Could $B_s \to K^- \pi^+$ of CDF unveil new physics ?

Chuan-Hung Chen

Department of Physics,
National Cheng-Kung U.,
Tainan, Taiwan

- Motivation inspired by current exps. at CDF
- Analysis of only tree & penguin related decays

  -- toward new physics at tree --
- W_R effects on B decays
- Summary

Motivation

- Some important quantities & identity in the SM
  - ■ The Cabibbo-Kobayashi-Maskawa (CKM) matrix
    - ➢ by diagonalizing the Yukawa mass matrices of quarks, from charged weak currents, we have

$$J^C_\mu W^\mu = \left(\bar{u}, \bar{c}, \bar{t}\right)_L \gamma_\mu \underbrace{V^U_L V^{D\dagger}_L}_{CKM} \begin{pmatrix} d \\ s \\ b \end{pmatrix}_L W^\mu$$

    - ➢ Theoretical constraint

$V_{CKM} V^\dagger_{CKM} = 1$ ➡ 6 off-diagonal elements form 6 triangles with the same area

    - ➢ Exact identities:

$$\mathrm{Im}\left(V^*_{\alpha k} V_{\alpha j} V_{\beta k} V^*_{\beta j}\right) = J \sum_{\gamma, \ell} \varepsilon_{\alpha\beta\gamma} \varepsilon_{jk\ell}$$

J: Jarlskog const.

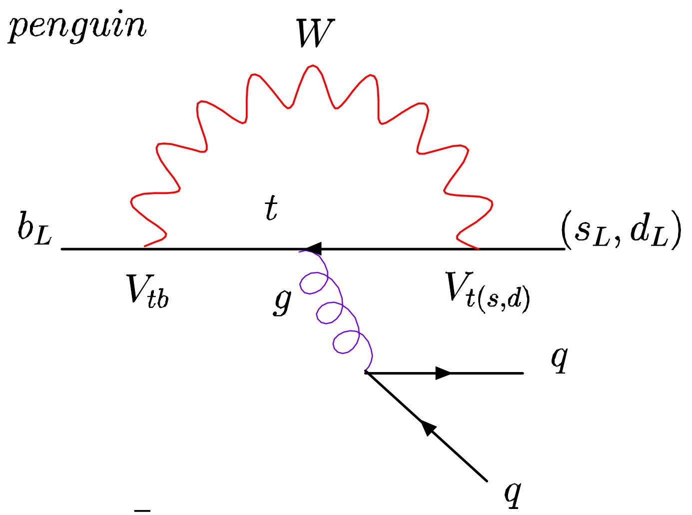
$$\mathrm{Im}\left(V^*_{ts} V_{tb} V_{us} V^*_{ub}\right) = -\mathrm{Im}\left(V^*_{td} V_{tb} V_{ud} V^*_{ub}\right)$$

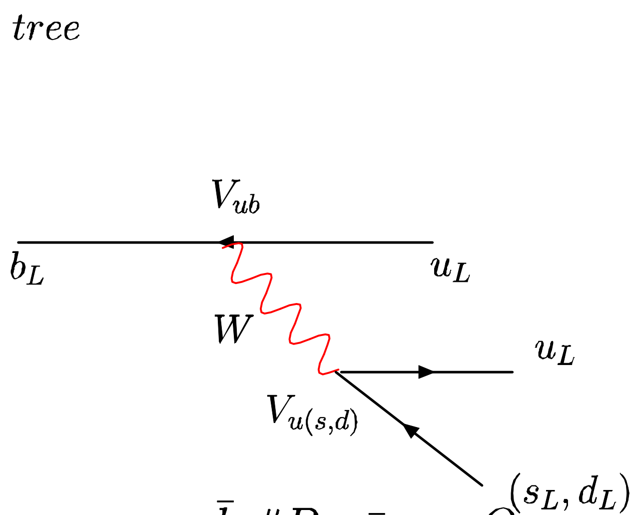
By Wolfenstein parametrization:

$V_{ub} \sim O(1.5\lambda^4)$

$$V_{CKM} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} = \begin{pmatrix} & & |V_{ub}|e^{-i\gamma} \\ & & \\ |V_{td}|e^{-i\beta} & V_{ts} & \end{pmatrix}$$

- Effective interactions for b decays in the SM





$\bar{b}\gamma^\mu P_L Q \bar{q}\gamma_\mu p_L q$

$\bar{b}\gamma^\mu P_L Q \bar{q}\gamma_\mu p_R q \qquad Q = s, d$

$\bar{b}\gamma^\mu P_L u \bar{u}\gamma_\mu p_L Q$

- b→ s is penguin dominance while b → d is tree
- Due to $V_{cb}^* V_{cs} \approx -V_{tb}^* V_{ts}$ & $-V_{cb}^* V_{cd} \approx V_{tb}^* V_{td}$, in the following analysis, we will express the decay amplitude in terms of $V^*_{tb}\ V_{t(s,\ d)}$

The related experimental results :

TABLE I: Branching ratios in units of 10^{-6}

Decay Mode	BABAR	BELLE	CLEO	CDF	Avg
$B^+ \to \pi^+ K^0$	$23.9 \pm 1.1 \pm 1.0$	$22.8^{+0.8}_{-0.7} \pm 1.3$	$18.8^{+3.7+2.1}_{-3.3-1.8}$	$--$	23.1 ± 1.0
$B_d \to \pi^- K^+$	$19.1 \pm 0.6 \pm 0.6$	$19.9 \pm 0.4 \pm 0.8$	$18.0^{+2.3+1.2}_{-2.1-0.9}$	$--$	19.4 ± 0.6
$B_d \to \pi^- \pi^+$	$5.5 \pm 0.4 \pm 0.3$	$5.1 \pm 0.2 \pm 0.2$	$4.5^{+1.4+0.5}_{-1.2-0.4}$	$5.10 \pm 0.33 \pm 0.36$	5.16 ± 0.22
$B_d \to K^+ K^-$	$0.04 \pm 0.15 \pm 0.08$	$0.09^{+0.18}_{-0.13} \pm 0.01$	< 0.8	$0.39 \pm 0.16 \pm 0.12$	$0.15^{+0.11}_{-0.10}$
$B_s \to K^- \pi^+$	$--$	$--$	$--$	$5.0 \pm 0.75 \pm 1.0$	5.00 ± 1.25
$B_s \to K^+ K^-$	$--$	$--$	$--$	$24.4 \pm 1.4 \pm 4.6$	24.4 ± 4.8
$B_s \to \pi^+ \pi^-$	$--$	$--$	$--$	$0.53 \pm 0.31 \pm 0.40$	0.53 ± 0.51

※ http://www.slac.stanford.edu/xorg/hfag/

- The interesting thing is the small BR for $B_s \to K^- \pi^+$
- $B(B_d \to K^+ K^-), B(B_s \to \pi^+ \pi^-) \leq O(10^{-7})$,

  the corresponding effects could be neglected

TABLE II: CP asymmetries in units 10^{-2}

Decay Mode	BABAR	BELLE	CLEO	CDF	Avg
$B^+ \to \pi^+ K^0$	$-2.9 \pm 3.9 \pm 1.0$	$3.0 \pm 3.0 \pm 1.0$	$18.0 \pm 24.0 \pm 2.0$	$--$	0.9 ± 2.5
$B_d \to \pi^- K^+$	$-10.7 \pm 1.8^{+0.7}_{-0.4}$	$-9.3 \pm 1.8 \pm 0.8$	$-4.0 \pm 16.0 \pm 2.0$	$-8.6 \pm 2.3 \pm 0.9$	-9.7 ± 1.2
$B_d \to \pi^- \pi^+$	$21 \pm 9 \pm 2$	$55 \pm 8 \pm 5$	$--$	$--$	38 ± 7
$B_d \to K^+ K^-$	$--$	$--$	$--$	$--$	$--$
$B_s \to K^- \pi^+$	$--$	$--$	$--$	$39 \pm 15 \pm 8$	39 ± 17
$B_s \to K^+ K^-$	$--$	$--$	$--$	$--$	$--$
$B_s \to \pi^+ \pi^-$	$--$	$--$	$--$	$--$	$--$

* $A_{CP} = \dfrac{\overline{B} - B}{\overline{B} + B} \propto \sin\theta_W \sin\theta_S$; interference effects between tree and penguin

- The interesting things are the large CP asymmetries of $B_d \to \pi^+ \pi^-$ & $B_s \to K^- \pi^+$

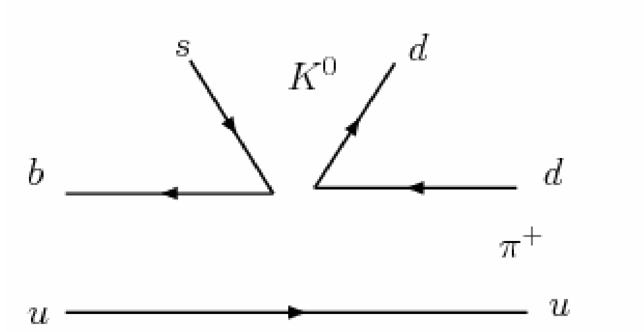
The detailed analysis on the decays

- $B^+ \to \pi^+ K^0$

At quark level, the decay is governed by $\bar{b} \to \bar{s} d \bar{d}$

$$A\left(B^+ \to \pi^+ K^0\right) = -V_{ts} V_{tb}^{*} P' e^{i\delta'_P}$$

- penguin dominance
- due to CPA ~0, tree ~ 0
- V_{ts} ~ –0.041 < 0
- P’ > 0, besides QCD effects,
  P’ also depends on weak interactions
- δ'_P : strong phase; from short- and long-distance



$$B = (23.1 \pm 1.0) 10^{-6}$$
$$A_{CP} = (0.9 \pm 2.5) 10^{-2}$$

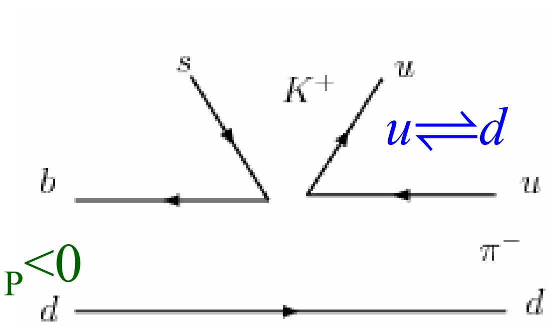
- $B_d \to \pi^- K^+$

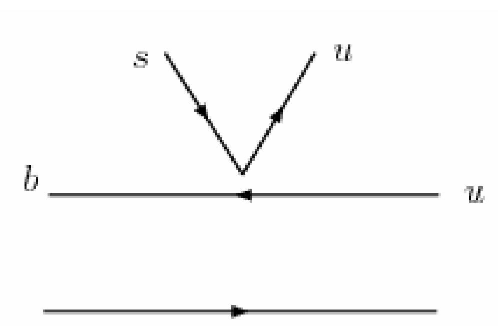
At quark level, the decay is governed by $\bar{b} \to \bar{s} u \bar{u}$

$$A\left(B_d \to \pi^- K^+\right) = -V_{ts} V_{tb}^{*} P' e^{i\delta'_P} - V_{us} V_{ub}^{*} T'$$

$$B = (19.4 \pm 0.6) 10^{-6}$$
$$A_{CP} = -0.097 \pm 0.012$$

- T’ > 0 and color allowed
- V_{us}, V_{ub} > 0
- from BR, it is destructive
  between P’ and T’
- $\cos\delta'_P$ > 0, by CPA, δ'_P<0





- Now, the two decays have 3 observables; 3 measurements could determine the parameters P’, δ'_P and T’ completely

- $B^+ \to \pi^+ K^0$ gives a strict limit on $V_{ts}P'$

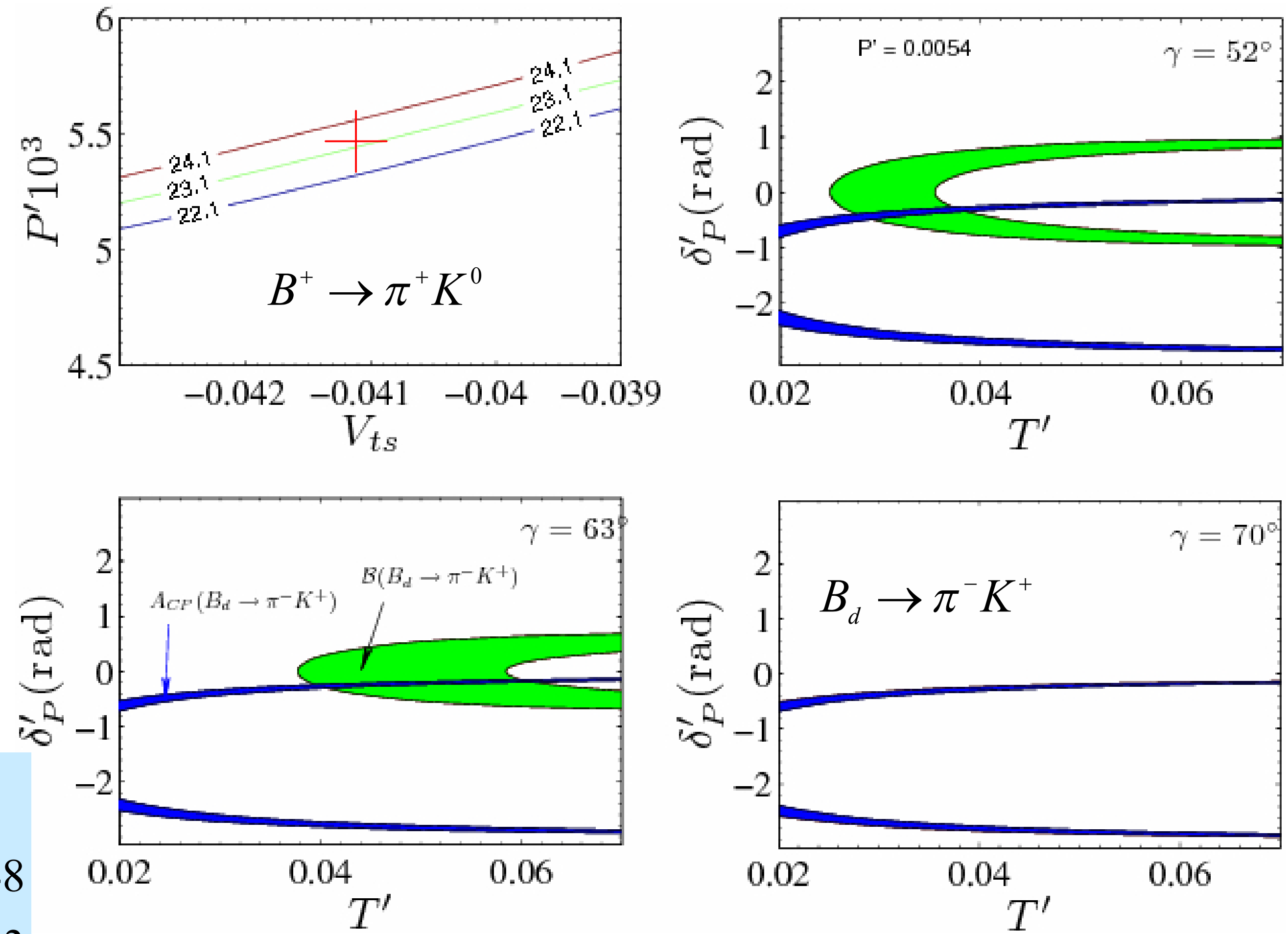
- With $|V_{ts}\, P'| = 2.2\ 10^{-4}$, we could see that the needed T’ depends on angle γ

$$\gamma_{fit} = \left(63^{+15}_{-12}\right)^0$$

- What is the reasonable value for T’ ?

$$T' \approx a_1 f_K F_0^{B\to\pi}\left(m_K^2 = 0\right)$$

$$\approx 1 \cdot 0.16 \cdot \begin{cases} 0.30 \\ 0.27 \\ 0.24 \end{cases} = \begin{cases} 0.048 \\ 0.043 \\ 0.038 \end{cases}$$



$$V_{ub} = 4.3 \times 10^{-3} e^{-i\gamma}$$

Data with 1σ errors

- $B_s \to K^- \pi^+$

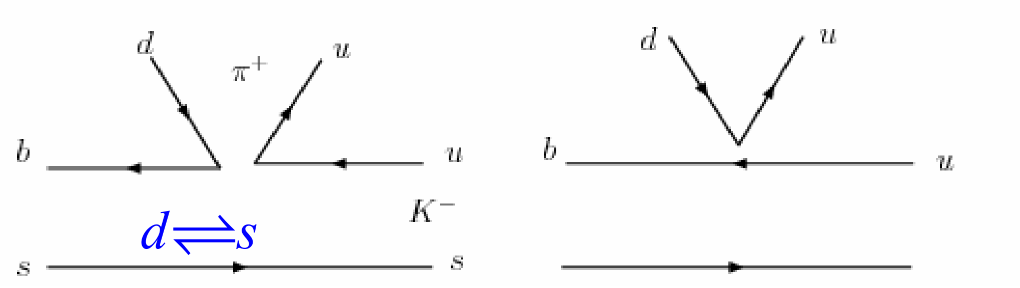
At quark level, the decay is governed by $\bar{b} \to \bar{d} u \bar{u}$

$$A\left(B_s \to K^- \pi^+\right) = -V_{td} V_{tb}^{*} \bar{P}' e^{i\bar{\delta}'_P} - V_{ud} V_{ub}^{*} \bar{T}'$$

- Tree dominance, T'bar > 0
- V_{td} and V_{ud} > 0
- CPA is positive
- From previous analysis, we see that at least the signs of P'bar, δ'_Pbar and T'bar should be the same as those in $B_d \to \pi^- K^+$
- There is a U-spin symmetry between $B_s \to K^- \pi^+$ and $B_d \to \pi^- K^+$
  If U-spin is a good symmetry, we have

$$P' = \bar{P}', \; T' = \bar{T}', \; \delta'_P = \bar{\delta}'_P$$

- strong correlation between the two decays
- constructive between P'bar and T'bar



$d \rightleftharpoons s$

$B = (5.00 \pm 1.25) 10^{-6}$

$A_{CP} = 0.39 \pm 0.17$

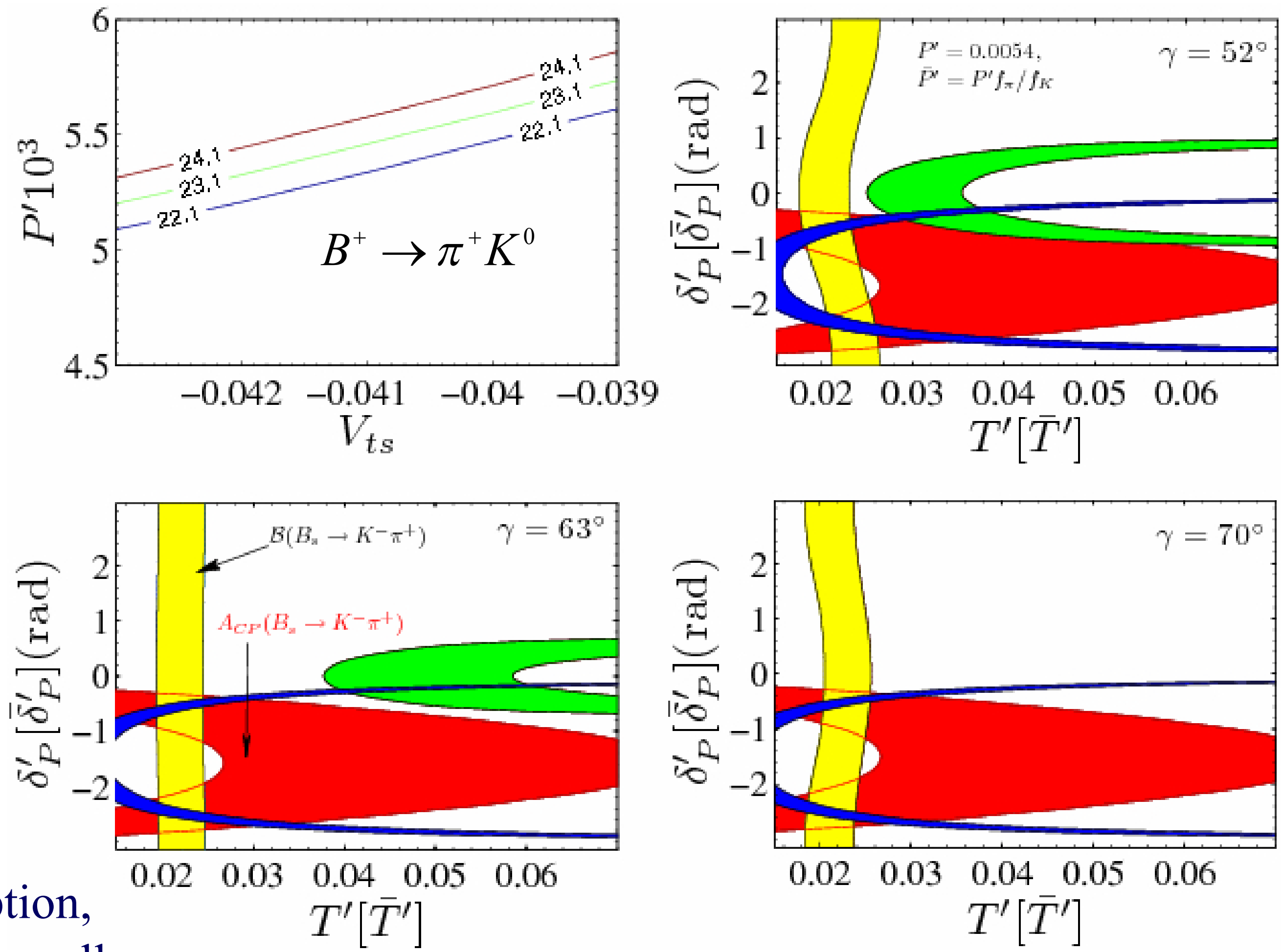
- Because $B_s \to K^- \pi^+$ is tree dominance, for simplicity, we set P'bar = $P' f_\pi / f_K$

- We see clearly we need small T'bar to fit the CDF's data

- What is the reasonable value for T'bar ?

$$\bar{T}' \approx a_1 f_\pi F_0^{B_s \to K}\left(m_\pi^2 = 0\right) \approx 1 \cdot 0.13 \cdot \begin{cases} 0.30 \\ 0.27 \\ 0.24 \end{cases} = \begin{cases} 0.039 \\ 0.035 \\ 0.031 \end{cases}$$

- Hint from U-spin assumption, angle γ is preferred to be small; otherwise, U-spin should be broken badly



$V_{ub} = 4.3 \times 10^{-3} e^{-i\gamma}$

Data with 1σ errors

Summarize the analysis:

$B=(19.4\pm 0.6)10^{-6}$
$A_{CP}=-0.097\pm 0.012$

$B=(5.00\pm 1.25)10^{-6}$
$A_{CP}=0.39\pm 0.17$

$\gamma_{fit}=\left(63^{+15}_{-12}\right)^{0}$

$B_d\to\pi^- K^+$ $B_s\to K^-\pi^+$	$\gamma\sim 52^0$	$\gamma\sim 63^0$	$\gamma\sim 70^0$
$T',\ \bar{\bar{T}}'$	$T'\sim\bar{\bar{T}}'$	$T'>\bar{\bar{T}}'$	$T'\gg\bar{\bar{T}}'$
U-spin	Not bad	bad	worse
problem	small $T'\ \&\ \bar{\bar{T}}'$	small $\bar{\bar{T}}'$	large T′ small $\bar{\bar{T}}'$

■**accuracy of few degrees in angle γ is necessary**

※ Do U-spin symmetry break badly ?
What can we learn from the U-spin relation ?

Recall the implication of U-spin

- "A theorem" : " pairs of U-spin related processes involve CP rate differences which are equal in magnitude and are opposite in sign.", **by M. Gronau, PLB492(00)**

For instance:

$$s \to b: \quad H(\Delta S=1) = V_{ts}V_{tb}^{*}O_P^s - V_{us}V_{ub}^{*}O_T^s$$

$$d \to b: \quad H(\Delta S=0) = V_{td}V_{tb}^{*}O_P^d - V_{ud}V_{ub}^{*}O_T^d$$

Consider two decays ΔS=1 and ΔS=0 are related by U-spin symmetry, s → d and d → s

The decay amplitudes could be written by

$$A(B \to f, \Delta S=1) = V_{ts}V_{tb}^{*}A_t - V_{us}V_{ub}^{*}A_u \quad \xrightarrow{\text{U-spin}} \quad A(UB \to Uf, \Delta S=0) = V_{td}V_{tb}^{*}A_t - V_{ud}V_{ub}^{*}A_u$$

$\downarrow$ CP $\qquad\qquad\qquad\qquad$ $\downarrow$ CP

$$A(\bar{B} \to \bar{f}, \Delta S=-1) = V_{ts}^{*}V_{tb}A_t - V_{us}^{*}V_{ub}A_u \quad \xrightarrow{\text{U-spin}} \quad A(U\bar{B} \to U\bar{f}, \Delta S=0) = V_{td}^{*}V_{tb}A_t - V_{ud}^{*}V_{ub}A_u$$

- Due to $\text{Im}\left(V_{ts}^{*}V_{tb}V_{us}V_{ub}^{*}\right) = -\text{Im}\left(V_{td}^{*}V_{tb}V_{ud}V_{ub}^{*}\right)$

  the rate differences are the same in magnitude but opposite in sign:

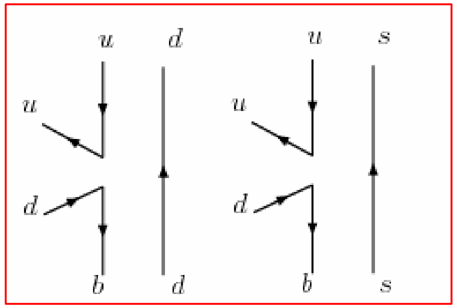
$$\left|A\left(B \to f\right)\right|^2 - \left|A\left(\bar{B} \to \bar{f}\right)\right|^2 = -\left(\left|A\left(UB \to Uf\right)\right|^2 - \left|A\left(U\bar{B} \to U\bar{f}\right)\right|^2\right) \quad \Delta\Gamma^s = -\Delta\Gamma^d$$

- Some related pairs:

$B_d \to \pi^- K^+$ *vs.* $B_s \to K^- \pi^+$

$B_d \to \pi^- \pi^+$ *vs.* $B_s \to K^- K^+$

partial U-spin:



- with the U-spin concept,

$$A_{CP}\left(B_s \to K^- \pi^+\right) = -\frac{\tau_{B_s}}{\tau_{B_d}} \frac{BR\left(B_d \to \pi^- K^+\right)}{BR\left(B_s \to K^- \pi^+\right)} A_{CP}\left(B_d \to \pi^- K^+\right)$$

By H.J. Lipkin, PLB621 (05)

With current data, one can get

$$A_{CP}\left(B_s \to \pi^+ K^-\right) = -\frac{1.466}{1.53} \frac{19.4 \times 10^{-6}}{5.0 \times 10^{-6}} \left(-0.097\right) = 0.36$$

Nothing to do with the value of angle γ

- Interestingly, the result with U-spin is consistent with CDF's result

$$A_{CP}\left(B_s \to K^- \pi^+\right) = 0.39 \pm 0.17$$

certainty ?
accident ?

- Furthermore, if we neglect the contributions from small penguin and tree annihilations, which dictate the decays $B_d \to K^+ K^-$ and $B_s \to \pi^+ \pi^-$, the BRs are $\leq 10^{-7}$

$$A\left(B_d \to \pi^- K^+\right) \approx A\left(B_s \to K^- K^+\right)$$ ➡ penguin dominance

$$A\left(B_d \to \pi^- \pi^+\right) \approx A\left(B_s \to K^- \pi^+\right)$$ ➡ tree dominance

- Accordingly, we get

$$A_{CP}\left(B_d \to K^+ \pi^-\right) \approx A_{CP}\left(B_s \to K^+ K^-\right)$$

$$A_{CP}\left(B_d \to \pi^+ \pi^-\right) \approx A_{CP}\left(B_s \to \pi^+ K^-\right)$$

➡ $$A_{CP}\left(B_d \to \pi^+ \pi^-\right) \approx A_{CP}\left(B_s \to \pi^+ K^-\right) \approx 0.39$$

$$A_{CP}\left(B_d \to \pi^- \pi^+\right)_{Avg} = 0.38 \pm 0.07$$

- Deduction :

$$BR\left(B_s \to K^- K^+\right) \approx 20 \times 10^{-6};$$
$$A_{CP}\left(B_s \to K^- K^+\right) \approx -10\%$$

$$BR\left(B_s \to K^- K^+\right)_{\exp} = (24 \pm 4.8) \times 10^{-6}$$
$$A_{CP} = --$$

- One more shot at the rate difference ratio

$$R \equiv \frac{\Gamma\left(\bar{B}_d \to \pi^+ K^-\right) - \Gamma\left(B_d \to \pi^- K^+\right)}{\Gamma\left(B_s \to K^- \pi^+\right) - \Gamma\left(\bar{B}_s \to K^+ \pi^-\right)} \xrightarrow{\text{U-spin}} 1$$

M. Gronau, PLB492(00); H.J. Lipkin, PLB621 (05)

with the parametrizations for decay amplitudes

$$A\left(B_d \to \pi^- K^+\right) = -V_{ts} V_{tb}^* P' e^{i\delta'_P} - V_{us} V_{ub}^* T'$$

$$A\left(B_s \to K^- \pi^+\right) = -V_{td} V_{tb}^* \bar{P}' e^{i\bar{\delta}'_P} - V_{ud} V_{ub}^* \bar{T}'$$

$$\mathrm{Im}\left(V_{ts}^* V_{tb} V_{us} V_{ub}^*\right) = -\mathrm{Im}\left(V_{td}^* V_{tb} V_{ud} V_{ub}^*\right)$$

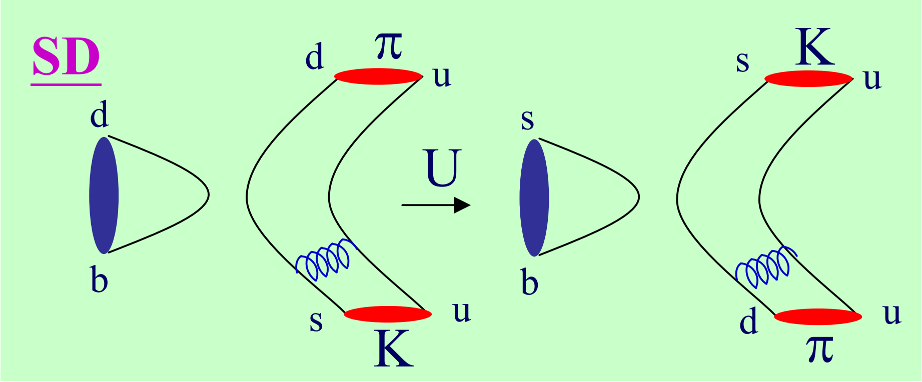
$$R \equiv \frac{T' P' \sin\delta'_P}{\bar{T}' \bar{P}' \sin\bar{\delta}'_P} = \left(\frac{T'}{\bar{T}'}\right)\left(\frac{P' \sin\delta'_P}{\bar{P}' \sin\bar{\delta}'_P}\right)$$

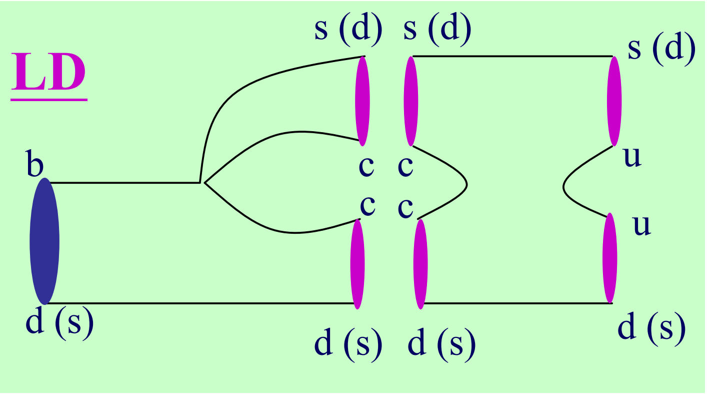
absorptive parts of decays

- The final states in $B_d \to \pi^- K^+$ and $B_s \to K^- \pi^+$ are charge conjugate states

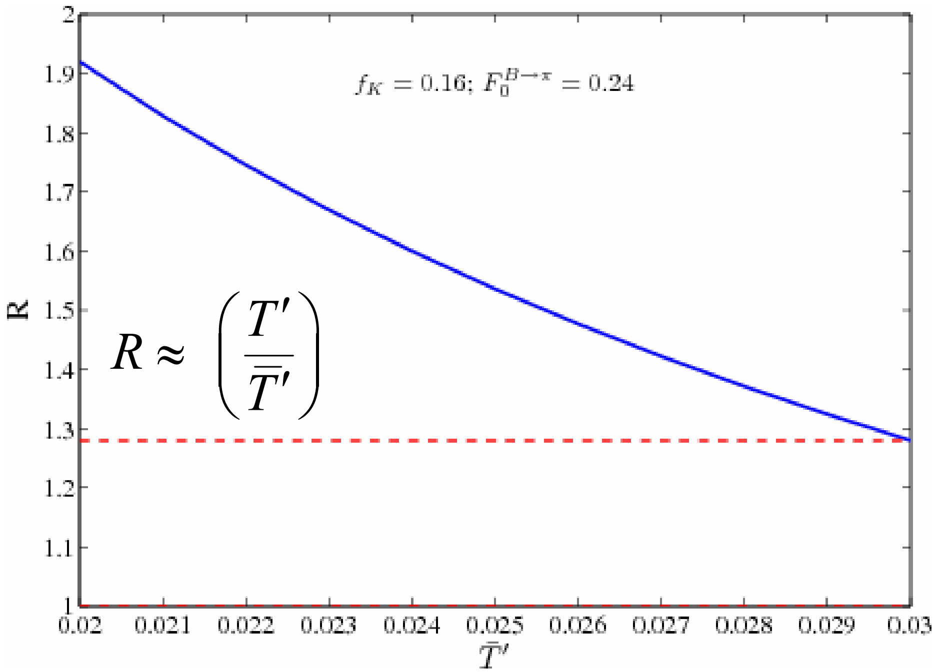
H.J. Lipkin, PLB621 (05)

- Suppose the absorptive parts, generated by short- and/or long-distance effects, should be the same when $m_{Bs} = m_{Bd}$





- As a result, →



- The CDF's result is

$$R \equiv 0.84 \pm 0.42 \pm 0.15$$
$$= 0.84 \pm 0.44$$

- Based on the analysis, we learn
  - by the BR, T'bar for $B_s \to K^- \pi^+$ should be smaller than usual expectation
  - However, the value of T' for $B_d \to \pi^- K^+$ depends on the angle γ
  - Could the result of U-spin be a good sign? It depends on γ. (small γ is preferred)
  - By the current value of R by CDF, the prediction of U-spin is not bad
  - This indicates T' and T'bar should be close to each other and smaller than the ordinary values.

It'll be interesting, if R<1

-- A motivation to introduce New Physics --

W_R effects on B decays

- Usually, people think that new physics will appear in the loop, in which SM contributions are small due to
  a. loop suppression
  b. GIM

- Therefore, rare decays are the good candidates to search for the new physics

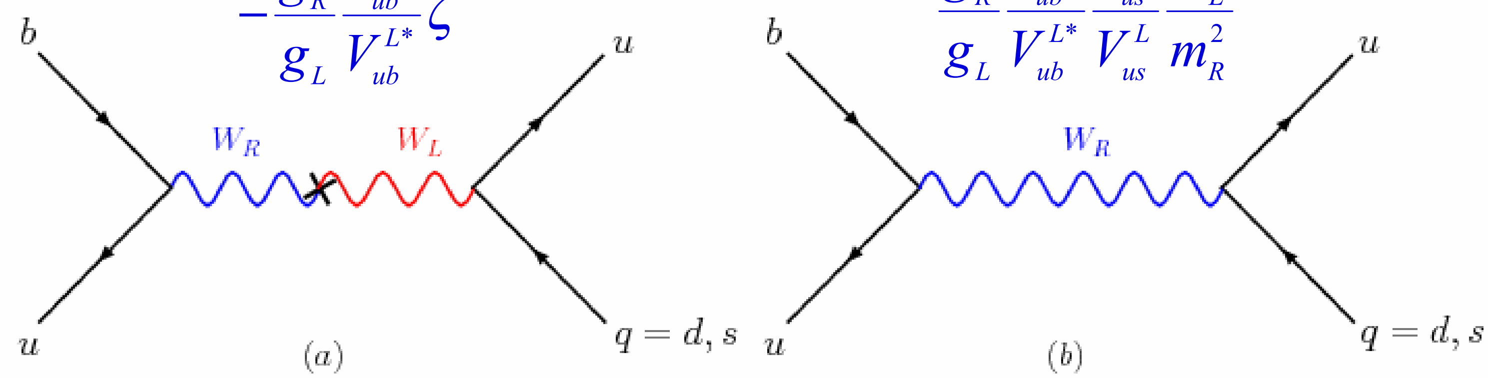
- However, rare decays could mean the tree processes in the SM

  For instance, the smallest CKM matrix element is $V_{ub} \sim O(1.5\,\lambda^4)$ for $b \to u$, however, the vertex for $b \to u$ by new physics could be $O(\lambda)$ but suppressed by the heavy mass of new particle, M

- The situation in the non-manifest left-right model:

$$SU(2)_L \times SU(2)_R \times U(1)_X$$

$$-\frac{g_R}{g_L}\frac{V_{ub}^{R*}}{V_{ub}^{L*}}\zeta \qquad \frac{g_R}{g_L}\frac{V_{ub}^{R*}}{V_{ub}^{L*}}\frac{V_{us}^{R}}{V_{us}^{L}}\frac{m_L^2}{m_R^2}$$



■ It has been known that for satisfying K-K mixing

$$V^R = \begin{pmatrix} O(\lambda^3) & \cos\theta & \sin\theta \\ O(\lambda^3) & -\sin\theta & \cos\theta \\ O(1) & O(\lambda^3) & O(\lambda^3) \end{pmatrix}$$

F.I. Olness & M.E. Ebel, PRD30 (84)

■ The contributions of L-R model to tree

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

$$T'_{LR} = \left(1 - \frac{g_R}{g_L} \frac{V_{ub}^{R*}}{V_{ub}^{*}} \zeta - \left(\frac{g_R}{g_L} \right)^2 \frac{V_{ub}^{R*}}{V_{ub}^{*}} \frac{V_{us}^{R*}}{V_{us}^{*}} \frac{m_W^2}{m_R^2} \right) f_\pi F_0^{B\to\pi}$$

$$\frac{0.1}{4.2 \cdot 10^{-3}} 5\times 10^{-3} \qquad \frac{0.1}{4.3\cdot 10^{-3}} \frac{1}{0.22} \left(\frac{80}{1000} \right)^2$$

$$\zeta \le 5\times 10^{-3}$$

$$m_W^2 / m_R^2 \sim \left(\frac{80}{1000} \right)^2 = 6.4\times 10^{-3}$$

$$b \to d u \bar{u}$$

$$\bar{T}'_{LR} = \left(1 - \frac{g_R}{g_L} \frac{V_{ub}^{R*}}{V_{ub}^{*}} \zeta - \underbrace{\left(\frac{g_R}{g_L} \right)^2 \frac{V_{ub}^{R*}}{V_{ub}^{*}} \frac{V_{ud}^{R*}}{V_{ud}^{*}} \frac{m_W^2}{m_R^2}}_{\text{negligible}} \right) f_\pi F_0^{B_s\to K}$$

Summary

- By CDF's results on BR and CPA of $B_s \to K^- \pi$,
  we find that smaller tree is needed to fit the data
- If U-spin symmetry is broken mildly, small angle γ is preferred;
  In addition, we have to face the problem of small trees, T' and T'bar;
  a good chance to search for new physics
- We point out that non-manifest left-right model could be the
  good candidate of new physics