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Determining the Unitarity Triangle from Two-Body Charmless Hadronic B Decays

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Outline

- Unitarity triangle
- Flavor diagram approach to rare *B* decays
- Global χ^2 fits with different $SU(3)_F$ breaking schemes
- Fitting results and predictions (particularly B_s)
- Summary

Talk primarily based upon the following works:

CWC, Gronau, Luo, Rosner, and Suprun, PRD **69**, 034001 (2004);

CWC, Gronau, Rosner, and Suprun, PRD **70**, 034020 (2004);

CWC and Zhou, hep-ph/0609128, to appear in JHEP.

More References

- General references on $SU(3)_F$ to meson decays:

  Zeppenfeld, Z. Phys. C **8**, 77 (1981);
  Savage and Wise, PRD **39**, 3346 (1989); Erratum-ibid. **40**, 3127 (1989);
  Chau et. al., PRD **43**, 2176 (1991); Erratum-ibid. **58**, 019902 (1998);
  Gronau et. al., PRD **50**, 4529 (1994); *ibid*. **52**, 6374 (1995).

- Other works related to $SU(3)_F$ fitting:

  Zhou et. al., PRD **63**, 054011 (2001);
  He et. al., PRD **64**, 034002 (2001); Fu et. al., Nucl. Phys. Proc. Suppl. **115**, 279 (2003);
  Fu, He and Hsiao, PRD **69**, 074002 (2004);
  Wu and Zhou, EPJC **5**, 014 (2003);
  Malcles, arXiv:hep-ph/0606083.

- Other works about new physics in $K\pi$ and related decays:

  Yoshikawa,PRD **68**, 054023 (2003); Mishima and Yoshikawa, PRD **70**, 094024 (2004);
  Buras et. al., EPJC **32**, 45 (2003); PRL **92**, 101804 (2004); EPJC **45**, 701 (2006);
  Baek et. al., PRD **71**, 057502 (2005);
  Hou, Nagashima and Soddu, hep-ph/0605080.

KM Mechanism

- The couplings between the up-type and down-type quarks are described by the Cabibbo-Kobayashi-Maskawa (CKM) matrix within the SM.

$$V_{\rm CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$
$$= \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3[(1-\bar{\rho}) - i\bar{\eta}] & -A\lambda^2 & 1 \end{pmatrix}$$

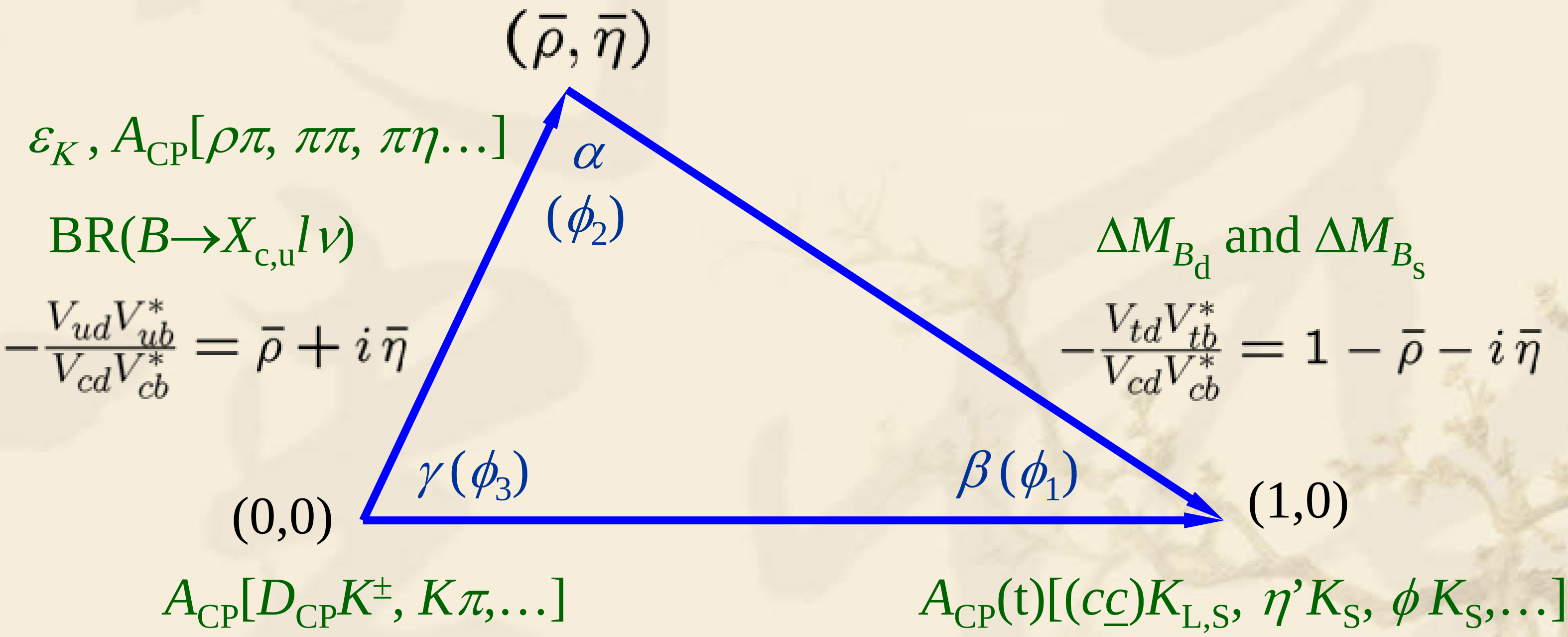
- Using the Wolfenstein parameterization, CP violation is encoded by the parameter η.
- V_{ub} and V_{td} carry the largest weak phases, but are the least known elements due to their smallness.

Unitarity Triangle

- Unitarity relation for $V_{\rm ub}$ and V_{td} :

$$V_{\rm ud}V_{\rm ub}^* + V_{\rm cd}V_{\rm cb}^* + V_{\rm td}V_{\rm tb}^* = 0\ .$$

It can be visualized as a triangle on a complex plane whose *area* characterizes CPV.



CKMfitter Results

- FPCP06 update: [CKMfitter: http://ckmfitter.in2p3.fr/]

  $\lambda = 0.2272 \pm 0.0010$

  $A = 0.809 \pm 0.014$

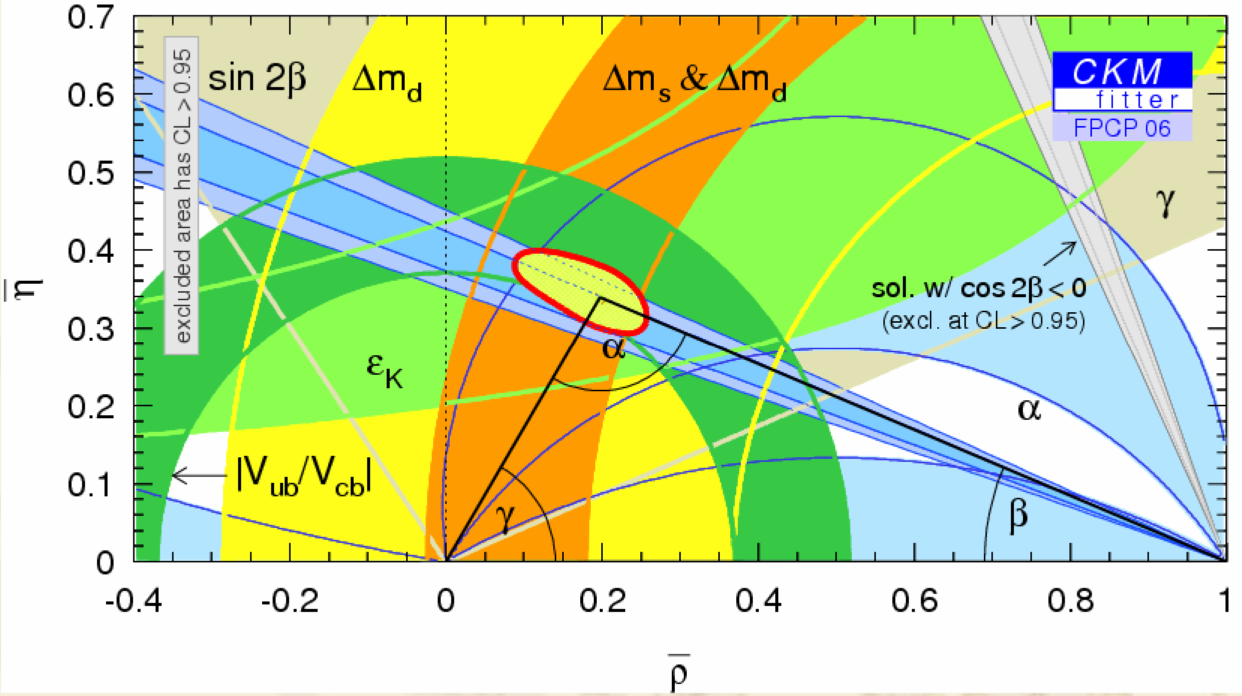
  $\bar{\rho} = 0.202^{+0.027}_{-0.031}$

  $\bar{\eta} = 0.348^{+0.020}_{-0.018}$

  $\alpha = 97.3^{+4.5}_{-5.0}$

  $\beta = 22.86 \pm 1.00$

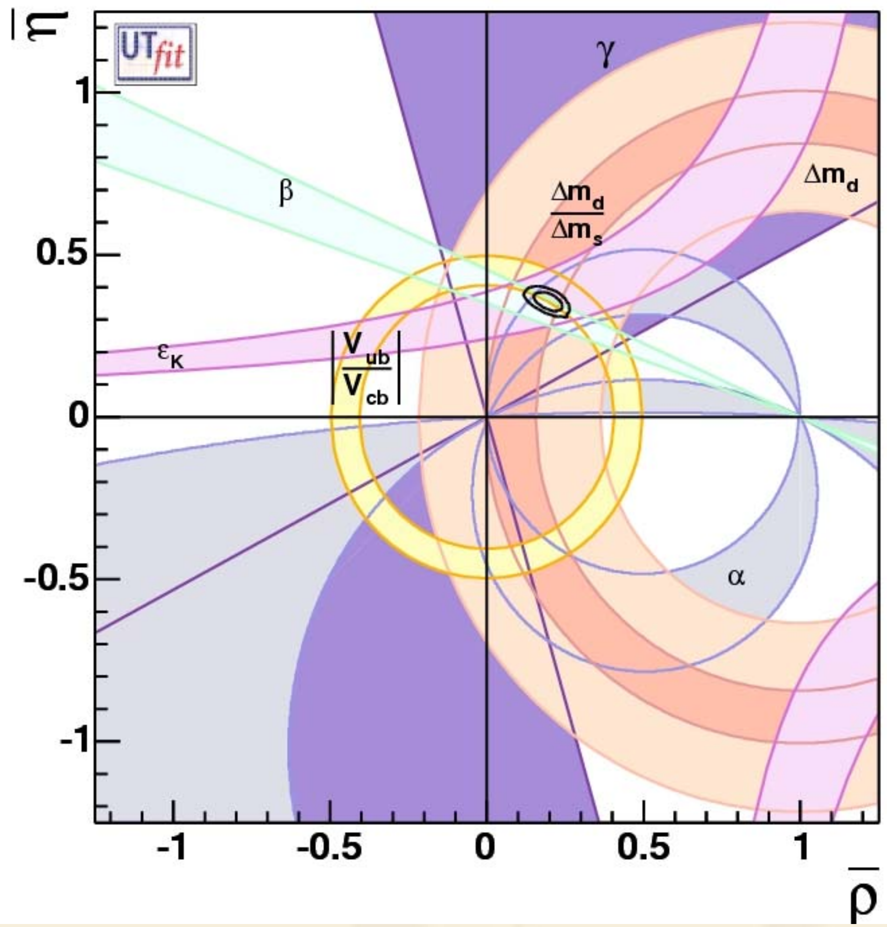
  $\gamma = 59.8^{+4.9}_{-4.1}$



UTFit's Results

- FPCP06 Updates:
  - $\lambda = 0.2258 \pm 0.0014$
  - $\underline{\rho} = 0.198 \pm 0.030$
  - $\underline{\eta} = 0.364 \pm 0.019$
  - $\alpha = (94.6 \pm 4.6)^{o}$
  - $\beta = (23.9 \pm 1.0)^{o}$
  - $\gamma = (61.3 \pm 4.5)^{o}$

[UTFit: http://utfit.roma1.infn.it/]



Questions

- Can we extract useful information for the UT from purely charmless *B* decays (even though each of them individually may not be theoretically clean)?
- Will they provide results consistent with other methods?
- Can the predictions of our theory (perturbative / nonperturbative) for the rare decays agree with data? [e.g., Beneke and Neubert, 2003]
- Can we get any hint of new physics from the analysis?

Why Charmless?

- Charmless two-body hadronic *B* decay modes are often sensitive to V_{td} and/or V_{ub}. Thus, they are actually charmful and can play a more important role in the determination of the unitarity triangle.
- With increasing precision on the BRs and CPAs, it is possible to provide an additional constraint on the $(\underline{\rho},\underline{\eta})$ vertex and/or some hints for new physics via a global fit.
- We relate two types of rare decays using flavor SU(3) symmetry:
  - strangeness-conserving ($\Delta S = 0$, $b \to q\,\underline{q}\,d$); and
  - strangeness-changing ($|\Delta S| = 1$, $b \to q\,\underline{q}\,s$).
- The former type is dominated by the color-allowed tree amplitude; whereas the latter type is dominated by the QCD penguin amplitudes.

Flavor Diagram Approach

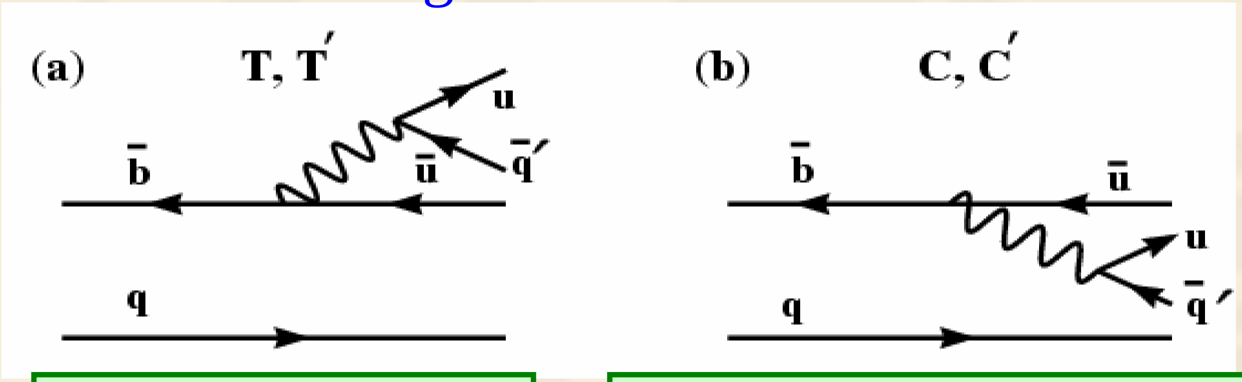
[Zeppenfeld (1981); Chau + Cheng (1986, 1987, 1991); Savage + Wise (1989); Grinstein + Lebed (1996); Gronau et. al. (1994, 1995, 1995)]

- This approach is intended to rely, to the greatest extent, on *model independent flavor SU(3) symmetry* arguments, rather than on specific model calculations of amplitudes.
- The three light quarks (u, d, s) ~ **3** under $SU(3)_F$.
- The flavor diagram approach:
  - only concerns with the *flavor flow* (nonperturbative in strong interactions);
  - has a clearer *weak phase structure* (unlike isospin analysis where different weak phases usually mix).

Tree-Level Diagrams

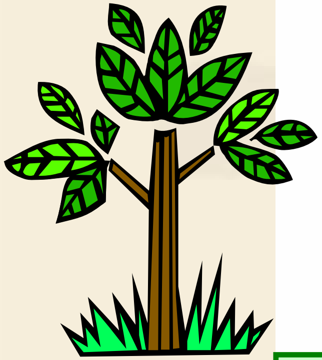
- All these tree-level diagrams involve the same CKM factor.

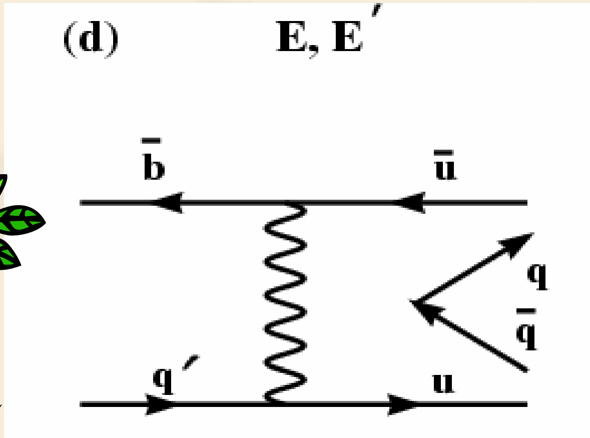
q = u,d,s
q' = d,s

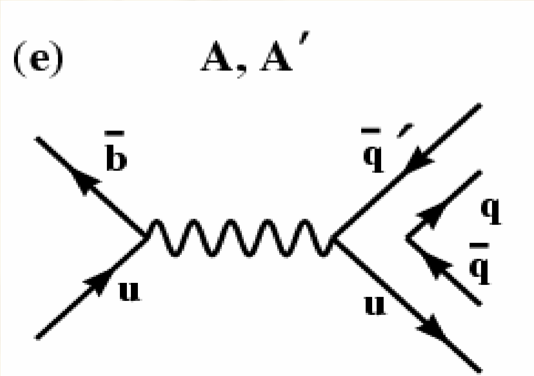


tree (external W emission)

color-suppressed (internal W emission)







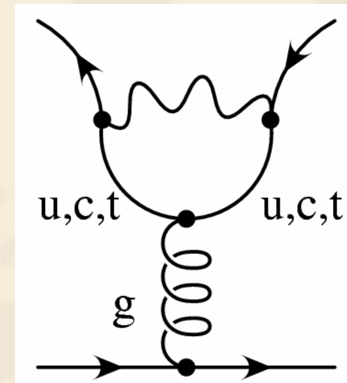
$1/m_b$ suppressed due to f_B.
-- to be ignored

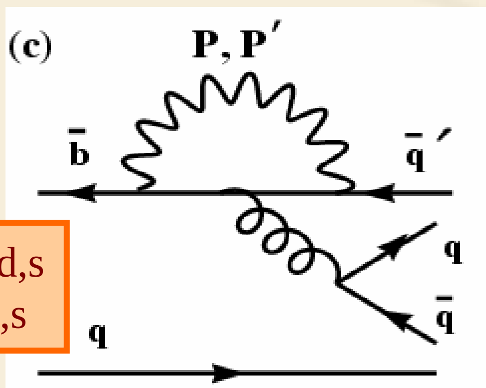
exchange (neutral mesons only)

annihilation (charged mesons only)

Loop-Level (Penguin) Diagrams

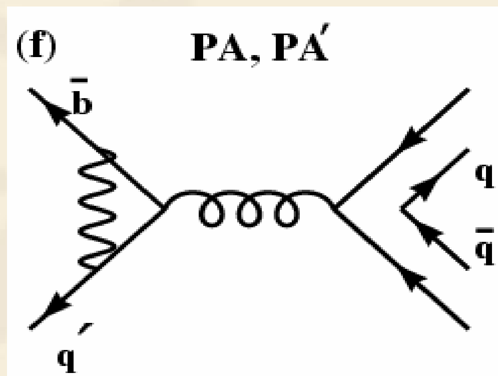
- All these loop-level diagrams also have the same CKM factors, with *u*-, *c*-, and *t*-quark running in the loop.
- Will use the unitarity condition to remove the top-mediated loop diagrams.



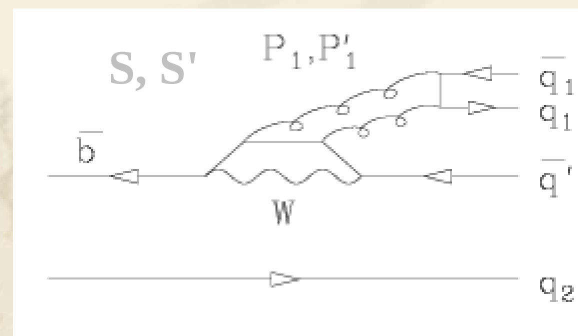


q=u,d,s
q'=d,s

QCD (strong) penguin
(internal gluon emission)



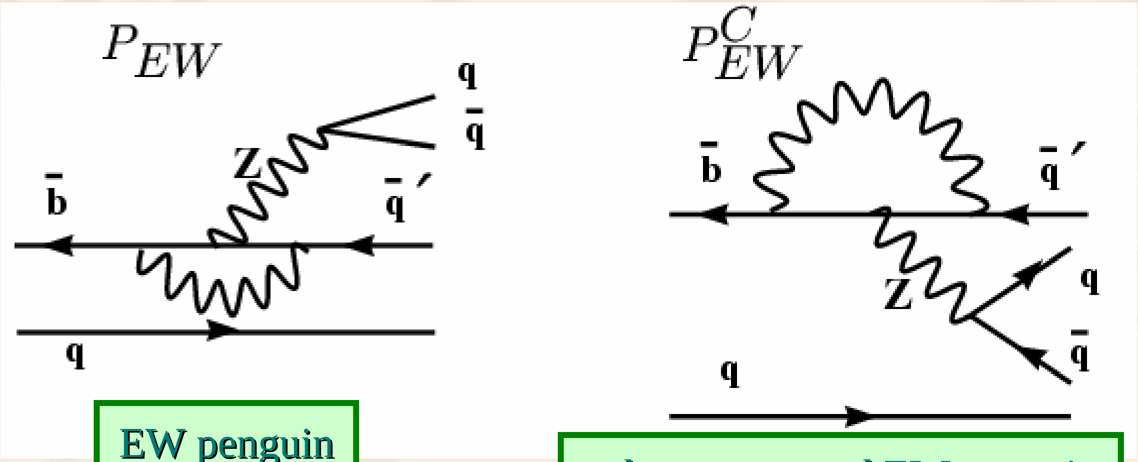
penguin annihilation
(neutral mesons)



flavor singlet
(external gluon emission)

Next-to-Leading-Order Flavor Diagrams

- Nothing forbids one from drawing one of the following diagrams whenever you see *T*, *C*, or *P* in your amplitude list.
- They are higher order in weak interactions.



EW penguin

color-suppressed EW penguin

appear together with *C* and *S* in decay amps

appear together with *T* and *P* in decay amps

A Hierarchical Structure

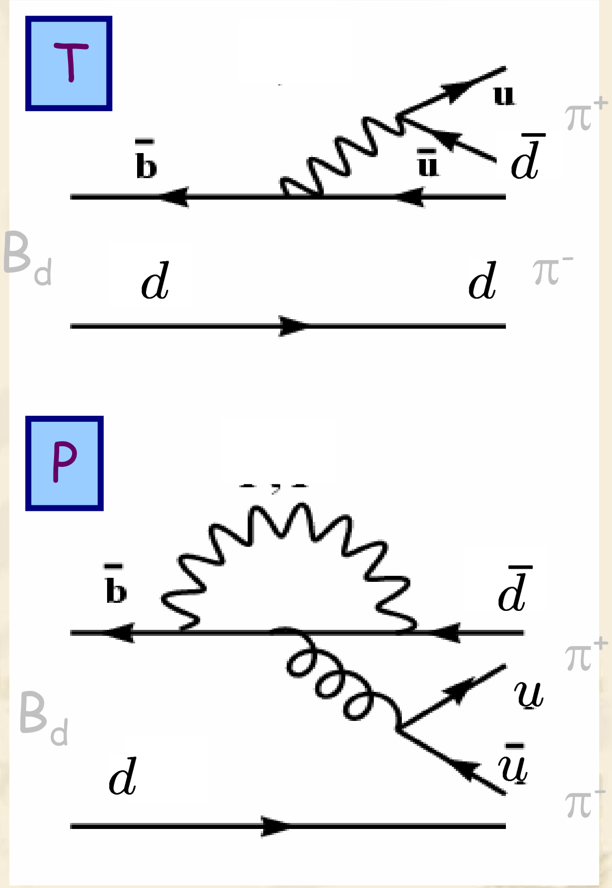
π⁺π⁻

- Without factoring out CKM factors, we have for the flavor diagrams:

TABLE I. Hierarchies among magnitudes of flavor-SU(3) amplitudes in powers of a parameter $\lambda \equiv |V_{us}| \simeq 0.22$.

	$O(1)$	$O(\lambda)$	$O(\lambda^2)$	$O(\lambda^3)$	$O(\lambda^4)$
$\Delta S=0$	T	C,P	E,A,P_{EW}	PA,P_{EW}^C	PA_{EW}
	t	c,p	e,a,s	pa	
$\|\Delta S\|=1$	P'	T',P'_{EW}	C',PA',P'^C_{EW}	E',A',PA'_{EW}	
	p'	t',c',s'	pa'	e',a'	

- As an example, the decay of $B_d \to \pi^+\pi^-$ can be decomposed as – (T + P), where the minus sign comes from our convention for the meson wave functions.



Examples of Rescattering

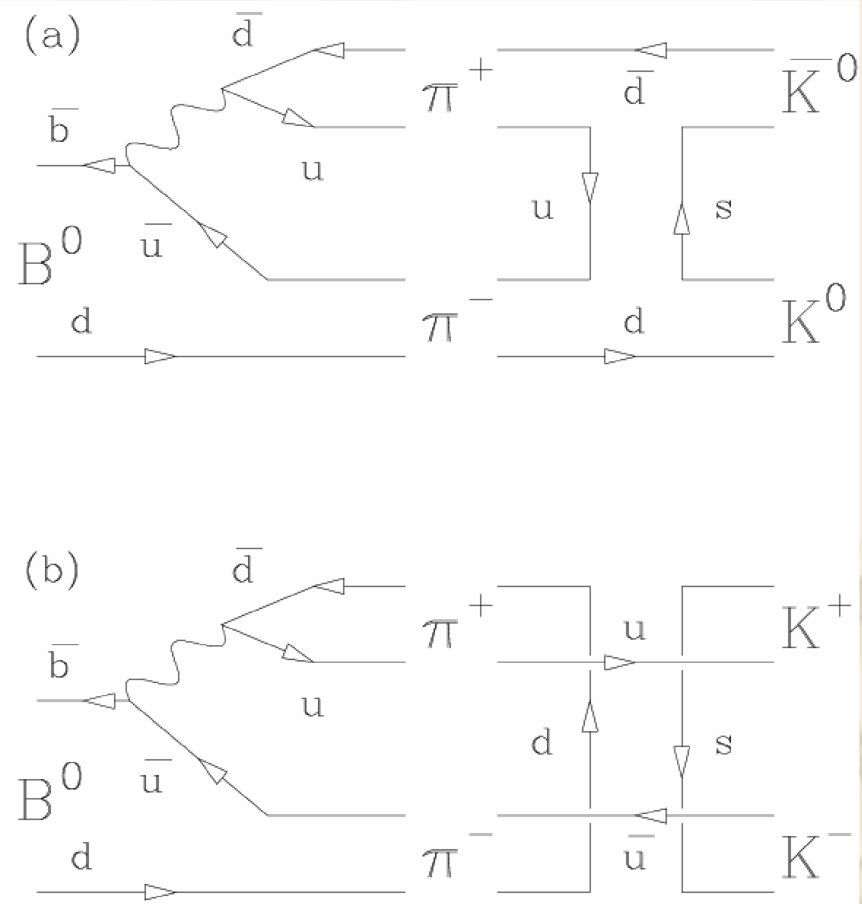
- Significant strong phases can result from final-state rescattering effects, in contrast to BSS-type perturbative phases.

  [Bander et. al., PRL **43**, 242 (1979)]

- Rescattering contributions to $B^0 \to K\underline{K}$ from the $\pi^+\pi^-$ intermediate state:

  (a) an initial T amplitude turns into a P (u-penguin) amplitude;

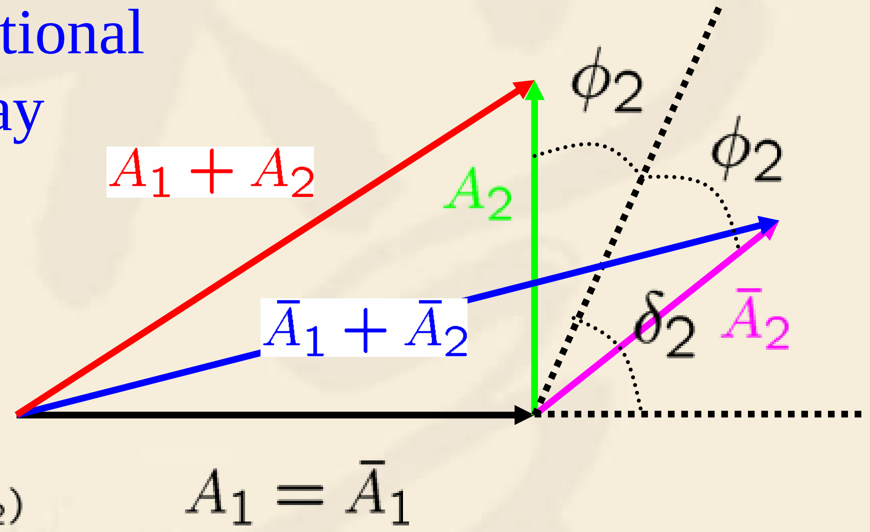
  (b) an initial T amplitude turns into an E amplitude.



What's So Cool About Strong Phases?

- Strong interactions contribute additional phases to decay amplitudes in a way that is *flavor-blind*.
- Consider rate CP asymmetry of modes with the amplitudes:

$$A(B \to f) = A_1 e^{i(\phi_1+\delta_1)} + A_2 e^{i(\phi_2+\delta_2)}$$
$$A(\overline{B} \to \overline{f}) = A_1 e^{i(-\phi_1+\delta_1)} + A_2 e^{i(-\phi_2+\delta_2)}$$



$$a_{CP} = \frac{\Gamma(\overline{B} \to \overline{f}) - \Gamma(B \to f)}{\Gamma(\overline{B} \to \overline{f}) + \Gamma(B \to f)} = \frac{2A_1A_2 \sin(\phi_1 - \phi_2)\sin(\delta_1 - \delta_2)}{A_1^2 + A_2^2 + 2A_1A_2\cos(\phi_1 - \phi_2)\cos(\delta_1 - \delta_2)}$$

- The observation of CPAs needs at least *two* amplitudes with *distinct* strong and weak phases.

χ^2 Fits

- We constrain theory parameters by minimizing

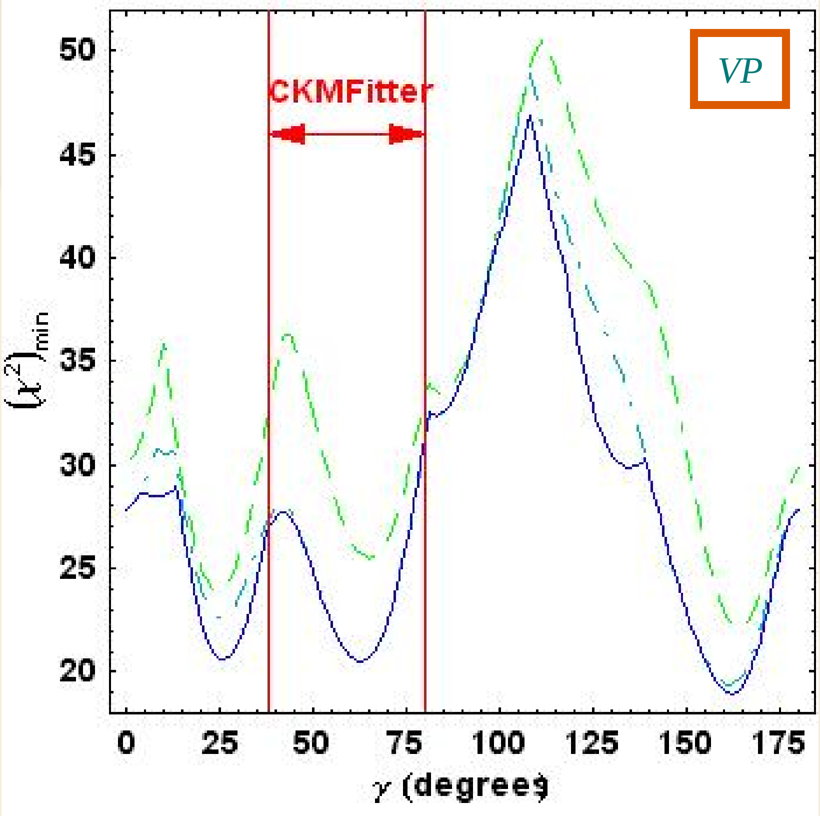
$$\chi^2 \equiv \sum_{\text{all obs.}} \left(\frac{X_{\text{th}} - X_{\text{data}}}{\Delta X_{\text{data}}} \right)^2$$

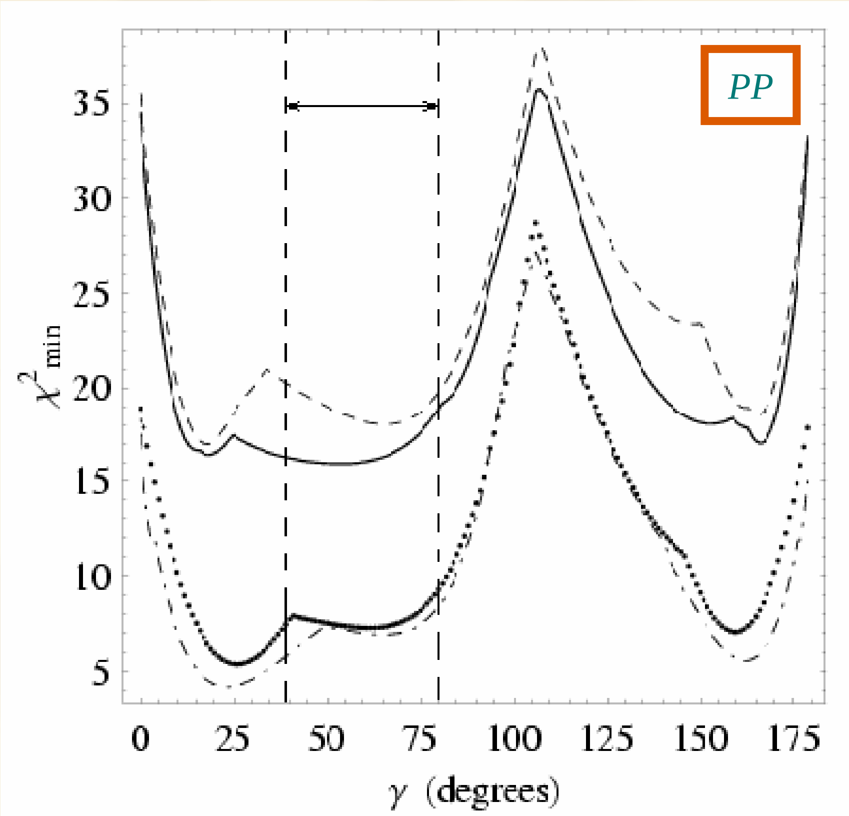
- Advantages:
  (1) it is less sensitive to statistical fluctuations of individual observables (particularly for rare processes);
  (2) it helps finding out which observable deviates from theory and how serious that is (leading to new physics); and
  (3) one may conveniently find errors associated with theory parameters and thus make predictions.

Old Results of Global $SU(3)_F$ Fits

[CWC, Gronau, Luo, Rosner, and Suprun, PRD **69**, 034001 (2004); PRD **70**, 034020 (2004)]

- Charmless *V P* modes, $\gamma = 57^o \sim 69^o$; charmless *P P* modes, $\gamma = 54^o \sim 66^o$; both 1 σ ranges and consistent with other constraints.





Flavor Amplitudes

- We use the following notation:

$$t \equiv Y_{db}^u T - (Y_{db}^u + Y_{db}^c) P_{EW}^C \ , \qquad t' \equiv Y_{sb}^u \xi_t T - (Y_{sb}^u + Y_{sb}^c) P_{EW}^C \ ,$$

$$c \equiv Y_{db}^u C - (Y_{db}^u + Y_{db}^c) P_{EW} \ , \qquad c' \equiv Y_{sb}^u \xi_c C - (Y_{sb}^u + Y_{sb}^c) P_{EW} \ ,$$

$$p \equiv -(Y_{db}^u + Y_{db}^c) \left(P - \frac{1}{3} P_{EW}^C \right) \ , \qquad p' \equiv -(Y_{sb}^u + Y_{sb}^c) \left(\xi_p P - \frac{1}{3} P_{EW}^C \right) \ .$$

$$s \equiv -(Y_{db}^u + Y_{db}^c) \left(S - \frac{1}{3} P_{EW} \right) \ , \qquad s' \equiv -(Y_{sb}^u + Y_{sb}^c) \left(\xi_s S - \frac{1}{3} P_{EW} \right) \ ,$$

where $Y_{qb}^{q'} = V_{q'q} V_{q'b}^*$, and each amplitude has its strong phase.

- We assume that the top-penguin dominates.
- The CKM factors have been explicitly pulled out.
- Unprimed amplitudes are used for $\Delta S = 0$ transitions and primed amplitudes for $|\Delta S| = 1$ ones.

Amplitude Decomposition

Mode		Flavor Amplitude	BR	$\mathcal{A}_{CP}$
$B^- \to$	$\pi^-\pi^0$	$-\frac{1}{\sqrt{2}}(t+c)$	5.7 ± 0.5	0.04 ± 0.05
	$K^-\overline{K}^0$	p	1.4 ± 0.3	0.12 ± 0.18
	$\pi^-\eta$	$-\frac{1}{\sqrt{3}}(t+c+2p+s)$	4.4 ± 0.4	-0.19 ± 0.07
	$\pi^-\eta'$	$\frac{1}{\sqrt{6}}(t+c+2p+4s)$	2.6 ± 0.8	0.15 ± 0.15
$\bar{B}^0 \to$	K^+K^-	$-(e+pa)$	0.07 ± 0.11	-
	$K^0\overline{K}^0$	p	1.0 ± 0.2	-
	$\pi^+\pi^-$	$-(t+p)$	5.2 ± 0.2	0.39 ± 0.19
				-0.58 ± 0.09
	$\pi^0\pi^0$	$\frac{1}{\sqrt{2}}(-c+p)$	1.3 ± 0.2	0.36 ± 0.32
	$\pi^0\eta$	$-\frac{1}{\sqrt{6}}(2p+s)$	0.60 ± 0.46	-
	$\pi^0\eta'$	$\frac{1}{\sqrt{3}}(p+2s)$	1.2 ± 0.7	-
	$\eta\eta$	$\frac{1}{3\sqrt{2}}(2c+2p+2s)$	< 1.2	-
	$\eta\eta'$	$-\frac{1}{3\sqrt{2}}(2c+2p+5s)$	< 1.7	-
	$\eta'\eta'$	$\frac{1}{3\sqrt{2}}(c+p+4s)$	< 10	-
$\bar{B}_s^0 \to$	$K^+\pi^-$	$-(t+p)$	< 5.6	-
	$K^0\pi^0$	$-\frac{1}{\sqrt{2}}(-c+p)$	-	-
	$\bar{K}^0\eta$	$-\frac{1}{\sqrt{3}}(c+s)$	-	-
	$\bar{K}^0\eta'$	$\frac{1}{\sqrt{6}}(c+3p+4s)$	-	-

Mode		Flavor Amplitude	BR	$\mathcal{A}_{CP}$
$B^- \to$	$\pi^-\bar{K}^0$	p'	23.1 ± 1.0	0.01 ± 0.02
	π^0K^-	$-\frac{1}{\sqrt{2}}(p'+t'+c')$	12.8 ± 0.6	0.05 ± 0.03
	$K^-\eta$	$-\frac{1}{\sqrt{3}}(s'+t'+c')$	2.2 ± 0.4	-0.29 ± 0.11
	$K^-\eta'$	$\frac{1}{\sqrt{6}}(3p'+4s'+t'+c')$	69.7 ± 2.8	0.03 ± 0.02
$\bar{B}^0 \to$	π^+K^-	$-(p'+t')$	19.7 ± 0.6	-0.098 ± 0.015
	$\pi^0\bar{K}^0$	$\frac{1}{\sqrt{2}}(p'-c')$	10.0 ± 0.6	-0.12 ± 0.11
				0.33 ± 0.21
	$\bar{K}^0\eta$	$-\frac{1}{\sqrt{3}}(s'+c')$	1.2 ± 0.3	-
	$\bar{K}^0\eta'$	$\frac{1}{\sqrt{6}}(3p'+4s'+c')$	64.9 ± 4.4	-0.09 ± 0.06
				0.60 ± 0.08
$\bar{B}_s^0 \to$	K^+K^-	$-(p'+t')$	34 ± 9	-
	$K^0\overline{K}^0$	p'	-	-
	$\pi^+\pi^-$	$-(e'+pa')$	< 1.7	-
	$\pi^0\pi^0$	$\frac{1}{\sqrt{2}}(e'+pa')$	< 2.1	-
	$\pi^0\eta$	$-\frac{1}{\sqrt{6}}c'$	-	-
	$\pi^0\eta'$	$-\frac{1}{\sqrt{3}}c'$	-	-
	$\eta\eta$	$-\frac{1}{3\sqrt{2}}(2p'-2s'-2c')$	-	-
	$\eta\eta'$	$\frac{1}{3\sqrt{2}}(4p'+2s'-c')$	-	-
	$\eta'\eta'$	$\frac{1}{3\sqrt{2}}(4p'+8s'+2c')$	-	-

ICHEP 06
w/ scale factors

$SU(3)_F$ Breaking

- In general, one expects factorization (into the product of a decay constant and a weak transition form factor) to work in *T* and *C* amplitudes. Therefore, a dominant correction for the former two topologies is obviously f_K / f_π.
- However, whether the penguin amplitude can be factorized is more questionable.
- Comparing $|p|$ from $B^0 \to K^0 \underline{K}^0$ and $B^+ \to K^+ \underline{K}^0$ with $|p'|$ from $B^+ \to K^0 \pi^+$, one gets $|p/p'|$ ' 0.23 ± 0.02 consistent with $|V_{cd}/V_{cs}|$.
- This partly justifies our use of $SU(3)_F$ as the working assumption and that f_K / f_π is not preferred when relating p to p^0.

SU(3) Breaking

- We use ρ and η as our fitting parameters, instead of weak phases.
- We consider various SU(3) breaking schemes, and present the following four representatives:
  1. exact flavor SU(3) symmetry for all amplitudes;
  2. including the factor f_K / f_π for $|T|$ only;
  3. including the factor f_K / f_π for both $|T|$ and $|C|$ only; and
  4. including a universal SU(3) breaking factor ξ for all amplitudes on top of Scheme 3.
- Including the factor f_K / f_π for $|P|$ does not improve χ^2_{min}.
- Still keep exact SU(3) symmetry for the strong phases.

Partial Fits ($\pi\,\pi$, $\pi\,K$, and $K\,K$)

- There are 22 data points in this set, including the BRs and CPAs, along with $|V_{ub}|$ = (0.426±0.036)£10^{-4} and $|V_{cb}|$ = (41.63±0.65)£ 10^{-4} that help fixing A and $\sqrt{(\underline{\rho}^2+\underline{\eta}^2)}$.

10 to 11 parameters

- Robust results against SU(3) breaking.
- Prefer f_K / f_π for T and C, factorizable to a good approximation.
- ξ ' 1.04.
- More reliable because no uncertainties from η and η^0.

Parameter	Scheme 1	Scheme 2	Scheme 3	Scheme 4
$\bar\rho$	$0.139^{+0.042}_{-0.037}$	$0.134^{+0.041}_{-0.036}$	$0.134^{+0.041}_{-0.036}$	$0.133^{+0.039}_{-0.035}$
$\bar\eta$	0.401 ± 0.030	0.403 ± 0.031	0.404 ± 0.031	0.399 ± 0.031
A	0.807 ± 0.013	0.807 ± 0.013	0.807 ± 0.013	0.807 ± 0.013
$\lvert T\rvert$	$0.573^{+0.055}_{-0.047}$	$0.575^{+0.055}_{-0.047}$	$0.574^{+0.055}_{-0.047}$	$0.582^{+0.056}_{-0.049}$
$\lvert C\rvert$	0.371 ± 0.050	0.364 ± 0.050	0.364 ± 0.049	0.372 ± 0.051
δ_C	-57.6 ± 10.3	-55.9 ± 10.7	-55.8 ± 10.2	-56.3 ± 10.1
$\lvert P\rvert$	0.121 ± 0.002	0.122 ± 0.002	0.122 ± 0.002	0.117 ± 0.008
δ_P	-22.7 ± 4.0	-18.8 ± 3.2	-19.3 ± 3.2	$-18.6^{+3.2}_{-3.5}$
$\lvert P_{EW}\rvert$	$0.011^{+0.006}_{-0.003}$	$0.011^{+0.006}_{-0.003}$	$0.011^{+0.005}_{-0.003}$	$0.011^{+0.004}_{-0.003}$
$\delta_{P_{EW}}$	$-4.3^{+34.1}_{-50.6}$	$2.2^{+32.0}_{-49.3}$	$-10.0^{+37.2}_{-45.3}$	-15.1 ± 39.9
ξ	1(fixed)	1(fixed)	1(fixed)	$1.04^{+0.08}_{-0.07}$
δ_{EW}	0.013 ± 0.006	0.013 ± 0.006	0.013 ± 0.005	0.013 ± 0.004
$\chi^2_{\min}/dof$	18.9/12	18.0/12	16.4/12	16.1/11

amps. in units of 10^4 eV

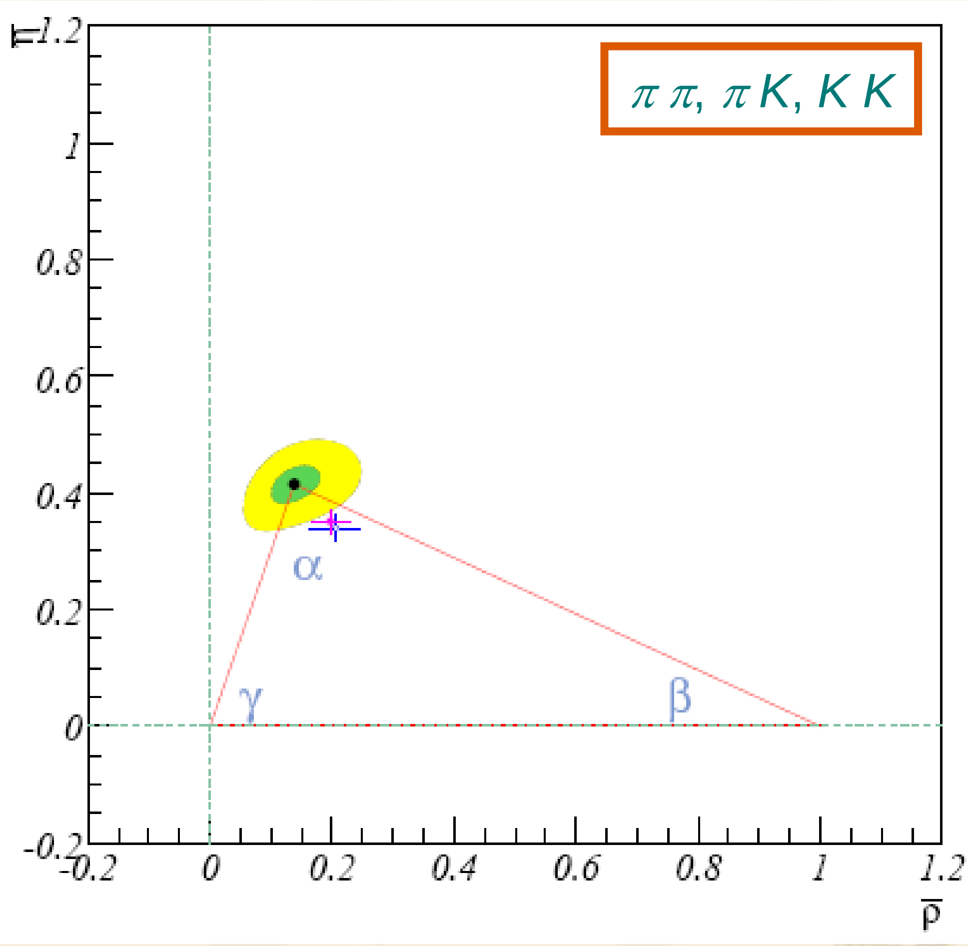
UT from $\pi\,\pi$, $\pi\,K$, and $K\,K$ Only

- Scheme 3 only (preferred and difference from others miniscule):

$$\alpha = \left(83^{+6}_{-7}\right)^\circ \;, \quad 69^\circ \le \alpha \le 96^\circ \quad (95\%\ \mathrm{CL})\;;$$

$$\beta = (26 \pm 2)^\circ \;, \quad 21^\circ \le \beta \le 31^\circ \quad (95\%\ \mathrm{CL})\;;$$

$$\gamma = \left(72^{+4}_{-5}\right)^\circ \;, \quad 62^\circ \le \gamma \le 81^\circ \quad (95\%\ \mathrm{CL})\;.$$



- Slightly higher (ρ,η) vertex; partly because of $|V_{ub}|$.
- *cf*. CKMfitter (pink) and UTfit (blue).

Large C Amplitude

- We observe a large C, with the ratio $|C/T|$ being about 0.63 ± 0.08 and a sizeable strong phase of about $(-56 \pm 10)^{o}$ relative to T.

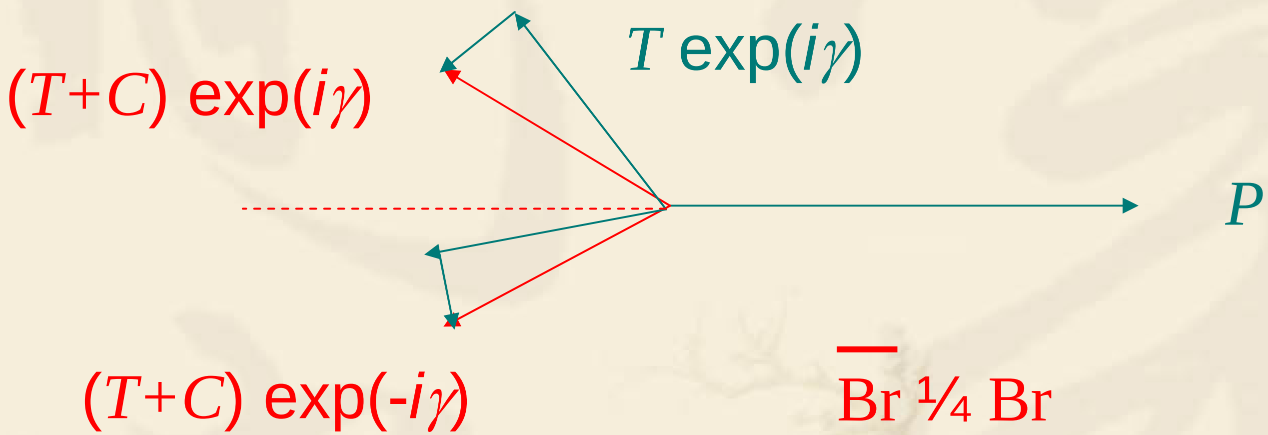
  [In our old fits, the ratio and relative strong phase between C and T are ≥ 0.7 and $\sim -(110\text{-}130)^{o}$.]

- These are mainly driven by the facts that the $\pi^0\pi^0$ mode has a large branching ratio and that $A_{CP}(K^+\pi^0)$ is very different from $A_{CP}(K^+\pi^-)$ [the new $K\pi$ problem].

$$
\begin{aligned}
A(B^+ \to K^0\pi^+) &= P' \\
\sqrt{2}A(B^+ \to K^+\pi^0) &= -(P' + T' + C' + P'_{EW}) \\
A(B^0 \to K^+\pi^-) &= -(P' + T') \\
\sqrt{2}A(B^0 \to K^0\pi^0) &= P' - C' - P'_{EW}
\end{aligned}
$$

Pictorially

- The large $|C|$ and strong phase may be explained within SM by including NLO vertex corrections. [Li, Mishima, and Sanda, 2005]



- However, it may as well be the EW penguin…

Electroweak Penguins

- Within the SM, the color-allowed penguin can be related to the sum of color-allowed and -suppressed tree amplitudes via a Fierz transformation: [Neubert and Rosner, 1998; Gronau, Pirjol and Yan, 1999.]

$$P_{EW} = -\delta_{EW}|T + C|e^{i\delta_{PEW}} \; ,$$

where $\delta_{EW} \simeq -\frac{3}{2}\frac{C_9 + C_{10}}{C_1 + C_2} \simeq 0.0135 \pm 0.0012 \; .$

- In our fits, we treat P_{EW} and the strong phase δ_{PEW} (~ –10^o w.r.t. T) as free parameters; their values do not vary much in different schemes and agree with the SM expectation.

- We ignore the color-suppressed penguin amplitude because it will introduce one more free parameter but not improve the fitting confidence level.

Predictions for $B_{u,d}$ Decays

/ $p - c$, cf. exp't: 1.45±0.29

result of comparable amps

/ $p^0 + t^0$, cf. exp't: –0.098±0.015

/ $p^0 + t^0 + c^0$,
cf. exp't: 0.05±0.03

/ $p - c$, large S_{CP} predicted

/ $p^0 - c^0$, cf. exp't: 0.33±0.21

Observable	Scheme 1	Scheme 2	Scheme 3	Scheme 4
$Br(\pi^+\pi^-)$	5.4 ± 1.1	5.4 ± 1.0	5.3 ± 1.0	5.3 ± 1.1
$Br(\pi^0\pi^0)$	1.6 ± 0.4	1.6 ± 0.4	1.6 ± 0.4	1.5 ± 0.4
$Br(\pi^-\pi^0)$	5.3 ± 1.2	5.4 ± 1.2	5.4 ± 1.2	5.4 ± 1.3
$Br(\pi^+K^-)$	20.2 ± 1.0	20.1 ± 1.1	20.1 ± 1.1	20.3 ± 4.3
$Br(\pi^0\bar{K}^0)$	9.9 ± 1.0	9.9 ± 1.0	10.0 ± 0.9	10.1 ± 2.3
$Br(\pi^-\bar{K}^0)$	23.0 ± 1.1	23.1 ± 1.1	23.1 ± 1.1	23.4 ± 4.8
$Br(\pi^0K^-)$	12.0 ± 1.2	12.1 ± 1.2	12.0 ± 1.1	12.2 ± 2.5
$Br(K^+K^-)$	0	0	0	0
$Br(K^0\bar{K}^0)$	1.0 ± 0.1	1.0 ± 0.1	1.0 ± 0.1	1.0 ± 0.2
$Br(K^-\bar{K}^0)$	1.1 ± 0.1	1.1 ± 0.1	1.1 ± 0.1	1.0 ± 0.2
$\mathcal{A}(\pi^+\pi^-)$	0.32 ± 0.07	0.27 ± 0.06	0.28 ± 0.06	0.26 ± 0.06
$\mathcal{A}(\pi^0\pi^0)$	0.47 ± 0.15	0.49 ± 0.15	0.49 ± 0.14	0.50 ± 0.14
$A_{CP}(\pi^-\pi^0)$	-0.01 ± 0.04	-0.02 ± 0.03	-0.01 ± 0.03	-0.01 ± 0.03
$A_{CP}(\pi^+K^-)$	-0.08 ± 0.02	-0.09 ± 0.02	-0.09 ± 0.02	-0.09 ± 0.02
$\mathcal{A}(\pi^0K_S)$	-0.07 ± 0.03	-0.08 ± 0.02	-0.09 ± 0.03	-0.10 ± 0.03
$A_{CP}(\pi^-\bar{K}^0)$	0	0	0	0
$A_{CP}(\pi^0K^-)$	0.00 ± 0.03	0.00 ± 0.03	0.01 ± 0.04	0.02 ± 0.04
$A_{CP}(K^+K^-)$	0	0	0	0
$\mathcal{A}(K^0\bar{K}^0)$	0	0	0	0
$A_{CP}(K^-\bar{K}^0)$	0	0	0	0
$\mathcal{S}(\pi^+\pi^-)$	-0.580 ± 0.130	-0.585 ± 0.130	-0.584 ± 0.130	-0.565 ± 0.141
$\mathcal{S}(\pi^0\pi^0)$	0.814 ± 0.109	0.812 ± 0.108	0.810 ± 0.106	0.786 ± 0.113
$\mathcal{S}(\pi^0K_S)$	0.851 ± 0.042	0.850 ± 0.041	0.861 ± 0.041	0.858 ± 0.042
$\mathcal{S}(K^0\bar{K}^0)$	-0.000 ± 0.014	-0.000 ± 0.014	-0.000 ± 0.014	-0.000 ± 0.015

BR in units of 10^{-6}

Predictions for B_s Decays

cf. (34±9)£10^{-6} by CDF 2005; fluctuation or big SU(3) breaking?

involve p^0, can test SU(3)

/ $t + p$

/ $t^0 + p^0$, related to $B_d \to \pi^+ K^-$

/ $p - c$, related to $B_d \to \pi^0 \pi^0$

Observable	Scheme 1	Scheme 2	Scheme 3	Scheme 4
$Br(\pi^+\pi^-)$	0	0	0	0
$Br(\pi^0\pi^0)$	0	0	0	0
$Br(\pi^+K^-)$	5.0 ± 1.0	5.0 ± 1.0	5.0 ± 1.0	5.0 ± 1.0
$Br(\pi^0K^0)$	1.5 ± 0.3	1.5 ± 0.3	1.5 ± 0.3	1.4 ± 0.3
$Br(K^+K^-)$	18.9 ± 1.0	18.8 ± 1.0	18.8 ± 1.0	19.0 ± 4.0
$Br(K^0\bar{K}^0)$	20.0 ± 1.0	20.2 ± 1.0	20.1 ± 1.0	20.4 ± 4.2
$\mathcal{A}(\pi^+\pi^-)$	0	0	0	0
$\mathcal{A}(\pi^0\pi^0)$	0	0	0	0
$A_{CP}(\pi^+K^-)$	0.32 ± 0.07	0.27 ± 0.06	0.28 ± 0.06	0.26 ± 0.06
$\mathcal{A}(\pi^0K_S)$	0.47 ± 0.15	0.49 ± 0.15	0.49 ± 0.14	0.50 ± 0.14
$\mathcal{A}(K^+K^-)$	-0.08 ± 0.02	-0.09 ± 0.02	-0.09 ± 0.02	-0.09 ± 0.02
$\mathcal{A}(K^0\bar{K}^0)$	0	0		0
$\mathcal{S}(\pi^+\pi^-)$	0	0		0
$\mathcal{S}(\pi^0\pi^0)$	0	0		0
$\mathcal{S}(\pi^0K_S)$	0.340 ± 0.202	0.365 ± 0.194	0.359 ± 0.193	0.308 ± 0.201
$\mathcal{S}(K^+K^-)$	0.147 ± 0.022	0.199 ± 0.028	0.198 ± 0.028	0.211 ± 0.035
$\mathcal{S}(K^0\bar{K}^0)$	-0.043 ± 0.004	-0.044 ± 0.004	-0.044 ± 0.004	-0.043 ± 0.004

New CDF result (9/21/2006)

BR = $(5.0 \pm 0.75 \pm 1.0)$£10^{-6}

ACP = $0.39 \pm 0.15 \pm 0.08$

BR in units of 10^{-6}

Adding One New Amplitude

- If we add one new amplitude N with its own weak and strong phases, ϕ_N and δ_N, (3 more parameters) to the strangeness-changing amplitude c^0

$$c' \to Y_{sb}^u \xi_c C - (Y_{sb}^u + Y_{sb}^c)\, P_{EW} + N \ .$$

$$\text{with } N = |N| \exp\left[i(\phi_N + \delta_N)\right]$$

  while fixing the Neubert-Rosner relation $\delta_{EW} = 0.0135$, the value of χ^2_{min} reduces from ~16 down to ~4 in Scheme 3.

- The new amplitude does not scale and appear like others in strangeness-conserving decays.

- We obtain $|N|$ ' 18^{+3}_{-4} eV (in comparison with $|T|$ ' 0.55£10^4 eV, $|C|$ ' 0.32£10^4 eV, and $|P|$ ' 0.12£10^4 eV that are not changed by much), ϕ_N ' $(92\pm4)^o$, and δ_N ' $(-14\pm5)^o$.

Discussions

- It seems difficult to determine whether the new amplitude N is associated with C or P_{EW}, since they always appear in pairs.
- Our results have $|N| / |V_{cb}V_{cs}| = 0.04$£$10^4$ eV and $|N| / |V_{ub}V_{us}| =$ 2.2£10^4 eV, showing that $|N|$ is unexpectedly large.
- Since N is assumed to enter only c' in the $K\pi$ modes but not c in the $\pi\pi$ modes, thus it behaves more like P_{EW} than C.
- The above finding may look contradictory to what we have found before, where $|P_{EW}|$ is preferred by data to have the SM value. This is because in the previous fit, the weak phase of P_{EW} is fixed according to the SM. But here the electroweak penguin-like new amplitude N is allowed to have its own weak phase.

Global Fits

- There are totally 34 data points to fit.

12 to 13 parameters

- The singlet penguin S is required to explain large BRs of the $\eta^0 K$ modes.
- Worse fitting quality, largely due to $S_{\eta^0 K_S}$, BR (ηK^+) and BR$(\pi^+ \eta')$.
- May need of more theory parameters.

Parameter	Scheme 1	Scheme 2	Scheme 3	Scheme 4
$\bar{\rho}$	$0.089^{+0.031}_{-0.027}$	$0.087^{+0.029}_{-0.026}$	$0.087^{+0.029}_{-0.026}$	$0.096^{+0.029}_{-0.026}$
$\bar{\eta}$	0.377 ± 0.027	0.378 ± 0.028	0.379 ± 0.027	0.370 ± 0.027
A	0.809 ± 0.012	0.809 ± 0.012	0.809 ± 0.012	0.809 ± 0.012
$\|T\|$	$0.641^{+0.056}_{-0.050}$	$0.642^{+0.056}_{-0.050}$	$0.640^{+0.056}_{-0.049}$	$0.649^{+0.056}_{-0.049}$
$\|C\|$	0.426 ± 0.048	0.418 ± 0.048	0.415 ± 0.047	0.436 ± 0.049
δ_C	-72.5 ± 7.3	-70.4 ± 7.5	-70.0 ± 7.3	-68.3 ± 7.2
$\|P\|$	0.121 ± 0.002	0.121 ± 0.002	0.121 ± 0.002	0.110 ± 0.008
δ_P	-17.8 ± 3.2	-16.0 ± 2.8	-16.4 ± 2.8	-15.9 ± 2.6
$\|P_{EW}\|$	$0.012^{+0.006}_{-0.004}$	$0.011^{+0.005}_{-0.003}$	$0.012^{+0.006}_{-0.004}$	$0.013^{+0.006}_{-0.004}$
$\delta_{P_{EW}}$	$-58.8^{+39.8}_{-20.6}$	$-47.7^{+42.9}_{-24.9}$	$-58.1^{+35.9}_{-19.3}$	$-57.6^{+32.5}_{-18.2}$
$\|S\|$	$0.048^{+0.004}_{-0.003}$	$0.047^{+0.004}_{-0.003}$	$0.047^{+0.003}_{-0.003}$	0.042 ± 0.004
δ_S	-48.3 ± 10.6	-44.8 ± 10.2	-44.2 ± 9.8	-42.9 ± 9.3
ξ	1(fixed)	1(fixed)	1(fixed)	$1.10^{+0.09}_{-0.07}$
δ_{EW}	0.014 ± 0.006	0.013 ± 0.005	0.014 ± 0.006	0.015 ± 0.006
χ^2/dof	$37.4/22$	$34.8/22$	$32.9/22$	$30.6/21$

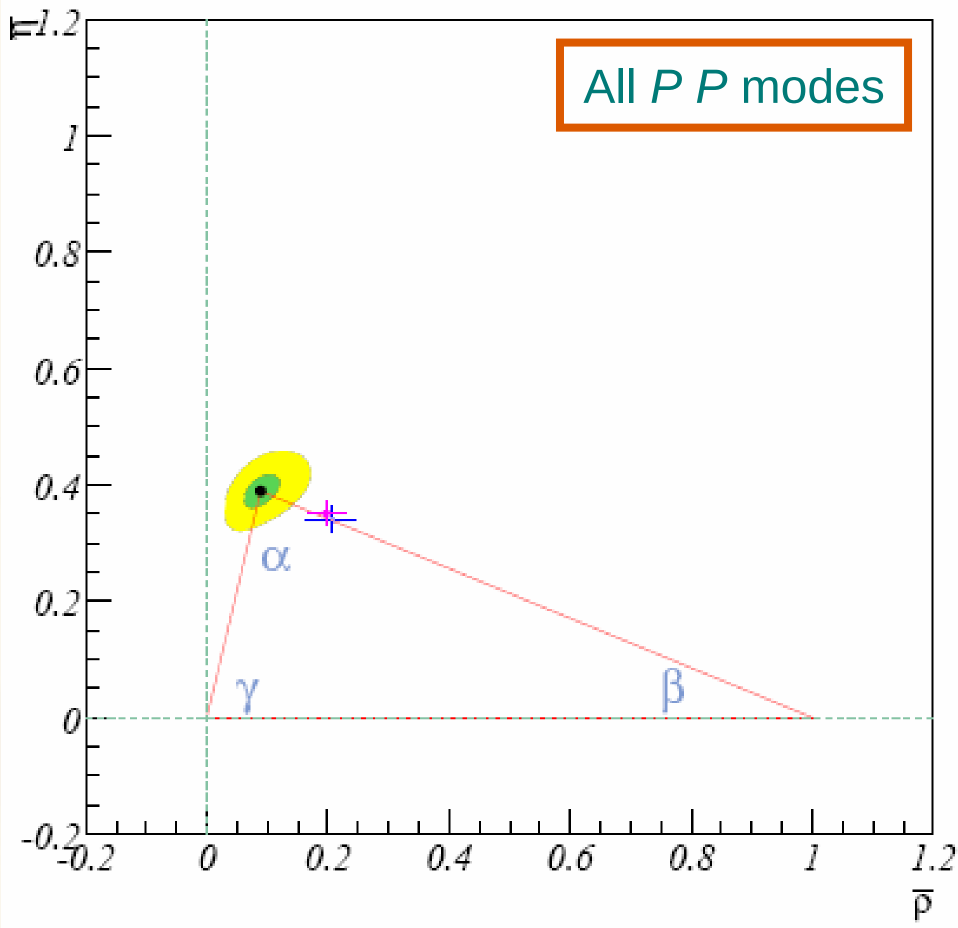
amps. in units of 10^4 eV

UT from Global Fits

- Scheme 3 only (difference from others miniscule):

$$\alpha = (80 \pm 6)^\circ \ , \quad 69^\circ \leq \alpha \leq 92^\circ \quad (95\% \text{ CL}) \ ;$$
$$\beta = (23 \pm 2)^\circ \ , \quad 20^\circ \leq \beta \leq 27^\circ \quad (95\% \text{ CL}) \ ;$$
$$\gamma = (77 \pm 4)^\circ \ , \quad 69^\circ \leq \gamma \leq 84^\circ \quad (95\% \text{ CL}) \ .$$

- The (ρ, η) is further shifted toward larger γ, but with β consistent with other fits.



Comparison With Limited Fits

- The magnitudes of P and $P_{\rm EW}$ are about the same in both the limited and global fits.
- $|T|$ and $|C|$ become slightly larger in the global fits, but the ratio $|T/C|$ ' 0.65 remains about the same.
- The extra SU(3)-breaking parameter ξ increases from 1.04 to 1.10.
- $|S|$ is about four times $|P_{\rm EW}|$, proving its significance.
- The strong phase of S is close to that of $P_{\rm EW}$ and about -30° from P.

Predictions for $B_{u,d}$ Decays

Observable	Scheme 1	Scheme 2	Scheme 3	Scheme 4
$Br(\pi^+\pi^-)$	5.3 ± 1.0	5.3 ± 1.0	5.3 ± 1.0	5.3 ± 1.0
$Br(\pi^0\pi^0)$	1.7 ± 0.3	1.7 ± 0.3	1.7 ± 0.3	1.6 ± 0.3
$Br(\pi^-\pi^0)$	4.8 ± 1.0	4.9 ± 1.0	4.9 ± 1.0	5.1 ± 1.1
$Br(\pi^+K^-)$	20.3 ± 1.0	20.2 ± 1.0	20.2 ± 1.0	20.4 ± 4.3
$Br(\pi^0\bar{K}^0)$	9.6 ± 1.0	9.6 ± 0.9	9.6 ± 1.0	9.8 ± 2.3
$Br(\pi^-\bar{K}^0)$	22.6 ± 1.1	22.7 ± 1.1	22.7 ± 1.1	23.1 ± 4.8
$Br(\pi^0K^-)$	12.3 ± 1.2	12.2 ± 1.1	12.3 ± 1.2	12.5 ± 2.7
$Br(K^0\bar{K}^0)$	1.1 ± 0.1	1.1 ± 0.1	1.1 ± 0.1	0.9 ± 0.1
$Br(K^-\bar{K}^0)$	1.2 ± 0.1	1.2 ± 0.1	1.2 ± 0.1	1.0 ± 0.2
$Br(\pi^0\eta)$	1.0 ± 0.1	1.0 ± 0.1	1.0 ± 0.1	0.8 ± 0.1
$Br(\pi^0\eta')$	1.0 ± 0.1	1.0 ± 0.1	1.0 ± 0.1	0.8 ± 0.1
$Br(\pi^-\eta)$	4.6 ± 0.6	4.6 ± 0.6	4.6 ± 0.6	4.6 ± 0.7
$Br(\pi^-\eta')$	3.2 ± 0.3	3.2 ± 0.3	3.2 ± 0.3	3.0 ± 0.4
$Br(\bar{K}^0\eta)$	1.4 ± 0.2	1.3 ± 0.2	1.4 ± 0.2	1.4 ± 0.3
$Br(\bar{K}^0\eta')$	65.3 ± 5.2	65.7 ± 5.0	65.5 ± 4.8	66.4 ± 13.0
$Br(K^-\eta)$	1.5 ± 0.3	1.5 ± 0.2	1.5 ± 0.3	1.5 ± 0.4
$Br(K^-\eta')$	69.2 ± 5.5	69.5 ± 5.3	69.3 ± 5.1	70.1 ± 13.8
$Br(\eta\eta)$	0.8 ± 0.1	0.8 ± 0.1	0.8 ± 0.1	0.8 ± 0.1
$Br(\eta'\eta')$	0.4 ± 0.0	0.4 ± 0.0	0.4 ± 0.0	0.4 ± 0.0
$Br(\eta\eta')$	1.2 ± 0.1	1.2 ± 0.1	1.2 ± 0.1	1.1 ± 0.1
$CP(\pi^+\pi^-)$	0.27 ± 0.06	0.24 ± 0.05	0.25 ± 0.05	0.22 ± 0.04
$CP(\pi^0\pi^0)$	0.71 ± 0.10	0.70 ± 0.10	0.70 ± 0.10	0.67 ± 0.09
$CP(\pi^-\pi^0)$	0.03 ± 0.03	0.02 ± 0.03	0.03 ± 0.03	0.04 ± 0.03
$CP(\pi^+K^-)$	-0.07 ± 0.02	-0.08 ± 0.02	-0.08 ± 0.02	-0.08 ± 0.02
$CP(\pi^0\bar{K}^0)$	-0.13 ± 0.02	-0.12 ± 0.02	-0.15 ± 0.03	-0.17 ± 0.03
$CP(\pi^-\eta)$	-0.09 ± 0.10	-0.11 ± 0.09	-0.10 ± 0.09	-0.10 ± 0.09

predicted to have same BR;
cf. exp't: 0.60±0.46 and 1.2±0.7.

predict larger $A(\pi^0\pi^0)$~0.7 but smaller $S(\pi^0\pi^0)$~0.65;
cf. exp't $A(\pi^0\pi^0) = 0.36 \pm 0.32$;
result of larger $|T|$ and $|C|$.

BR in units of 10^{-6}

Predictions for B_s Decays

Observable	Scheme 1	Scheme 2	Scheme 3	Scheme 4
$Br(\pi^+\pi^-)$	0	0	0	0
$Br(\pi^0\pi^0)$	0	0	0	0
$Br(\pi^+K^-)$	5.0 ± 0.9	5.0 ± 0.9	5.0 ± 0.9	5.0 ± 0.9
$Br(\pi^0K^0)$	1.6 ± 0.3	1.6 ± 0.3	1.6 ± 0.3	1.5 ± 0.3
$Br(K^+K^-)$	18.9 ± 1.0	18.9 ± 1.0	18.9 ± 1.0	19.1 ± 4.0
$Br(K^0K^0)$	19.7 ± 1.0	19.8 ± 1.0	19.8 ± 1.0	20.2 ± 4.2
$Br(\pi^0\eta)$	0	0	0.1 ± 0.0	0.1 ± 0.0
$Br(\pi^0\eta')$	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.1
$Br(\bar{K}^0\eta)$	0.7 ± 0.2	0.7 ± 0.2	0.7 ± 0.2	0.7 ± 0.2
$Br(\bar{K}^0\eta')$	3.3 ± 0.3	3.4 ± 0.3	3.4 ± 0.3	2.8 ± 0.3
$Br(\eta\eta)$	2.0 ± 0.4	2.0 ± 0.4	2.0 ± 0.4	2.0 ± 0.6
$Br(\eta'\eta')$	48.3 ± 4.4	48.6 ± 4.3	48.3 ± 4.1	48.9 ± 9.8
$Br(\eta\eta')$	22.4 ± 1.5	22.6 ± 1.4	22.5 ± 1.4	22.9 ± 4.7
$CP(\pi^+\pi^-)$	0	0	0	0
$CP(\pi^0\pi^0)$	0	0	0	0
$CP(\pi^+K^-)$	0.27 ± 0.06	0.24 ± 0.05	0.25 ± 0.05	0.22 ± 0.04
$CP(\pi^0K^0)$	0.71 ± 0.10	0.70 ± 0.10	0.70 ± 0.10	0.67 ± 0.09
$CP(K^+K^-)$	-0.07 ± 0.02	-0.08 ± 0.02	-0.08 ± 0.02	-0.08 ± 0.02
$CP(K^0K^0)$	0	0	0	0
$CP(\pi^0\eta)$	0.20 ± 0.47	0.32 ± 0.48	0.19 ± 0.46	0.18 ± 0.45
$CP(\pi^0\eta')$	0.20 ± 0.47	0.32 ± 0.48	0.19 ± 0.46	0.18 ± 0.45

destructive interference between p^0 and s^0 → $Br(\eta\eta)$

constructive interference between p^0 and s^0 → $Br(\eta'\eta')$, $Br(\eta\eta')$

BR in units of 10^{-6}

Summary

- We perform global χ^2 fits to charmless $B \to P\,P$ decays and determine theoretical parameters in various SU(3)-conserving and -breaking schemes (based on ICHEP06 data).
- The $(\underline{\rho},\underline{\eta})$ vertex obtained from the partial fit is higher than but consistent with the CKMfitter/UTfit results; global fits shifts it to a smaller ρ value. These results are robust in all the schemes.
- We observe a large $|C|$ with a nontrivial strong phase, and a P_{EW} about the right size as in the SM. However, the fitting results improve a lot with a new EWP-like amplitude having new strong and weak phases.
- We make predictions based upon the fitting results, particularly for the B_s system to be observed in the next few years.

Thank You
for Your Attentions

Amplitude Decomposition Again

Mode		Flavor Amplitude	BR	$\mathcal{A}_{CP}$
$B^- \to$	$\pi^-\pi^0$	$-\frac{1}{\sqrt{2}}(t+c)$	5.7 ± 0.5	0.04 ± 0.05
	$K^-\overline{K}^0$	p	1.4 ± 0.3	0.12 ± 0.18
	$\pi^-\eta$	$-\frac{1}{\sqrt{3}}(t+c+2p+s)$	4.4 ± 0.4	-0.19 ± 0.07
	$\pi^-\eta'$	$\frac{1}{\sqrt{6}}(t+c+2p+4s)$	2.6 ± 0.8	0.15 ± 0.15
$\bar{B}^0 \to$	K^+K^-	$-(e+pa)$	0.07 ± 0.11	-
	$K^0\overline{K}^0$	p	1.0 ± 0.2	-
	$\pi^+\pi^-$	$-(t+p)$	5.2 ± 0.2	0.39 ± 0.19
				-0.58 ± 0.09
	$\pi^0\pi^0$	$\frac{1}{\sqrt{2}}(-c+p)$	1.3 ± 0.2	0.36 ± 0.32
	$\pi^0\eta$	$-\frac{1}{\sqrt{6}}(2p+s)$	0.60 ± 0.46	-
	$\pi^0\eta'$	$\frac{1}{\sqrt{3}}(p+2s)$	1.2 ± 0.7	-
	$\eta\eta$	$\frac{1}{3\sqrt{2}}(2c+2p+2s)$	< 1.2	-
	$\eta\eta'$	$-\frac{1}{3\sqrt{2}}(2c+2p+5s)$	< 1.7	-
	$\eta'\eta'$	$\frac{1}{3\sqrt{2}}(c+p+4s)$	< 10	-
$\bar{B}_s^0 \to$	$K^+\pi^-$	$-(t+p)$	< 2.1	-
	$K^0\pi^0$	$-\frac{1}{\sqrt{2}}(-c+p)$	-	-
	$\bar{K}^0\eta$	$-\frac{1}{\sqrt{3}}(c+s)$	-	-
	$\bar{K}^0\eta'$	$\frac{1}{\sqrt{6}}(c+3p+4s)$	-	-

Mode		Flavor Amplitude	BR	$\mathcal{A}_{CP}$
$B^- \to$	$\pi^-\bar{K}^0$	p'	23.1 ± 1.0	0.01 ± 0.02
	π^0K^-	$-\frac{1}{\sqrt{2}}(p'+t'+c')$	12.8 ± 0.6	0.05 ± 0.03
	$K^-\eta$	$-\frac{1}{\sqrt{3}}(s'+t'+c')$	2.2 ± 0.4	-0.29 ± 0.11
	$K^-\eta'$	$\frac{1}{\sqrt{6}}(3p'+4s'+t'+c')$	69.7 ± 2.8	0.03 ± 0.02
$\bar{B}^0 \to$	π^+K^-	$-(p'+t')$	19.7 ± 0.6	-0.098 ± 0.015
	$\pi^0\bar{K}^0$	$\frac{1}{\sqrt{2}}(p'-c')$	10.0 ± 0.6	-0.12 ± 0.11
				0.33 ± 0.21
	$\bar{K}^0\eta$	$-\frac{1}{\sqrt{3}}(s'+c')$	1.2 ± 0.3	-
	$\bar{K}^0\eta'$	$\frac{1}{\sqrt{6}}(3p'+4s'+c')$	64.9 ± 4.4	-0.09 ± 0.06
				0.60 ± 0.08
$\bar{B}_s^0 \to$	K^+K^-	$-(p'+t')$	34 ± 9	-
	$K^0\overline{K}^0$	p'	-	-
	$\pi^+\pi^-$	$-(e'+pa')$	< 1.7	-
	$\pi^0\pi^0$	$\frac{1}{\sqrt{2}}(e'+pa')$	< 2.1	-
	$\pi^0\eta$	$-\frac{1}{\sqrt{6}}c'$	-	-
	$\pi^0\eta'$	$-\frac{1}{\sqrt{3}}c'$		
	$\eta\eta$	$-\frac{1}{3\sqrt{2}}(2p'-2s'-2c')$		
	$\eta\eta'$	$\frac{1}{3\sqrt{2}}(4p'+2s'-c')$		
	$\eta'\eta'$	$\frac{1}{3\sqrt{2}}(4p'+8s'+2c')$		

ICHEP 06
w/ scale factors

- The singlet penguin amplitude plays an important role in modes with η and η^0, where their wave functions are assumed to be:
  $\eta = (s\bar{s} - u\bar{u} - d\bar{d})/\sqrt{3}$ and $\eta^0 = (2s\bar{s} + u\bar{u} + d\bar{d})/\sqrt{6}$.

CKM Fitter Results