Dvodelčni razpadi mezonov B v SCET/ Charmless 2-body B decays in SCET

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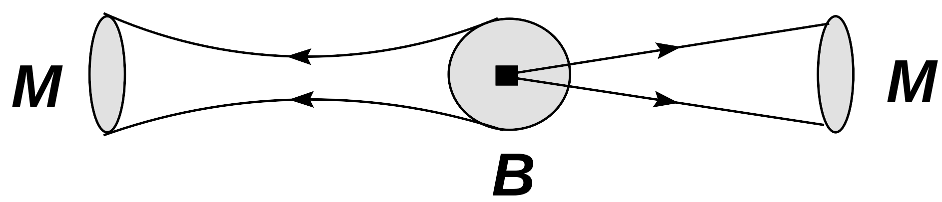
B decays/motivation

- B decays probe flavor dynamics of SM (or extensions)
- an abundance of information available from B-factories and Tevatron ($b \to s\gamma$, $b \to sl^+l^-$, $B_s \to \mu^+\mu^-$, $\ldots$)
- the weak dynamics folded with the QCD effects
  - to use $B \to MM$ decays: needs a reliable calculation + realistic estimate of errors

Charmless B decays

- B decays into two light mesons: $B \to \pi\pi, B \to \pi K, \ldots$
- the outgoing mesons look like 2 energetic jets with $p^2 \sim \Lambda_{\text{QCD}}$



- can use SCET to treat QCD effects
- already used to calculate $B \to$ nonisosinglets ($\pi\pi, \ldots$)
  Bauer, Pirjol, Rothstein, Stewart 2004, 2005
- many useful observable sensitive to NP in decays to isosinglet states $B \to K_S\eta', K_S\phi, \ldots$ Williamson, JZ 2006

Outline

- brief introduction to SCET
  - application to 2-body charmless B decays
  - extension to isosinglet final states
- phenomenology
  - $B \to \pi K$ puzzle
  - $B^0 \to \eta' K$ vs. $B \to \eta K$
  - S parameters in penguin dominated modes
- if time permits...
  - B_s decays
  - semiinclusive hadronic decays
- conclusions

Introduction to SCET

Bauer, Fleming, Luke, Pirjol, Stewart 2000,2001

- effective theory appropriate for jet-like events in QCD
- jet in z direction $\Rightarrow$ use light-cone coord.

$$p^\mu = (E + p_3, E - p_3, \vec{p}_\perp) = (p_+, p_-, \vec{p}_\perp)$$

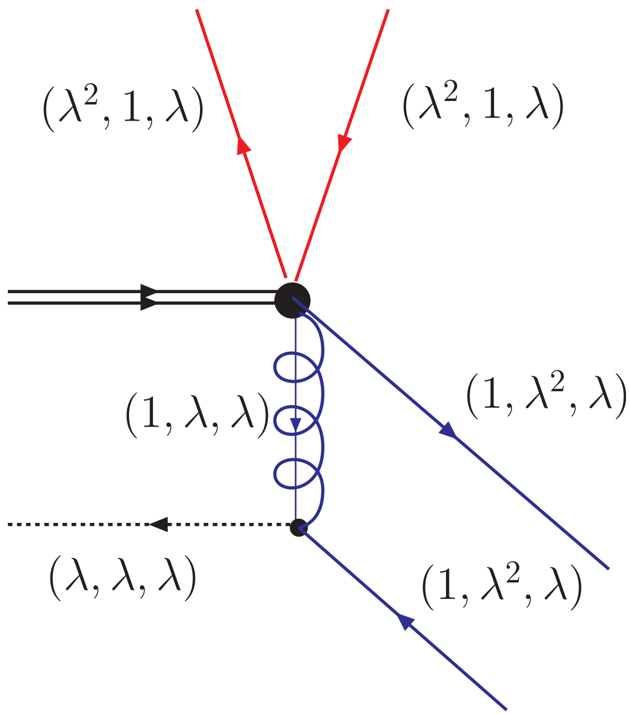
Note: $p^2 = p_+ p_- - \vec{p}_\perp^{\,2}$

- introduce expansion parameter $\lambda = \Lambda/m_b$
  - collinear gluon, quark: $p \sim m_b(1, \lambda^2, \lambda)$
  - soft gluon, quark: $p \sim m_b(\lambda, \lambda, \lambda)$

Scales in charmless 2-body B decay

Bauer, Pirjol, Stewart 2002

- outgoing states are jet-like with $p^2 = \Lambda^2$
- the "brown muck" in B is soft
- a typical configuration

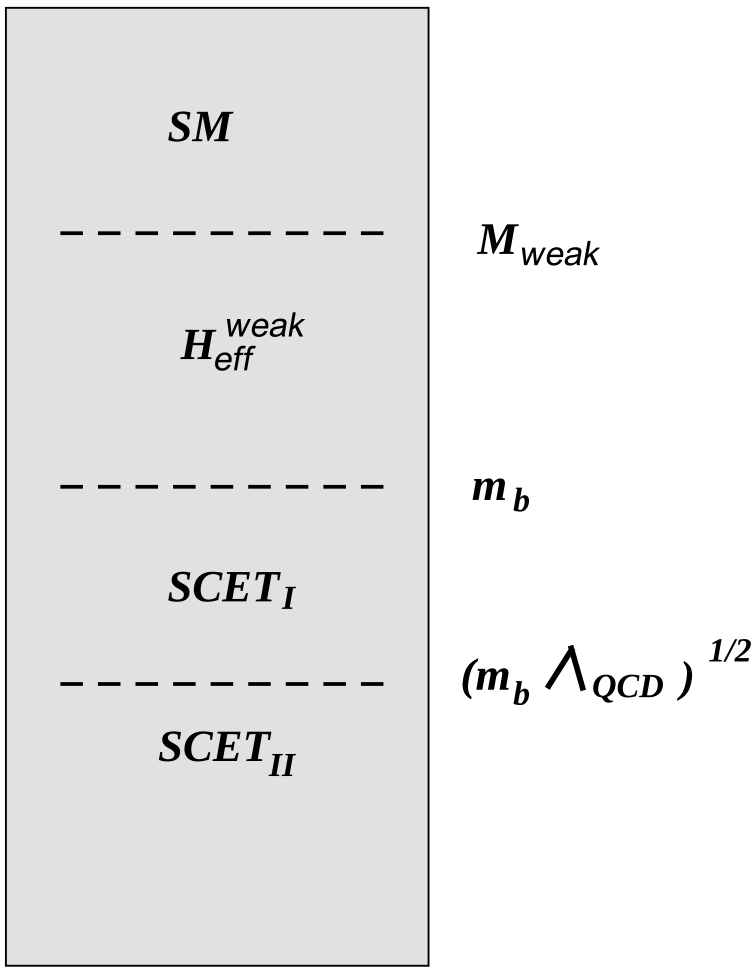


- intermediate hard-collinear modes: $p^2 = m_B^2 \lambda = m_B \Lambda$
- assume ordering
  $$\Lambda \ll \sqrt{m_B \Lambda} \ll m_B$$
- two step matching
  - QCD$\to$SCET$_{\rm I}$
    $\Leftarrow$ expan. param. $\sqrt{\lambda}$
  - SCET$_{\rm I}$ $\to$SCET$_{\rm II}$
    $\Leftarrow$ expan. param. λ

Effective theories in 2-body B decays

Bauer, Pirjol, Rothstein, Stewart 2004
Bauer, Rothstein, Stewart 2005
Williamson, JZ 2006

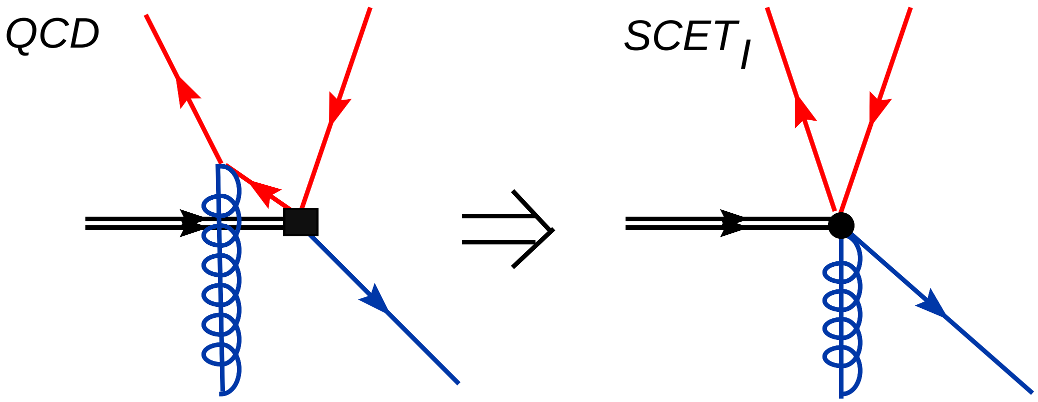
- a sequence of effective theories



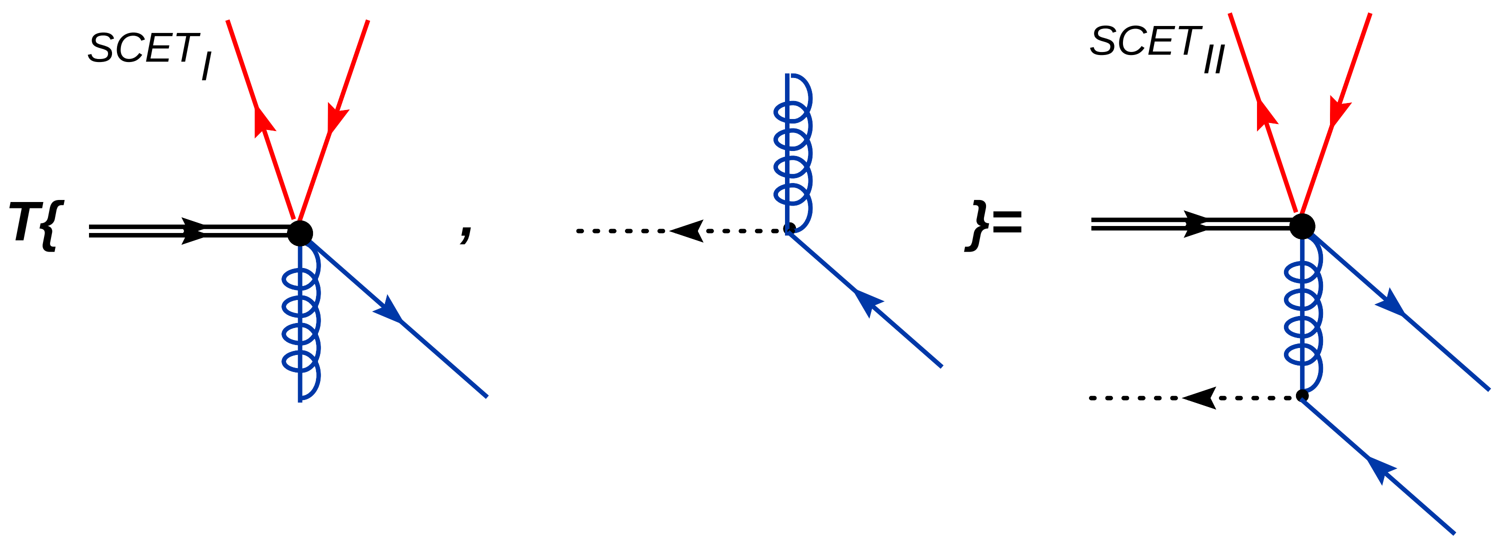
- $H_{\rm eff}^{\rm weak}$ in terms of four quark operators $O_i \sim (\bar{q}\Gamma_i q')(\bar{q}''\Gamma_i' q''')$ and magnetic operators
- in SCET$_{\rm I}$ at LO in $1/m_B$ factorization of collinear modes in opposite directions $O_i \sim (\bar{q}_n \Gamma_i q_n') \times (\bar{q}''_{\bar{n}} \Gamma_i' q'''_{\bar{n}})$
- these then match to nonlocal operators in SCET$_{\rm II}$

Matching examples

- example of QCD$\rightarrow$SCET$_{\rm I}$ matching



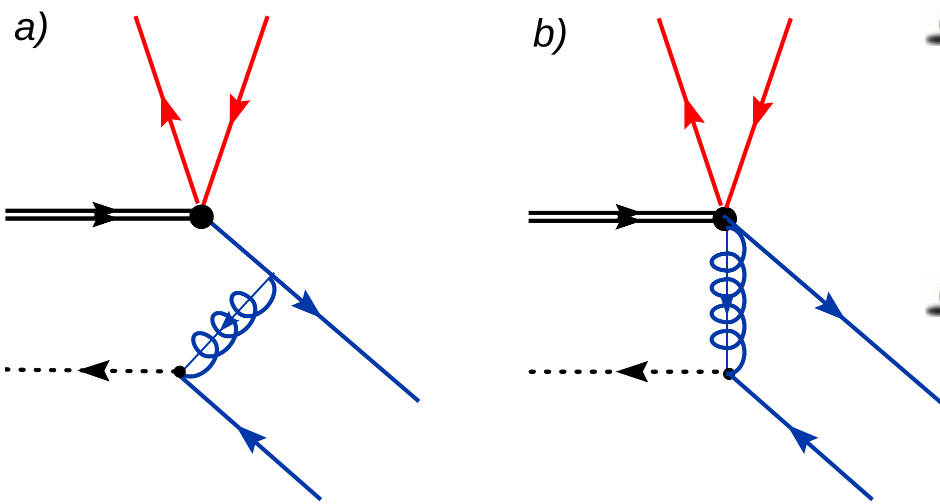
- example of SCET$_{\rm I}$ $\rightarrow$ SCET$_{\rm II}$ matching



Factorization formula

Bauer, Pirjol, Rothstein, Stewart 2004

- for start only nonisosinglet final states (such as $B \to \pi\pi$)
- $\text{SCET}_{\text{I}} \to \text{SCET}_{\text{II}}$ matching



- a) type diagrams have endpoint singularities $\Rightarrow$ introd. matrix el. ζ^{BM}
- b) type diagrams, $\alpha_S(\sqrt{\Lambda, m_B})$ expansion of function $\zeta_J^{BM}(z)$

- at LO in $1/m_B$

$$A(B \to M_1 M_2) \propto f_{M_1}\phi_{M_1}(u) \otimes T_{1J}(u,z) \otimes \zeta_J^{BM_2}(z)$$

$$+ f_{M_1}\phi_{M_1}(u) \otimes T_{1\zeta}(u)\zeta^{BM_2} + 1 \leftrightarrow 2 + \lambda_c^{(f)} A_{cc}^{M_1 M_2}$$

At LO in $\alpha_S(m_b)$

- hard kernels $T_{1(J),2(J)}(u,z)$ are calculable in $\alpha_S(m_b)$ expansion
- at LO in $\alpha_S(m_b)$
  - $T_{1,2}$ are constants
  - $T_{1J,2J}$ only functions of u
- this simplifies the factorization formula

$$A_{B\to M_1M_2} \propto f_{M_1}\phi_{M_1}(u)\otimes T_{1J}(u)\zeta_J^{BM_2} + f_{M_1}T_{1\zeta}\zeta^{BM_2} + 1\leftrightarrow 2 + \lambda_c^{(f)}A_{cc}^{M_1M_2}$$

- coefficients ζ^{BM}, ζ_J^{BM} are fit from data

Connection to form factors

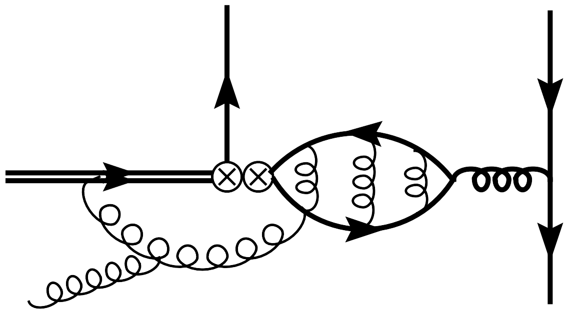
- ζ^{BM}, ζ_J^{BM} are related to $B \to M$ form factors
- at LO in $\alpha_S(m_b)$ for decays into pseudoscalars

$$f_+^{BP}(0) = \zeta^{BP} + \zeta_J^{BP}$$
$$f_+^{BP}(0) + f_-^{BP}(0) = 2\zeta_J^{BP}$$

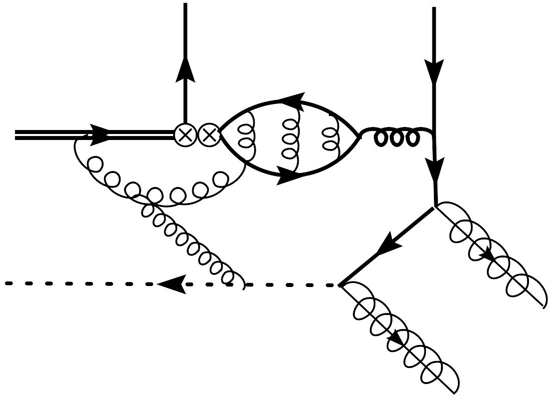
- at higher orders in $\alpha_S(m_b)$ more complicated hard kernels
- these nonperturbative inputs could be
  - obtained from lattice (+ exp. data on $B \to \pi l \nu$)
  - from sum rules
  - in our analysis will be fit from $B \to PP$ data

Charming penguins

- since $2m_c \sim m_b$ there are configurations with almost on-shell charm quarks



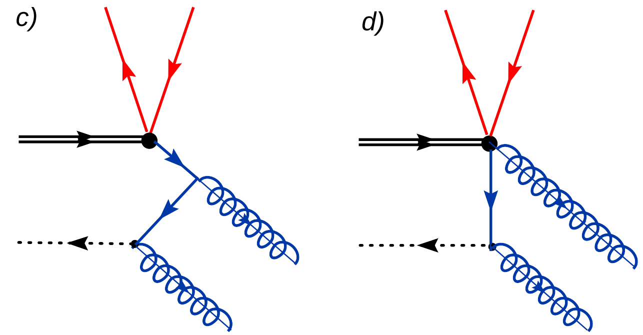
- BBNS: charming penguins perturbative
- BPRS: nonpert., NRQCD counting $\alpha_S(2m_c)f(2m_c/m_b)v$
- most conservative - introduce new nonpert. parameters $A_{cc}^{M_1M_2}$ that are fit from data (with isospin or SU(3) used)
- for isosinglets also "gluonic charming penguins" $\Rightarrow$ in SU(3) limit one additional parameter A_{ccg}



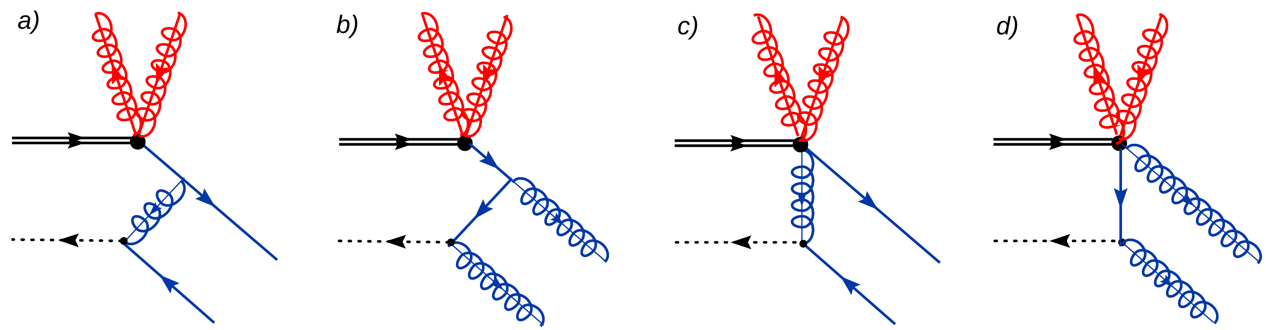
Isosinglet final states

Beneke, Neubert, 2002
Williamson, JZ 2006

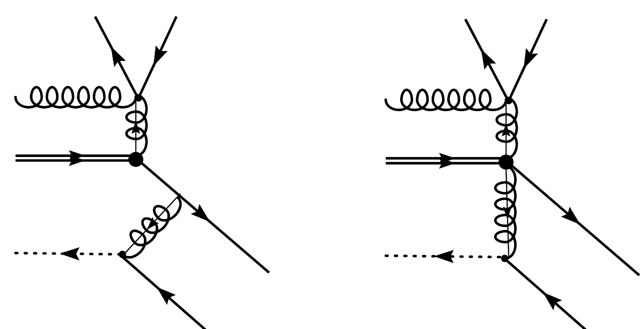
- additional operators in $\mathrm{SCET_I} \to \mathrm{SCET_{II}}$ matching, that contribute only for η, η'



- at $\alpha_S(m_b)$ also operators (at this order only from O_{8g})



- heavy quark–soft quark–soft gluon terms

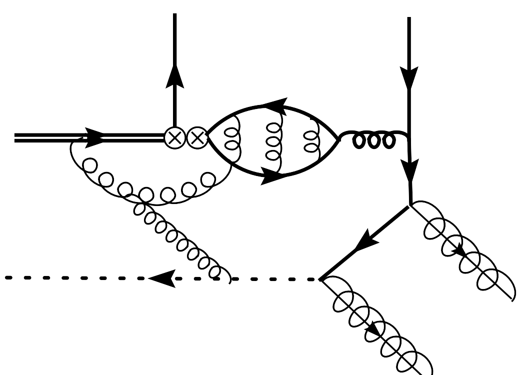


Factorization including isosinglets

- extended factorization formula

$$A(B \to M_1 M_2) \propto f_{M_1}\phi_{M_1}(u) \otimes T_{1J}(u,z) \otimes \zeta_J^{BM_2}(z)$$
$$+ f_{M_1}\phi_{M_1}(u) \otimes T_{1\zeta}(u)\zeta^{BM_2} + 1 \leftrightarrow 2 + \lambda_c^{(f)} A_{cc}^{M_1 M_2}$$
$$+\delta_{M_1,\eta^{(\prime)}}\big[f^1_{M_1}\bar{\Phi}^g_{M_1}(u) \otimes [T^g_{1J}(u,z) \otimes \zeta_J^{BM_2}(z) + T^g_{1\zeta}(u)\zeta^{BM_2}]$$
$$+ (f_{M_1}\phi_{M_1}(u) \otimes \zeta_3^{BM_2}(u) + f^1_{M_1}\bar{\Phi}^g_{M_1}(u) \otimes \zeta_{3g}^{BM_2}(u))\big]$$

- $\zeta^{B\eta^{(\prime)}}$, $\zeta_J^{B\eta^{(\prime)}}$ receive contribs. from gluonic operators
- for isosinglets also "gluonic charming penguins" $\Rightarrow$ in SU(3) limit one additional parameter A_{ccg}



Counting of parameters

- assuming only isospin at LO in $1/m_b$ and $\alpha_S(m_b)$
  - $B \to \pi\pi$: 4 real parameters $\zeta_{(J)}^{B\pi}$, $A_{cc}^{\pi\pi}$ vs. 8 observables (6 measured)
  - $B \to \pi\eta^{(\prime)}$: 14 new parameters $\zeta_{(J)}^{B\eta_{q,s}}$, $\zeta_{3(g)}^{B\pi(\eta_{q,s})}$, $A_{cc}^{\pi\eta_{q,s}}$ beyond $B \to \pi\pi$ vs. 19 observables (4 measured)
  - similarly $B \to \pi K$ vs. $B \to K\eta^{(\prime)}$
- at present in the analysis of isosinglets SU(3) needs to be used (this can be relaxed with more data)
- in the SU(3) limit 14 real parameters: ζ, ζ_J, A_{cc} and the "gluonic" ζ_g, ζ_{Jg}, A_{ccg}, $4 \times \zeta_{3,i}$ (these only for isosinglets)
- compare with 18 complex reduced matrix elements in most general SU(3) decomposition

Comments about diagrammatic approach

- the color suppression is lifted in SCET
- in "diagrammatic" SU(3) fits dynamical assump.: "annihilation-like" ampl. neglected for η, η' final states
  - 4 additional reduced matrix elements for isosinglets, only one (s) taken nonzero
  - in SCET counting all 4 LO in $1/m_b$: keeping only s corresponds to $\zeta_{(J)g} \ll \zeta_{(J)}$ limit not to $m_b \to \infty$ limit

Phenomenology

Overview

Williamson, JZ 2006

- will focus on $B \to PP$, work at LO in $1/m_b$ and $\alpha_S(m_b)$
- isosinglets included, at present SU(3) imposed on SCET parameters
- LO factorized amplitude

$$A_{B\to M_1 M_2} \propto f_{M_1}\phi_{M_1}(u)\otimes T_{1J}(u)\zeta_J^{BM_2} + f_{M_1}T_{1\zeta}\zeta^{BM_2} + 1\leftrightarrow 2 + \lambda_c^{(f)}A_{cc}^{M_1M_2}$$

- two subsequent fits determine SCET parameters
  - $\zeta_{(J)}$, A_{cc} from $B\to \pi\pi, \pi K$
  - $\zeta_{(J)g}$, A_{ccg},$(\zeta_{3i}\to 0)$ from $B\to \eta^{(\prime)}\pi, \eta^{(\prime)}K$
- in predictions SU(3) and $1/m_b$ errors included with parametrically expected sizes

$B \to \pi K$ "puzzle"

Br ratios

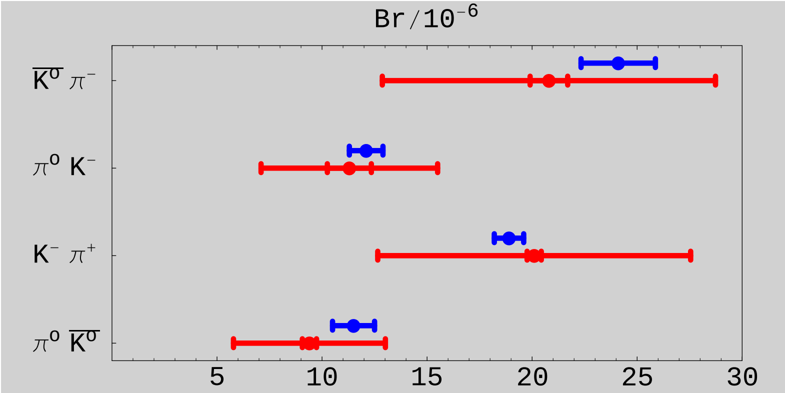
- $\Delta S = 1$ decay (i.e. $b \to s q \bar{q}$)
- define "tree" and "penguin" according to CKM factors

$$A_{\bar{B}\to f} = \lambda_u^{(s)} T_{\bar{B}\to f} + \lambda_c^{(s)} P_{\bar{B}\to f}$$

$$\lambda_u^{(s)} = V_{ub}V_{us}^*,\ \lambda_c^{(s)} = V_{cb}V_{cs}^*$$

- large hierarchy between T, P since $|\lambda_u^{(s)}| \sim 0.02|\lambda_c^{(s)}|$
- the dominant term: $A_{cc}^{K\pi}$ since $\lambda_c^{(s)}/\lambda_u^{(s)}$ enhanced $\Rightarrow$

$$Br_{\pi^+K^-} \simeq Br_{\pi^-\bar{K}^0} \simeq 2Br_{\pi^0K^-} \simeq 2Br_{\pi^0\bar{K}^0}$$



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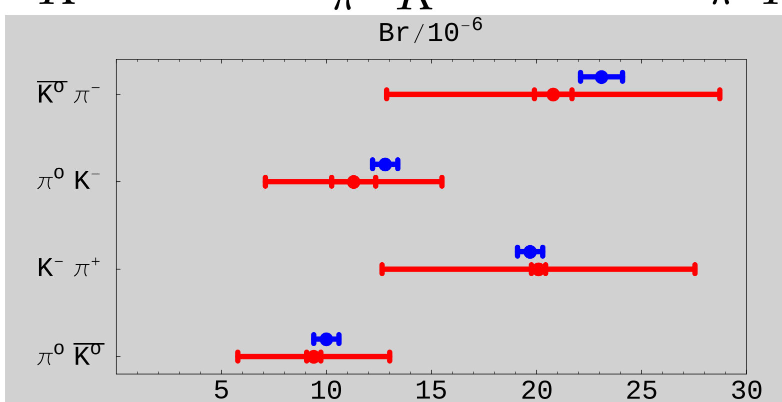

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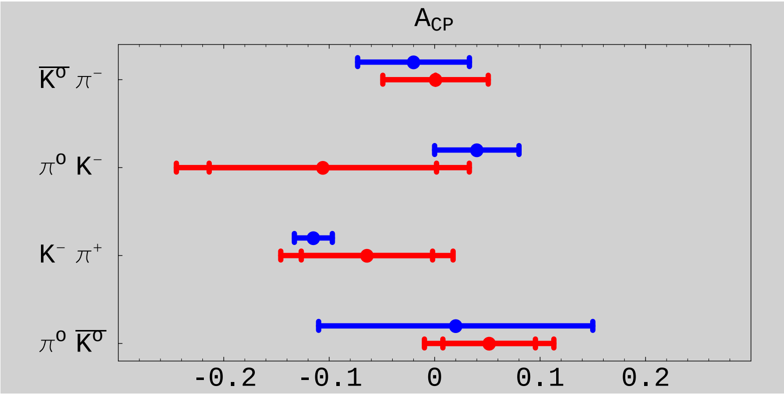
CP asymmetries

- from χ^2-fit to $B \to \pi\pi, K\pi \Rightarrow \zeta, \zeta_J$, $|A_{cc}|$ and $\arg(A_{cc})$
- $\zeta \sim \zeta_J$ as expected from SCET counting
- strong phase in A_{cc} is nonzero:

$$\arg(A_{cc}) = 156^\circ \pm 6^\circ$$

- $\chi^2/\text{d.o.f.} = 44.6/(13-4) \Rightarrow \chi^2/\text{d.o.f.} = 8.9/(13-4)$ if theory errors included
- the largest discrepancies are $\mathcal{A}^{\rm CP}_{\pi^0 K^-}$, $\mathcal{A}^{\rm CP}_{\pi^+ K^-}$



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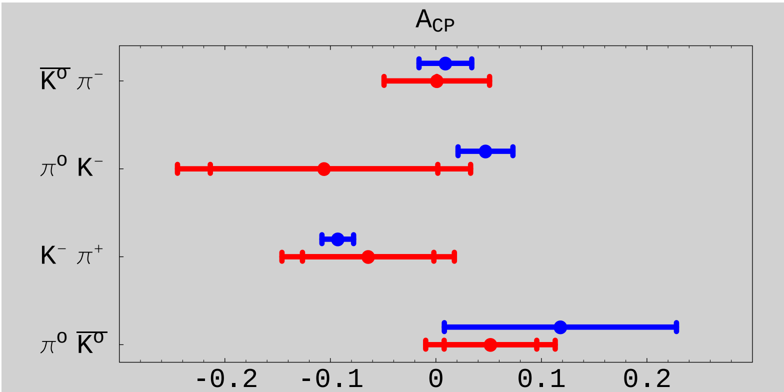

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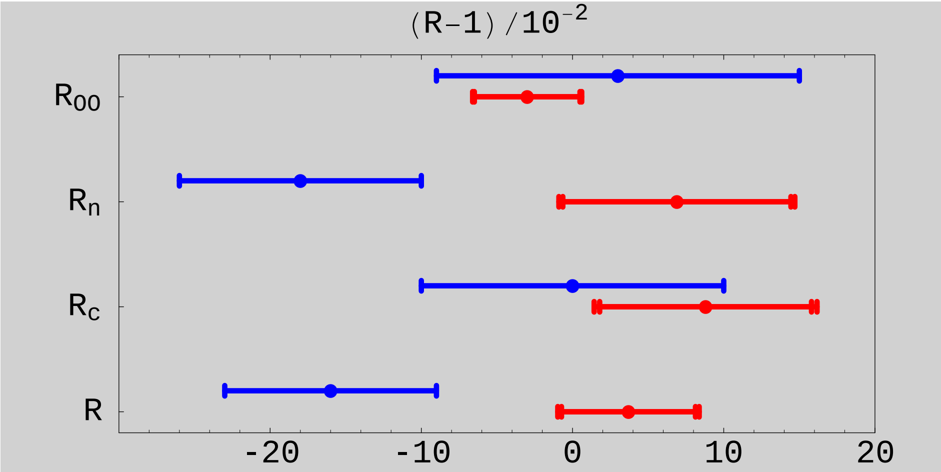
R ratios

- many errors cancel in the ratios of Br
- 4 ratios usually defined (3 independent)

$$R_c = 2\frac{\bar\Gamma(B^- \to K^-\pi^0)}{\bar\Gamma(B^- \to \bar K^0\pi^-)} \qquad R_n = \frac{1}{2}\frac{\bar\Gamma(\bar B^0 \to K^-\pi^+)}{\bar\Gamma(\bar B^0 \to \bar K^0\pi^0)}$$

$$R = \frac{\bar\Gamma(\bar B^0 \to K^-\pi^+)}{\bar\Gamma(B^- \to \bar K^0\pi^-)} \qquad R_{00} = 2\frac{\bar\Gamma(\bar B^0 \to \bar K^0\pi^0)}{\bar\Gamma(B^- \to \bar K^0\pi^-)} = \frac{R}{R_n}$$



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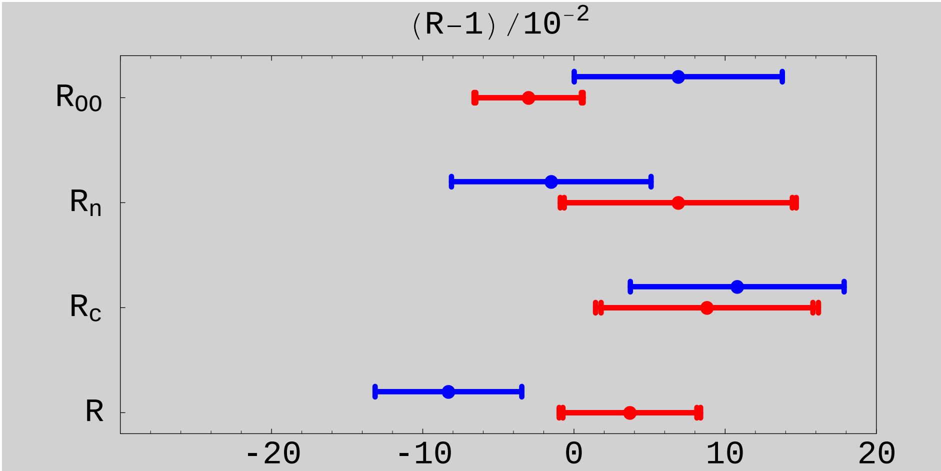

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R ratios

- especially interesting is the difference $R_n - R_c$
- expanding in tree/penguin and EWP/(charm. peng.) one gets

$$R_n = R_c + \cdots$$

up to corrections of second order in small parameters

- numerically

$$(R_c - R_n) \stackrel{\mathrm{Exp.05}}{=} 0.18 \pm 0.13 \stackrel{\mathrm{Exp.06}}{\Rightarrow} 0.12 \pm 0.10$$

$$(R_c - R_n) \stackrel{\mathrm{Th.}}{=} 0.018 \pm 0.013$$

$B \to \pi\eta^{(\prime)}$ and $B \to K\eta^{(\prime)}$ decays

Determination of SCET parameters

- use ζ, ζ_J and A_{cc} from $B \to \pi\pi, \pi K$ fit
- ζ_g, ζ_{Jg} and A_{ccg} are obtained from fit to $B \to \eta^{(\prime)}\pi, \eta^{(\prime)}K$ data on Br and $A_{CP} \Leftarrow$ no use of S parameters is made
- 2 solutions obtained that differ by

$$\arg(A_{ccg}) = -109^\circ \pm 3^\circ$$
$$\arg(A_{ccg}) = -68^\circ \pm 4^\circ$$

- the two solutions can be resolved by future measurm. of $A_{CP}(\eta K^-)$ and $A_{CP}(\eta \bar{K}^0)$
- we get $\zeta_{(J)g} \sim \zeta_{(J)}$and $|A_{ccg}| \sim |A_{cc}|$ as expected from SCET counting

$B \to K\eta$ vs $B \to K\eta'$

- is $\Delta S = 1$ so A_{cc} and A_{ccg} dominate
- large disparity between $BR(B \to K\eta') \simeq 60 \times 10^{-6}$ and $Br(B \to K\eta) \simeq 2 \times 10^{-6}$
- Lipkin '91: constructive and destructive interf.

$$A_{\bar{B}\to\bar{K}\eta'} = \cos\phi A_{\bar{B}\to\bar{K}\eta_s} + \sin\phi A_{\bar{B}\to\bar{K}\eta_q}$$
$$A_{\bar{B}\to\bar{K}\eta} = -\sin\phi A_{\bar{B}\to\bar{K}\eta_s} + \cos\phi A_{\bar{B}\to\bar{K}\eta_q}$$

with $\phi = (39.3 \pm 1.0)^\circ$, so that $\cos\phi \simeq \sin\phi$

- If $A_{\bar{B}\to\bar{K}\eta_q} \simeq A_{\bar{B}\to\bar{K}\eta_s}$
  - $\Rightarrow$ a constructive interference in $A_{\bar{B}\to\bar{K}\eta'}$
  - $\Rightarrow$ a destructive interference in $A_{\bar{B}\to\bar{K}\eta}$

$B \to K\eta^{(\prime)}$ in SCET

- this very natural in SCET

$$A_{B^- \to \eta K^-} \propto (\sqrt{2} - \tan\phi) A_{ccg} + \left(\frac{1}{\sqrt{2}} - \tan\phi\right) A_{cc} + \cdots$$
$$= 0.59 A_{ccg} - 0.11 A_{cc} + \cdots$$
$$A_{B^- \to \eta' K^-} \propto (1 + \sqrt{2}\tan\phi) A_{ccg} + \left(1 + \frac{\tan\phi}{\sqrt{2}}\right) A_{cc} + \cdots$$
$$= 2.16 A_{ccg} + 1.59 A_{cc} + \cdots$$

- no cancelation between A_{cc} and A_{ccg} needed
  $Br(B \to \eta' K) \gg Br(B \to \eta K)$ for most $\arg(A_{cc(g)}/A_{cc})$
- the suppression is much larger for A_{cc} than for A_{ccg}
- if $A_{ccg} = 0 \Rightarrow Br(B \to \eta K) \sim O(10^{-7})$ and not $\sim O(10^{-6})$

Ehancement of $B \to \eta' K$

- $Br(B \to \eta' K)$ enhanced over $Br(B \to \pi K)$ almost entirely due to A_{ccg}
- in SU(3) limit

$$\frac{A_{B^- \to \eta' K^-}}{A_{\bar{B}^0 \to \pi^+ K^-}} \simeq \left(\cos\phi + \frac{\sin\phi}{\sqrt{2}}\right)\frac{A_{cc}}{A_{cc}} + \left(\cos\phi + \sqrt{2}\sin\phi\right)\frac{A_{ccg}}{A_{cc}} + \cdots$$
$$\simeq 1.22 + 1.67\frac{A_{ccg}}{A_{cc}}$$

- part of the enhancement could come from SU(3) breaking

Further predictions

- we give predictions for observables in all $B \to \eta^{(\prime)}\eta^{(\prime)}$, $B \to \pi\eta^{(\prime)}$
- with observables measured so far the combination $\zeta_g - \zeta_{Jg}$ poorly constrained
- predictions for $\bar{B}^0 \to \pi^0\eta^{(\prime)}$ and $\bar{B}^0 \to \eta^{(\prime)}\eta^{(\prime)}$ fairly uncertain
- measurements in some of these modes will greatly improve on the knowledge of SCET parameters

S parameters in penguin dominated modes

$$S_f = 2\frac{\mathcal{I}m\left[e^{-i2\beta}\bar{A}_f/A_f\right]}{1+|\bar{A}_f|^2/|A_f|^2}$$

- interested in $\Delta S = 1$ where $A_f \propto \lambda_c^{(s)} P_{\bar{B}\to f} + \cdots \Rightarrow$

$$S_f \simeq -\eta_f^{\rm CP} \sin 2\beta$$

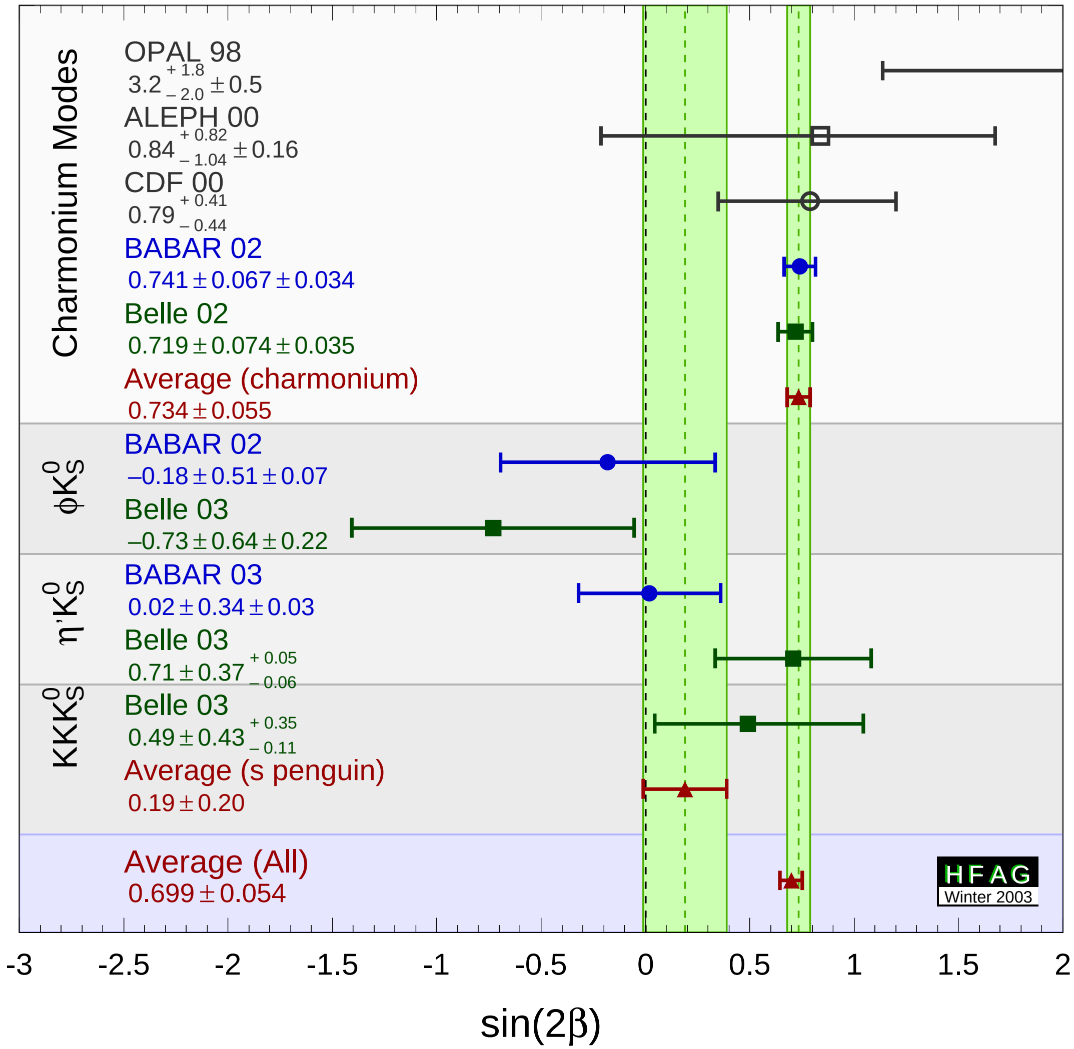
- more precisely

$$\Delta S_f \equiv -\eta_f^{\rm CP} S_f - \sin 2\beta = r_f \cos\delta_f \cos 2\beta + O(r_f^2)$$

$$r_f e^{i\delta_f} = -2\mathcal{I}m\left(\frac{\lambda_u^{(s)}}{\lambda_c^{(s)}}\right)\frac{T_{\bar{B}\to f}}{P_{\bar{B}\to f}}$$

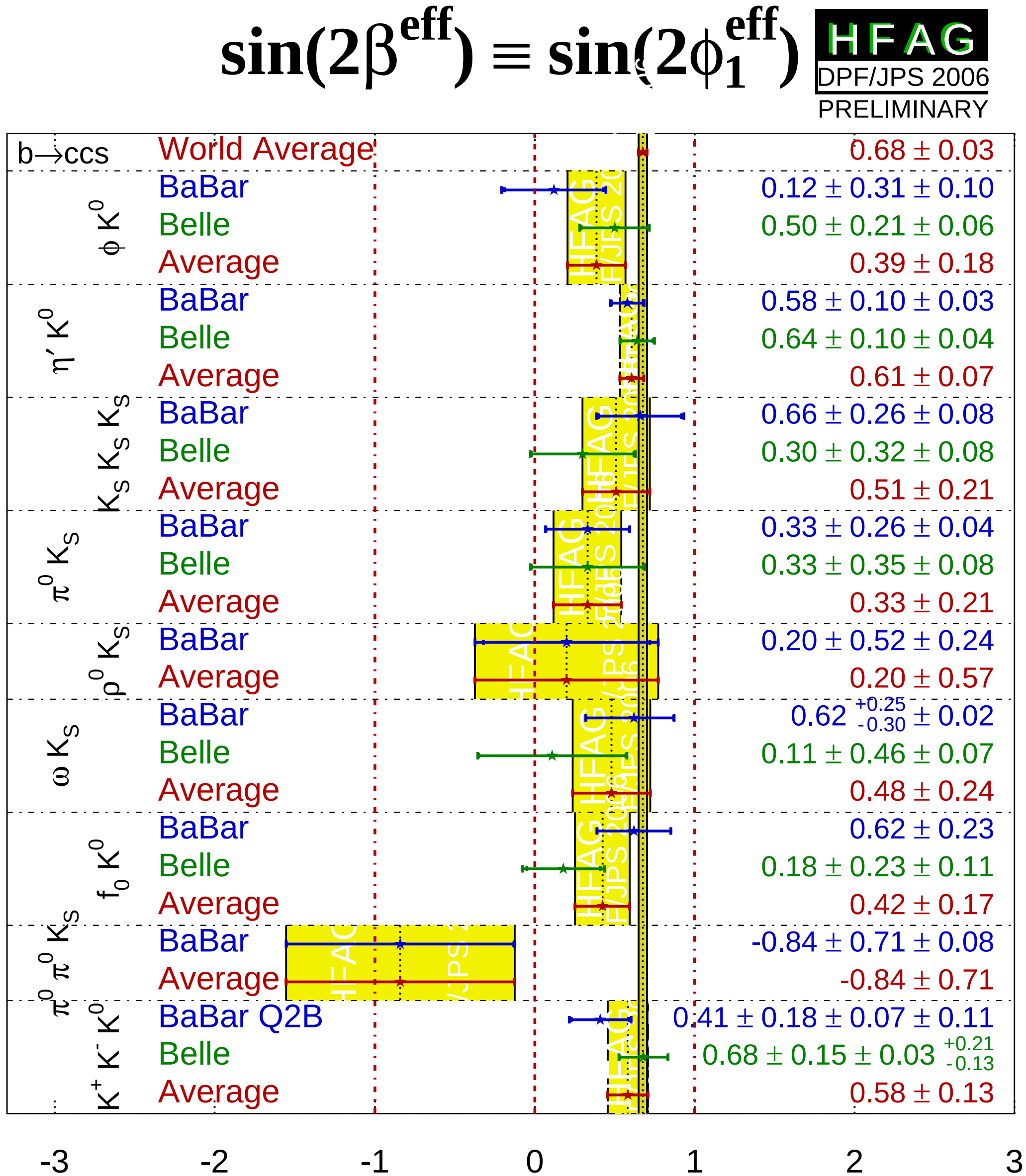
with $-2\mathcal{I}m(\lambda_u^{(s)}/\lambda_c^{(s)}) \simeq 0.037$

Winter 2003



Charmonium Modes
OPAL 98
$3.2^{+1.8}_{-2.0} \pm 0.5$
ALEPH 00
$0.84^{+0.82}_{-1.04} \pm 0.16$
CDF 00
$0.79^{+0.41}_{-0.44}$
BABAR 02
$0.741 \pm 0.067 \pm 0.034$
Belle 02
$0.719 \pm 0.074 \pm 0.035$
Average (charmonium)
0.734 ± 0.055
ϕK^0_S
BABAR 02
$-0.18 \pm 0.51 \pm 0.07$
Belle 03
$-0.73 \pm 0.64 \pm 0.22$
$\eta' K^0_S$
BABAR 03
$0.02 \pm 0.34 \pm 0.03$
Belle 03
$0.71 \pm 0.37^{+0.05}_{-0.06}$
KKK^0_S
Belle 03
$0.49 \pm 0.43^{+0.35}_{-0.11}$
Average (s penguin)
0.19 ± 0.20
Average (All)
0.699 ± 0.054
HFAG
Winter 2003
-3 -2.5 -2 -1.5 -1 -0.5 0 0.5 1 1.5 2
$\sin(2\beta)$

Summer 2006


sin(2β^eff) ≡ sin(2φ1^eff)
HFAG
DPF/JPS 2006
PRELIMINARY
b→ccs World Average 0.68 ± 0.03
φ K0
BaBar 0.12 ± 0.31 ± 0.10
Belle 0.50 ± 0.21 ± 0.06
Average 0.39 ± 0.18
η′ K0
BaBar 0.58 ± 0.10 ± 0.03
Belle 0.64 ± 0.10 ± 0.04
Average 0.61 ± 0.07
KS KS KS
BaBar 0.66 ± 0.26 ± 0.08
Belle 0.30 ± 0.32 ± 0.08
Average 0.51 ± 0.21
π0 KS
BaBar 0.33 ± 0.26 ± 0.04
Belle 0.33 ± 0.35 ± 0.08
Average 0.33 ± 0.21
ρ0 KS
BaBar 0.20 ± 0.52 ± 0.24
Average 0.20 ± 0.57
ω KS
BaBar 0.62 +0.25 -0.30 ± 0.02
Belle 0.11 ± 0.46 ± 0.07
Average 0.48 ± 0.24
f0 K0
BaBar 0.62 ± 0.23
Belle 0.18 ± 0.23 ± 0.11
Average 0.42 ± 0.17
π0 π0 KS
BaBar -0.84 ± 0.71 ± 0.08
Average -0.84 ± 0.71
K+ K- K0
BaBar Q2B 0.41 ± 0.18 ± 0.07 ± 0.11
Belle 0.68 ± 0.15 ± 0.03 +0.21 -0.13
Average 0.58 ± 0.13
-3
-2
-1
0
1
2
3

S parameters in $B \to \eta' K_S, \pi^0 K_S$

- using SCET parameters obtained from fit

$$\Delta S_{\eta' K_{S,L}} \overset{\text{Th.}}{=} \begin{cases} -0.019 \pm 0.008 \\ -0.010 \pm 0.010 \end{cases} \overset{\text{Exp.}}{=} -0.064 \pm 0.075$$

$$\Delta S_{\eta K_{S,L}} \overset{\text{Th.}}{=} \begin{cases} -0.03 \pm 0.17 \\ 0.07 \pm 0.14 \end{cases} \overset{\text{Exp.}}{=} -$$

$$\Delta S_{\pi^0 K_{S,L}} \overset{\text{Th.}}{=} (7.7 \pm 3.0) \times 10^{-2} \overset{\text{Exp.}}{=} -0.34 \pm 0.21$$

- S parameters not used in fit $\Rightarrow$ pure predictions
- if strong phases δ_f are taken to be arbitrary, largest ΔS_f given by

$$r_{\eta' K_S} \simeq 0.03 \pm 0.01$$

$$r_{\eta K_S} \simeq 0.2 \pm 0.2$$

$$r_{\pi^0 K_S} = 0.14 \pm 0.05$$

B_s decays

B_s decays

- the time dependent decay

$$\Gamma(B_q^0(t) \to f) = e^{-\Gamma t}\, \overline{\Gamma}(B_q \to f)\Big[\cosh\Big(\frac{\Delta\Gamma t}{2}\Big) + \\ + H_f \sinh\Big(\frac{\Delta\Gamma t}{2}\Big) - \mathcal{A}_f^{\rm CP}\cos(\Delta m t) - S_f \sin(\Delta m t)\Big]$$

- in SM: $(\Delta\Gamma/\Gamma)_{B_s} \overset{\rm Th.}{=} -0.12 \pm 0.05$

$$(\Delta\Gamma/\Gamma)_{B_s} \overset{\rm PDG'06}{=} -0.31^{+0.11}_{-0.10}$$

- H_f can be measured even in untagged B_s decays

$$(H_f)_{B_s} = 2\frac{\mathcal{R}e\Big[e^{+i2\epsilon}\bar{A}_f (A_f)^*\Big]}{|\bar{A}_f|^2 + |A_f|^2}$$

$(H_f)_{B_s}$

- for $\Delta S = 1$ decays

$$(S_f)_{B_s} = \eta_f^{\rm CP} \sin 2\epsilon - \eta_f^{\rm CP} r_f \cos\delta_f \cos 2\epsilon + O(r_f^2)$$
$$(H_f)_{B_s} = \eta_f^{\rm CP} \cos 2\epsilon + \eta_f^{\rm CP} \sin 2\epsilon\, r_f \cos\delta_f + O(r_f^2),$$

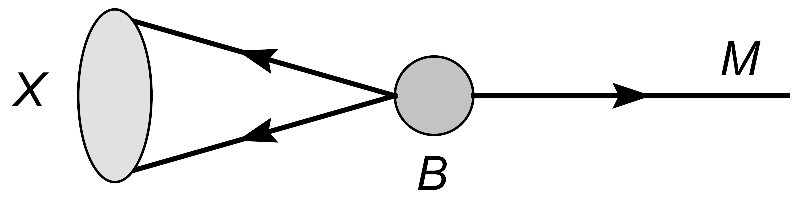
- $\epsilon \sim 1^\circ$ in SM $\Rightarrow 1 - (H_f)_{B_s} \sim O(r_f^2)$
  - even cleaner than $S_{B\to\phi K_S, \eta' K_S}$
  - for $\bar{B}_s^0 \to \eta\eta, \eta\eta', \eta'\eta' \Rightarrow |1 - (H_f)_{B_s}| \sim 10^{-3}$
  - for $\bar{B}_s^0 \to K^- K^+, K_S K_S \Rightarrow |1 - (H_f)_{B_s}| \sim 10^{-2}$
  - $(S_f)_{B_s}$ and order of magnitude larger
- BSM: same ops. important as in $B \to \phi K_S, \eta' K_S, \pi^0 K_S$
- $1 - (H_f)_{B_s}$ could be $O(1)$

Semiinclusive hadronic decays

Kinematics

Chay, Leibovich, Kim, JZ, hep-ph/0607004

- B decays to M and inclusive jet X back-to-back



- factorization as in 2-body B decays
- these decays simpler than 2-body B decays if
  - spectator does not end up in $M \Rightarrow$ matching to SCET$_{\text{II}}$ trivial
  - work in endpoint region $p_X^2 \sim m_b\Lambda \Rightarrow$ SCET$_{\text{I}}$
- no dependence on ζ, ζ_J, the same shape and jet function as in $B \to X_s\gamma$, even this cancels in A_{CP}
- very clean probes of sizes of charming penguins

First measurement

- BaBar, ICHEP06: $Br(B \to K^+ X)$ and $Br(B \to K^0 X)$, with $E_K > 2.34$ GeV
- points to a large charming penguin
- work in progress, one result (without charming penguins):

Soni, JZ 2005

$$A_{CP}(B \to K_S X^-_{d+s}) = -0.28 \pm 0.23\%$$

can be used as null test of new physics

Conclusions

- the LO SCET analysis has been extended to decays with η, η'
- πK and $S_{\eta' K_S, \pi^0 K_S}$ "puzzles" only at $\sim 1\sigma$ level
- enhancement of $Br(\eta' K)$ is naturally explained in SCET

Backup slides

Gluonic contributions

- $\zeta_{(J)g}$ connected to $B \to \eta^{(\prime)}$ semileptonic form factors, not known
- $\zeta_{3(g)}, A_{ccg}$ not known from anywhere else
- in QCD factorization (Beneke, Neubert):
  - at LO in $\alpha_S(\sqrt{\Lambda m_b})$: $\zeta_3^{BM}(u) = \zeta_3/(u\bar{u})$, ζ_{3g}^{BM} const.
  - ζ_g, ζ_3 varied in some (reasonable) range, ζ_{Jg}, ζ_{3g} set to zero
- in SCET analysis (Williamson, JZ):
  - SU(3) used, $\zeta_{(J)g}, A_{ccg}$ determined from data (fit)
  - ζ_3 omitted, even so $\zeta_{(J)g}$ poorly determ., 2 solutions
- measuring Br, A_{CP} for more modes with η, η' in the final state can help a lot!

Relation to diagrammatic approach

- in SU(3) limit, for $\Delta S = 0$ decay (at LO in $\alpha_S(m_b)$)

$$t \propto V_{ub}V_{ud}^* \Big[\Big(C_1 + \frac{C_2}{N}\big(1 + \langle x^{-1}\rangle\big)\Big)\zeta_J + \Big(C_1 + \frac{C_2}{N}\Big)\zeta\Big] + \dots$$

$$c \propto V_{ub}V_{ud}^* \Big[\Big(C_2 + \frac{C_1}{N}\big(1 + \langle x^{-1}\rangle\big)\Big)\zeta_J + \Big(C_2 + \frac{C_1}{N}\Big)\zeta\Big] + \dots$$

$$p \propto V_{cb}V_{cd}^* A_{cc} + V_{ub}V_{ud}^* F(\zeta, \zeta_J) + \dots$$

- at LO in $1/m_b$ no annihilation and exchange amplitudes
- at LO in $1/m_b$ and $\alpha_S(m_b)$ strong phase only in p (A_{cc})
- no color suppression (in SCET counting $\zeta \sim \zeta_J$)

$$t \propto V_{ub}V_{ud}^* \Big[0.77\zeta_J + 1.03\zeta\Big] + \dots, \qquad c \propto V_{ub}V_{ud}^* \Big[1.23\zeta_J + 0.12\zeta\Big] + \dots$$

Relation to diagrammatic approach II

- there are 4 additional reduced matrix elements in SU(3) decomposition
- usually in diagrammatic approach only $p_s = 3s$ was taken to be nonzero
- in SCET counting all 4 are of LO in $1/m_b$
  - t_s, c_s are "gluonic" tree and color suppressed amplitudes (depend on ζ_g, ζ_{Jg})
  - $p_s \propto V_{cb}V_{cd}^* A_{ccg} + F(\zeta_{(J)}, \zeta_{(J)g})$
  - s_0 enters only $B_{(s)} \to \eta_0\eta_0$ decays
- keeping only p_s corresponds to $\zeta_{(J)g} \ll \zeta_{(J)}$ limit not to $m_b \to \infty$ limit

Values for form factors

- from our analysis

$$10^3|V_{ub}|f_+^{B\pi}(0) = 0.69 \pm 0.03 \pm 0.14$$

- from exp. data on $B \to \pi l \nu$ (Becher, Hill ’05)

$$10^3|V_{ub}|f_+^{B\pi}(0) = 0.92 \pm 0.11 \pm 0.03$$

Other tests in $B \to K\pi$

- similarly the Lipkin sum rule

$$\Delta L = R_{00} - R + R_c - 1 \overset{\text{Exp.}}{=} 0.19 \pm 0.14 \overset{\text{Th.}}{=} 0.020 \pm 0.012$$

is only of second order in the same expansion

- even more precise is

Atwood, Soni 1997; Gronau, 2004

$$\begin{aligned}\Delta_{\sum} =& 2\Delta\Gamma(B^- \to K^-\pi^0) - \Delta\Gamma(B^- \to \bar{K}^0\pi^-) \\ &+ 2\Delta\Gamma(\bar{B}^0 \to \bar{K}^0\pi^0) - \Delta\Gamma(\bar{B}^0 \to K^-\pi^+)\end{aligned}$$

that does no depend on A_{cc}

- $\Delta_{\sum} = 0$ in the limit of exact isospin and no EWP
- for EWP$\neq 0$ still $\Delta_{\sum} = 0$ at LO in $1/m_B$ and $\alpha_S(m_b)$ since no relative strong phases

Example: CKM extraction from $B \to \pi\pi$

Bauer, Pirjol, Rothstein, Stewart 2004

- utilize the fact that t, c carry no strong phase at LO in $1/m_b$ and $\alpha_S(m_b)$
- take $\mathcal{I}m(T/C) < 0.2$ as an input instead of C_{00}
- using 2004 data $\Rightarrow \gamma = 74.9^\circ{}^{+2^\circ}_{-5.4^\circ}$