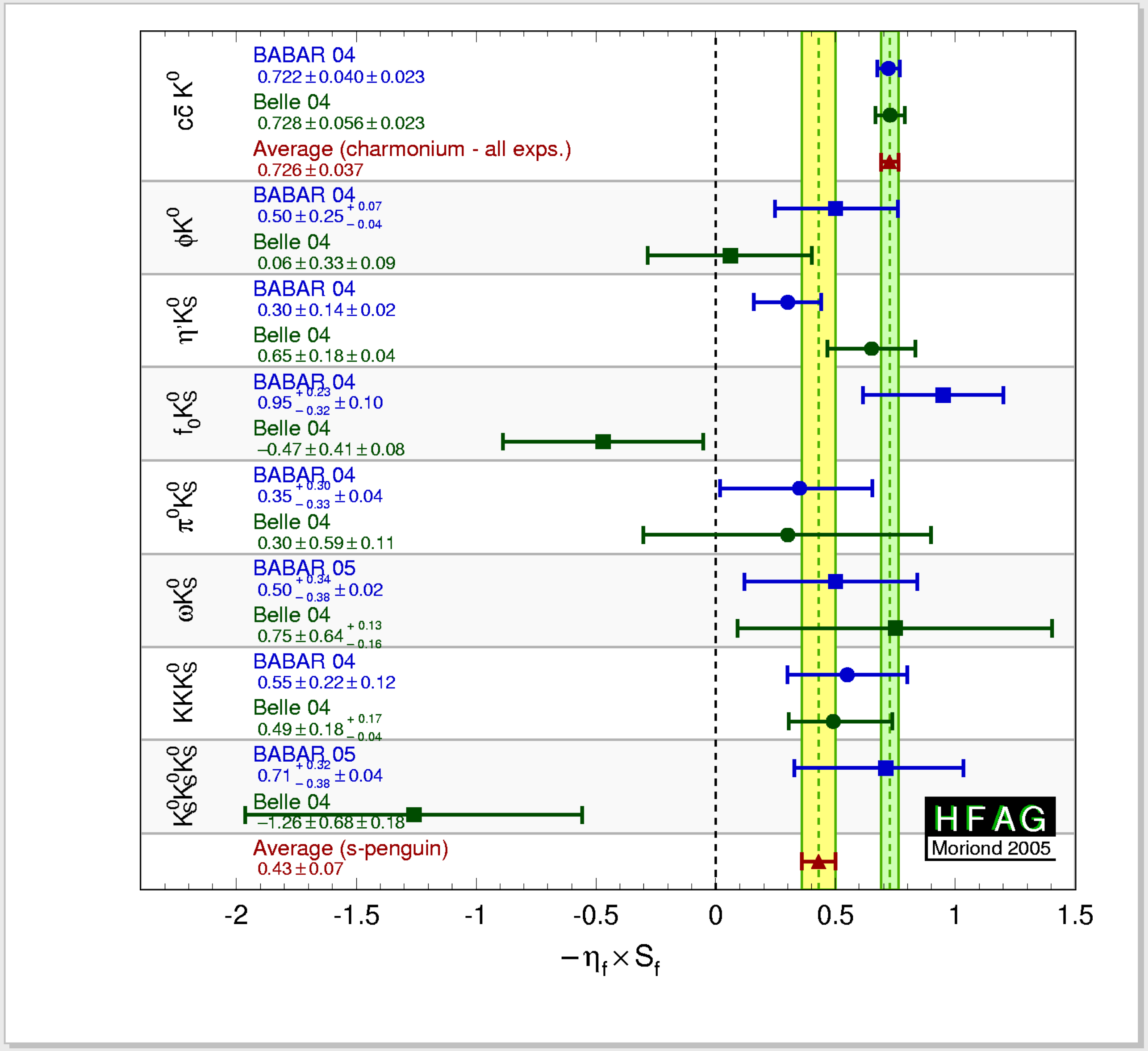
➡ is $B^0 \to K^+K^-K^0$ silver ?

- Note that

  if NP contributes significantly to CPV in loop decays, we naturally expect it to be different among the modes

  ➡ averaging only meaningful (if at all) in case of SM

Comparison BABAR vs. Belle



Moriond 2005

Averages:

BABAR : CL = 0.62

Belle : CL = 0.05

both : CL = 0.15

Characteristics of the Measurements

Different analysis strategies for charmless *B* decays:

- Belle :
  - cut on Likelihood ratio for cont. suppression followed by 2-variable (*CP*) fits (ΔE, m_B)
  - background PDFs from sidebands and assign parameter variations as systematics
- BABAR:
  - use continuum suppression Fisher/NN together with ΔE, m_B in fit
  - determine yields, *CP* and bkg. PDFs. simultaneously with multi (>30) parameter fits
  - determine fit bias due to increased correlations in full MC fits
- Consequence: larger statistical and systematic errors for Belle's analyses
- Note that Belle replaced SVD in fall 2003: 113 fb^{-1} with SVD-1, 140 fb^{-1} with SVD-2

Characteristics of the Measurements

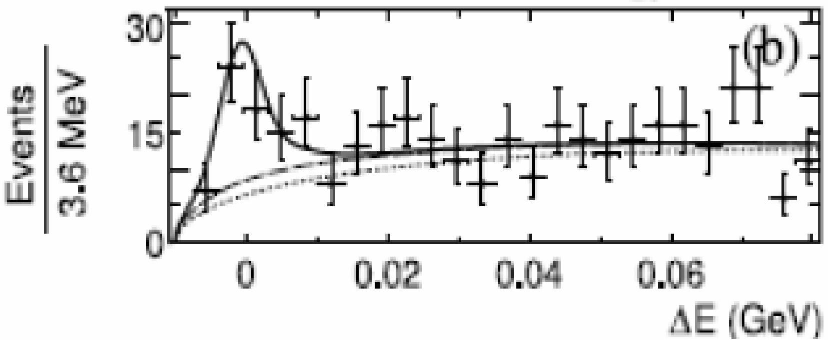
Specific analysis issues :

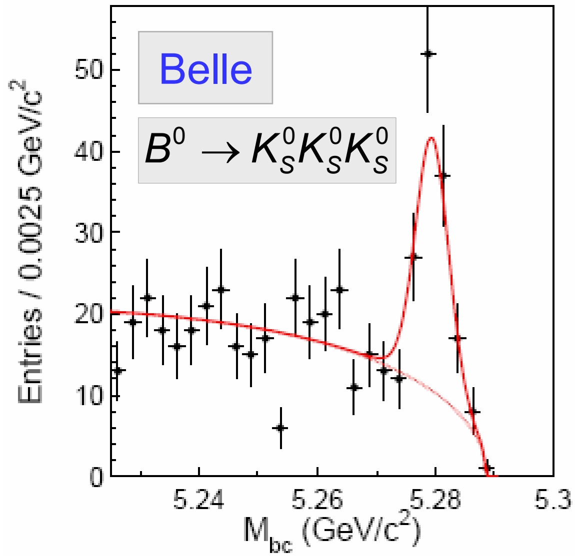
- ϕK_S : *CP*-even bkg from S-wave (*e.g.*, $f_0 \to K^+K^-$) – not yet seen; use UL in systematics
- ϕK_L : worse S/N ratio (needs NN); $\phi K^{*0}(\to K_L\pi^0)$ bkg; ($N_{\rm Signal}$ = 98 ± 18 (BABAR), 36 ± 15 (Belle)
- $K^+K^-K_S$: *CP*-even fraction : moments analysis (BABAR), isospin (Belle) [isospin violation ?]; *CP*-odd contribution treated as dilution: $S = -(2f_{CP\text{-even}} - 1) \times \sin 2\beta$
- $K_SK_SK_S$: all *CP*-even ☺ ; vertexing more efficient than for π^0K_S (~ 100%); veto (χ_{c0}, D^0) $\to K_SK_S$; Belle with large systematic error due to res. fcn and bkg (0.20)
- π^0K_S : sophisticated vertexing, some efficiency loss for long-lived K_S; BABAR almost twice more events; both experiments use $J/\psi K_S$ events *ignoring* J/ψ tracks as *CP* control sample
- $\eta' K_S$: mode with largest statistics; reconstruct $\eta' \to \eta\pi^+\pi^-, \rho^0\gamma$ and $\eta \to \gamma\gamma, \pi^+\pi^-\pi^0$ and $K_S \to \pi^+\pi^-$, BABAR also $K_S \to \pi^0\pi^0$
- f_0K_S ($f_0 \to \pi^+\pi^-$) : *CP*-odd dilution due to Q2B approximation ? Important systematics (0.10)
- ωK_S : new *s*-penguin mode; no particular problems; BABAR has 3× larger yield with less data; large syst for Belle: 0.15 ?

Characteristics of the Measurements

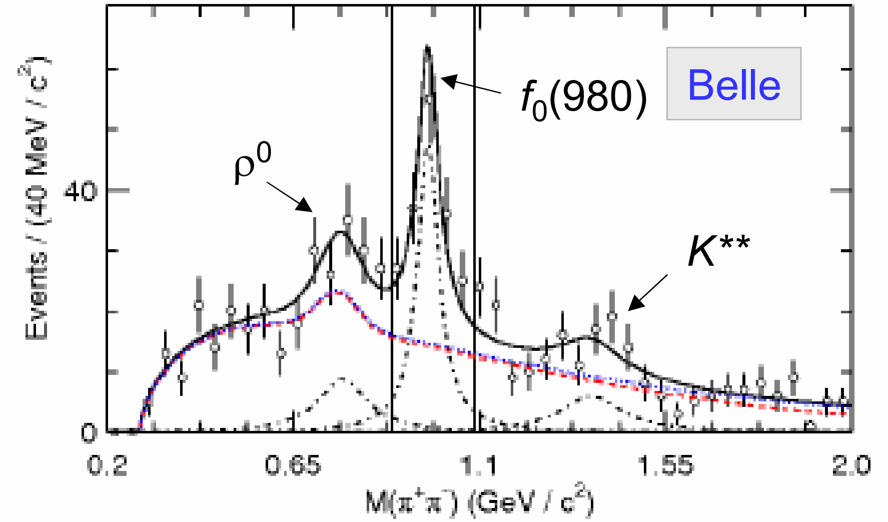
- A few plots…

$B^0 \to \phi K_L^0$ BABAR

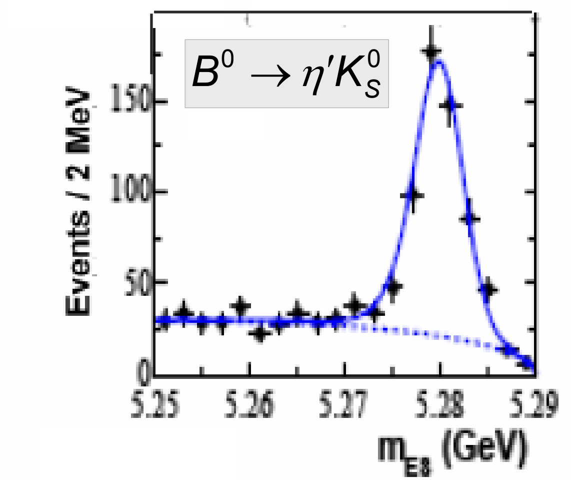




B-bkg fractions obtained from fit to $m(\pi^+\pi^-)$ spectrum



BABAR

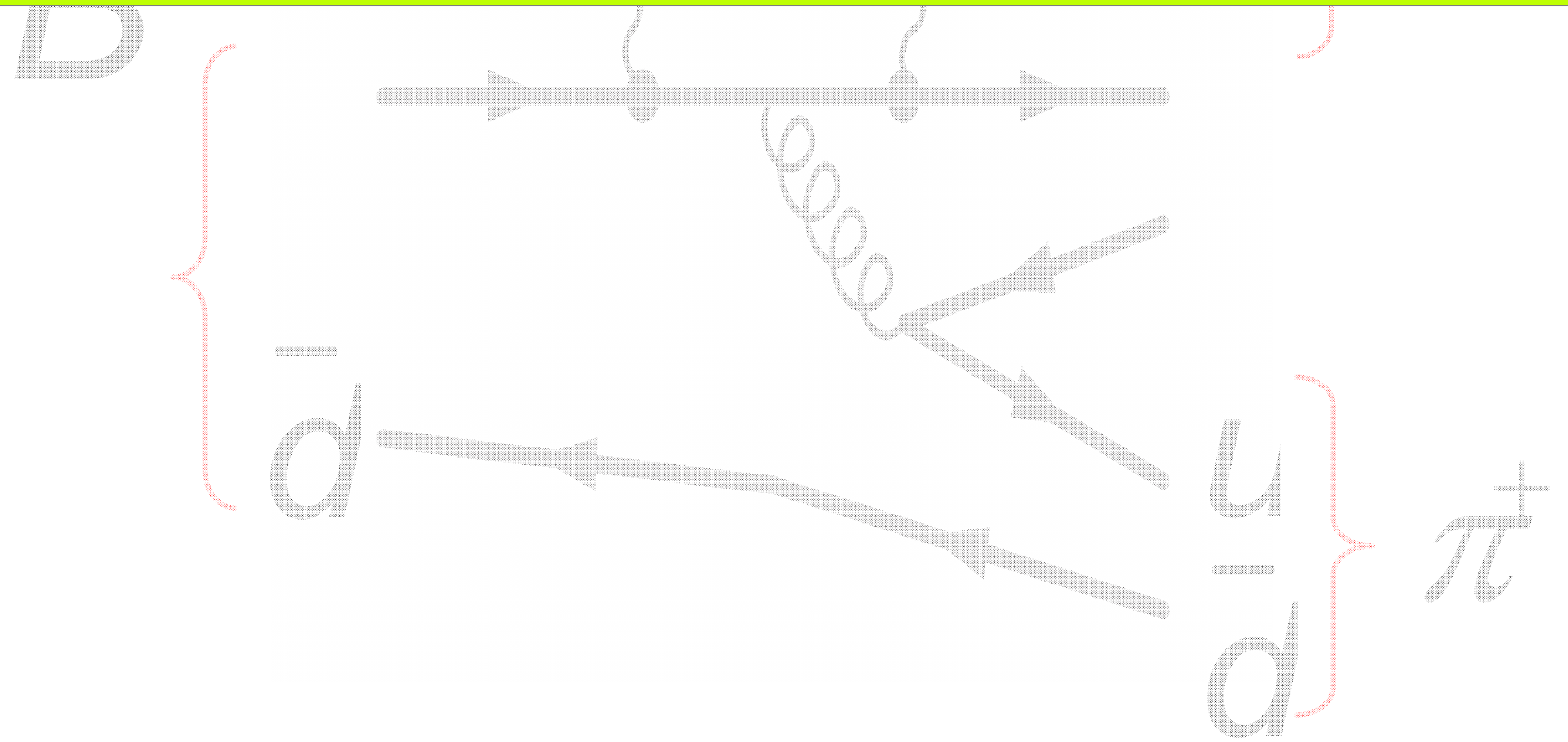


The Experimental Program for $\sin 2\beta_{eff}$

Mode	*CP*	Tot. error Belle $\mathcal{L} \sim 253\ fb^{-1}$	Tot. error BABAR $\mathcal{L} \sim 195\text{-}212\ fb^{-1}$	$\langle\Delta(SM)\rangle$ [in σ]	Error estimate at 2 ab^{-1}	Syste-matics	Max. central value for 5σ deviation at 2 ab^{-1}	Quality [naïve theoretical cleanliness]
ϕK^0	–1	0.34	0.26	– 1.9	0.10	small	0.22	☻ ☻ ☻
$\eta' K^0$	–1	0.18	0.14	– 2.6	< 0.05	small	0.45	☻ ☻ (☻)
$f_0(980)K^0$	+1	0.42	0.29	– 1.3	< 0.12	Q2B	0.12	☻ ☻
$K_S K_S K^0$	±1	0.71	0.36	– 1.4	< 0.16	vertex	– 0.08	☻ ☻ ☻
$K^+K^-K^0$	~+1	0.25	0.25	– 1.1	< 0.08	*CP*	0.31	☻ (☻)
$\pi^0 K_S$	–1	0.60	0.32	– 1.4	0.13	vertex	0.07	☻
ωK^0	–1	0.66	0.36	– 0.6	< 0.15	small	– 0.03	(☻)
$\rho^0 K^0$	–1	-	-	?	?	Q2B	?	(☻)
ηK_S	+1	-	-	?	?	vertex	?	-
Average	-	0.39 ± 0.11	0.45 ± 0.09	– 3.7	< 0.034	ok	0.53	☻ ☻

Quantifying the *u* Amplitude

VERY PRELIMINARY



Quantifying the *u* Amplitude

- The scope :

$$A(B^0 \to [s\bar{s}]K^0) = V_{us}V_{ub}^*(T + P_u) + V_{cs}V_{cb}^*P_c + V_{ts}V_{tb}^*P_t$$

$$\text{unitarity} = \begin{cases} V_{cs}V_{cb}^*(P_c - P_u - T) + V_{ts}V_{tb}^*(P_t - P_u - T) & \text{U - convention} \\ V_{us}V_{ub}^*(T + P_u - P_c) + V_{ts}V_{tb}^*(P_t - P_c) & \text{C - convention} \\ V_{us}V_{ub}^*(T + P_u - P_t) + V_{cs}V_{cb}^*(P_c - P_t) & \text{T - convention} \end{cases}$$

"Tree" : M_u

"Penguin" : M_t or M_c

Use C-convention in the following :

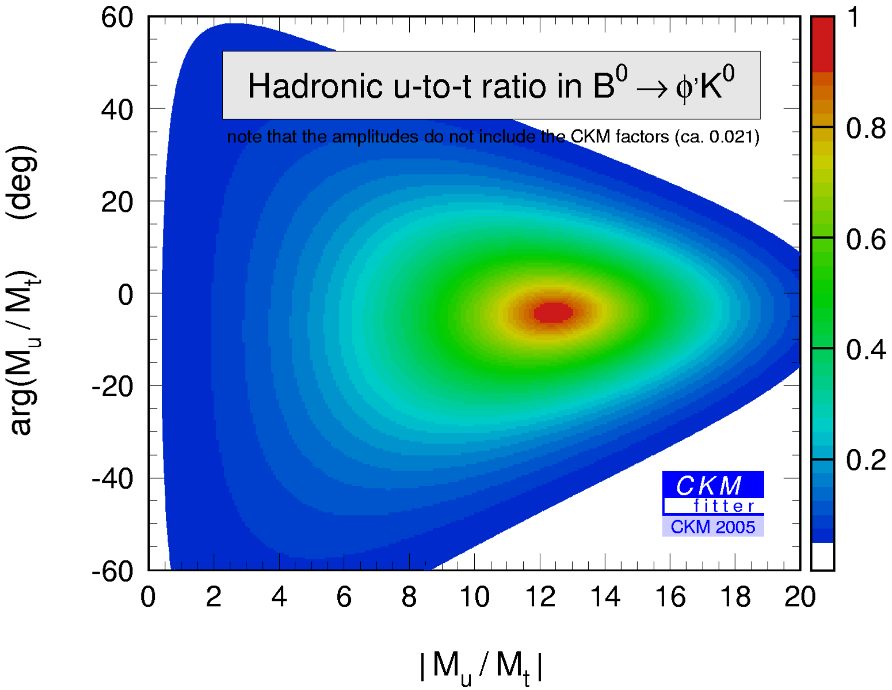
$$A(B^0 \to [s\bar{s}]K^0) = \left(V_{us}V_{ub}^* \left|\frac{M_u}{M_t}\right| e^{i\theta_{u-t}} + V_{ts}V_{tb}^* \right) M_t$$

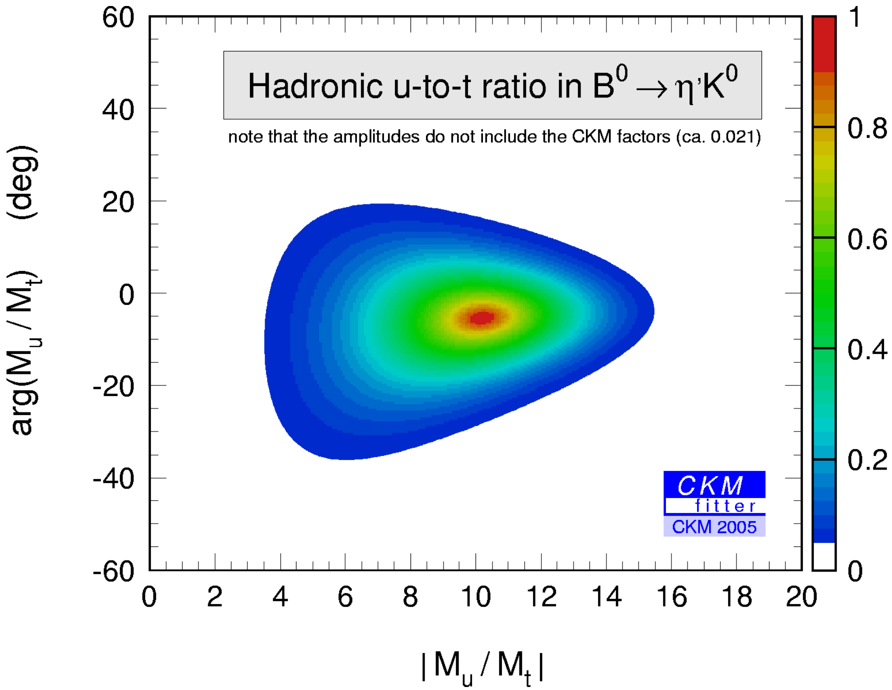
Quantifying the *u* Amplitude (assuming SM)

- Input to fit [HFAG] :
  - s-penguin observables : *S*, *C*
    BR (fixes normalization → irrelevant)
  - ρ, η from global CKM fit
- Relevant unknowns : $|M_u/M_t|$, θ_{u-t}

- Results :

Observable	$B \to \phi K^0$	$B \to \eta' K^0$
$\lvert M_u/M_t \rvert$	$12.4^{+4.5}_{-5.3}$	$10.2^{+2.8}_{-3.1}$
θ_{u-t}	-4 ± 20 deg	-5 ± 12 deg





Compare with B → *hh'* Decays ($h = \pi, K, \rho$)

- A similar (but more involved) analysis can be performed for $B \to hh'$ decays
  - GL isospin analysis ($\pi\pi$, $\rho\rho$)
  - or isospin and neglecting exchange diagrams ($K\pi$)
  - or SU(3) and neglecting OZI-suppressed penguins ($\rho\pi$)
  - or QCDF ($\pi\pi$, $K\pi$)

Charles *et al*., EPJ C41, 1–131 (2005) [hep-ph/0303171]

also many other/similar analyses by different authors !

C - convention

note: amplitude ratios given w/o CKM factors

	$\lvert P^{+-}/T^{+-}\rvert$	$\lvert T_C^{00}/T^{+-}\rvert$
$B \to \pi\pi$	$0.23^{+0.41}_{-0.10}$	$0.98^{+0.58}_{-0.30}$
$B \to \rho\rho$	$0.05^{+0.07}_{-0.05}$	$0.21^{+0.11}_{-0.15}$
$B \to K\pi$	$0.04^{+0.03}_{-0.01}$	$1.22^{+0.32}_{-0.16}$
$B \to \rho\pi[+-]$	$0.03^{+0.09}_{-0.03}$	$0.48^{+0.14}_{-0.16}$
$B \to \rho\pi[-+]$	$0.10^{+0.02}_{-0.03}$	$0.57^{+0.17}_{-0.18}$
$B \to \pi\pi$ (QCD FA)	$0.18^{+0.01}_{-0.03}$	1.17 ± 0.20
$B \to K\pi$ (QCD FA)	$0.17^{+0.01}_{-0.03}$	$1.52^{+0.42}_{-0.47}$

data-driven

Experimental status: ICHEP 2004 (not yet updated) !

update gives for $\pi\pi$:

$$\left|\frac{T_C^{00}}{P^{+-}}\right|_{B\to\pi\pi} = 7.1^{+3.7}_{-2.3}$$

- statistics ?
- huge *C* tree ?
- huge *u* penguin ?
- new physics ?