Large electroweak penguin contribution in $B \to K\pi$ decays

Tadashi Yoshikawa (Nagoya)

This talk is based on Phys.Rev.**D68**, 054023 (2003).

at Super B Factory Workshop in Hawaii (19-22 Jan. 2004)

HINT of NEW PHYSICS ?

- $B \longrightarrow K\pi$ Anomaly (T.Y., Gronau and Rosner, Buras and Fleischer $\cdots\cdots$)

Experimental data do not satisfy these relations among the branching ratios.

$$\frac{\bar{B}^{+-}}{2\bar{B}^{00}} \neq \frac{2\bar{B}^{+0}}{\bar{B}^{0+}},$$

$$\frac{2\bar{B}^{+0}}{\bar{B}^{0+}} - \frac{\tau^{+}}{\tau^{0}}\frac{\bar{B}^{+-}}{\bar{B}^{0+}} + \frac{\tau^{+}}{\tau^{0}}\frac{2\bar{B}^{00}}{\bar{B}^{0+}} - 1 \neq 0.$$

$$\Downarrow$$

To explain the differences, Large EW penguin and the Large strong phase differences are needed.

$$||$$

Discrepancy from the SM !!

Evidence of New Physics ???

$B \longrightarrow K\pi$ decays

The decay amplitudes of $B \longrightarrow K\pi$ are

$$A^{0+} \equiv A(B^+ \to K^0\pi^+) = \left[AV_{ub}^* V_{us} + \sum_{i=u,c,t} (P_i + EP_i - \frac{1}{3}P_{EWi}^C + \frac{2}{3}EP_{EWi}^C)V_{ib}^* V_{is} \right],$$

$$A^{00} \equiv A(B^0 \to K^0\pi^0) = -\frac{1}{\sqrt{2}} \left[CV_{ub}^* V_{us} - \sum_{i=u,c,t} (P_i + EP_i - P_{EWi} - \frac{1}{3}P_{EWi}^C)V_{ib}^* V_{is} \right],$$

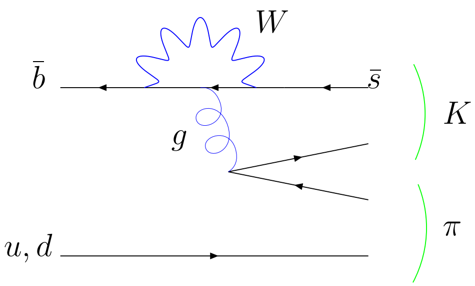
$$A^{+-} \equiv A(B^0 \to K^+\pi^-) = - \left[TV_{ub}^* V_{us} + \sum_{i=u,c,t} (P_i + EP_i + \frac{2}{3}P_{EWi}^C - \frac{1}{3}EP_{EWi}^C)V_{ib}^* V_{is} \right],$$

$$\begin{aligned} A^{+0} &\equiv A(B^+ \to K^+\pi^0) \\ &= -\frac{1}{\sqrt{2}} \left[(T + C + A)V_{ub}^* V_{us} + \sum_{i=u,c,t} (P_i + EP_i + P_{EWi} + \frac{2}{3}P_{EWi}^C + \frac{2}{3}EP_{EWi}^C)V_{ib}^* V_{is} \right]. \end{aligned}$$

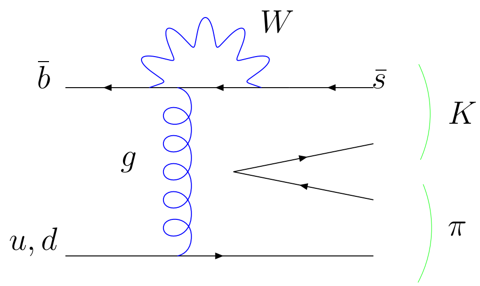
where

- T Color favored Tree
- C Color suppressed Tree
- A Annihilation
- P_i QCD Penguin — EP_i QCD Penguin Exchange (annihilation)
- P_{EW} Color favored EW Penguin
- P_{EW}^C Color suppressed EW Penguin — EP_{EW}^C Color suppressed EW Penguin Exchange (annihilation)

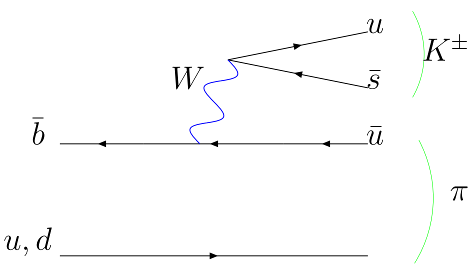
Diagrams



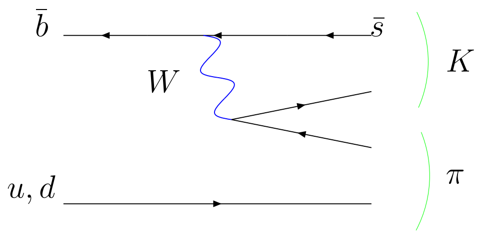
P



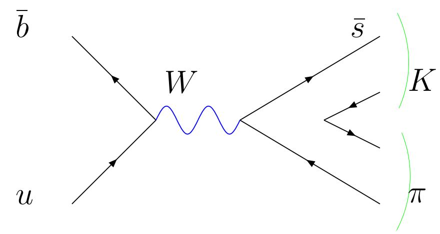
EP



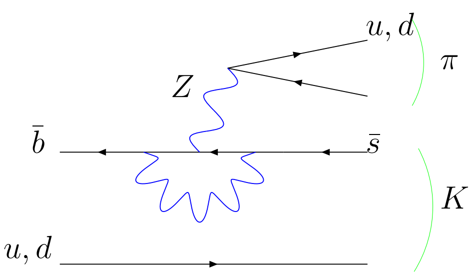
T



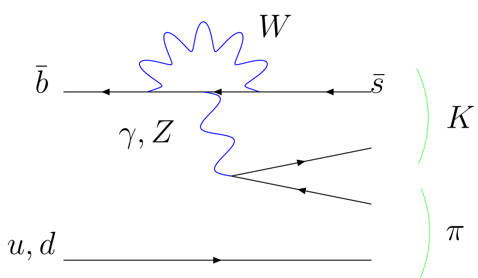
C



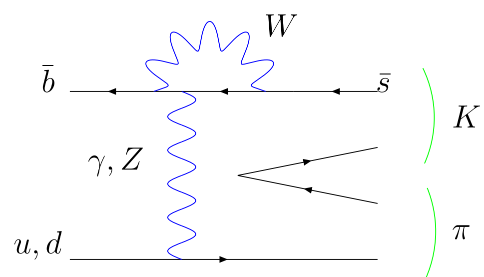
A



P_{EW}



P^C_{EW}



EP^C_{EW}

Reparametrization

The decay amplitudes of $B \longrightarrow K\pi$ after removing the term of $V_{cb}V_{cs}$ are

$$A^{0+} = \left[(A + P_u + EP_u - P_c - EP_c)V_{ub}^{*}V_{us} + (P_t + EP_t - P_c - EP_c - \frac{1}{3}P_{EW}^{C} + \frac{2}{3}EP_{EW}^{C})V_{tb}^{*}V_{ts}\right],$$

$$A^{00} = -\frac{1}{\sqrt{2}}\left[(C - P_u - EP_u + P_c + EP_c)V_{ub}^{*}V_{us} - (P_t + EP_t - P_c - EP_c - P_{EW} - \frac{1}{3}EP_{EW}^{C})V_{tb}^{*}V_{ts}\right],$$

$$A^{+-} = -\left[(T + P_u + EP_u - P_c - EP_c)V_{ub}^{*}V_{us} + (P_t + EP_t - P_c - EP_c + \frac{2}{3}P_{EW}^{C} - \frac{1}{3}EP_{EW}^{C})V_{tb}^{*}V_{ts}\right],$$

$$A^{+0} = -\frac{1}{\sqrt{2}}\left[(T + C + A + P_u + EP_u - P_c - EP_c)V_{ub}^{*}V_{us} + (P_t + EP_t - P_c - EP_c + P_{EW} + \frac{2}{3}P_{EW}^{C} + \frac{2}{3}EP_{EW}^{C})V_{tb}^{*}V_{ts}\right].$$

we redefine the each terms as following

$$T + P_u + EP_u - P_c - EP_c \longrightarrow T,$$ Color favored Tree

$$C - P_u - EP_u + P_c + EP_c \longrightarrow C,$$ Color suppressed Tree

$$A + P_u + EP_u - P_c - EP_c \longrightarrow A,$$ Annihilation

$$P_t + EP_t - P_c - EP_c - \frac{1}{3}P_{EW}^{C} + \frac{2}{3}EP_{EW}^{C} \longrightarrow P,$$ QCD Penguin

$$P_{EW} + EP_{EW}^{C} \longrightarrow P_{EW},$$ Color favored EW Penguin

$$P_{EW}^{C} - EP_{EW}^{C} \longrightarrow P_{EW}^{C}.$$ Color suppressed EW Penguin

Diagram decomposition

The decay amplitudes of $B \longrightarrow K\pi$ decays are

$$A(B \longrightarrow K^X \pi^Y) \equiv A^{XY}$$

$$\begin{aligned}
A^{0+} &= \left[P V_{tb}^* V_{ts} + A V_{ub}^* V_{us}\right] , \\
\sqrt{2} A^{00} &= \left[(P - P_{EW}) V_{tb}^* V_{ts} - C V_{ub}^* V_{us}\right] , \\
A^{+-} &= -\left[(P + P_{EW}^C) V_{tb}^* V_{ts} + T V_{ub}^* V_{us}\right] , \\
\sqrt{2} A^{+0} &= -\left[(P + P_{EW} + P_{EW}^C) V_{tb}^* V_{ts} + (T + C + A) V_{ub}^* V_{us}\right] .
\end{aligned}$$

where P : QCD Penguin, P_{EW}: color favored EW penguin, P_{EW}^C: color suppressed EW penguin, T: tree, C: color suppressed tree, A : annihilation.

By this diagram decomposition, one can easily find the isospin relation among the amplitudes,

$$\sqrt{2} A^{+0} + A^{0+} = \sqrt{2} A^{00} + A^{+-} .$$

They are rewritten as follows:

$$
\begin{aligned}
A^{0+} &= -P|V_{tb}^*V_{ts}|\left[1 - r_A e^{i\delta^A} e^{i\phi_3}\right], \\
\sqrt{2}A^{00} &= -P|V_{tb}^*V_{ts}|\left[1 - r_{EW} e^{i\delta^{EW}} + r_C e^{i\delta^C} e^{i\phi_3}\right], \\
A^{+-} &= P|V_{tb}^*V_{ts}|\left[1 - r_T e^{i\delta^T} e^{i\phi_3} + r_{EW}^C e^{i\delta^{EWC}}\right], \\
\sqrt{2}A^{+0} &= P|V_{tb}^*V_{ts}|\left[1 + r_{EW} e^{i\delta^{EW}} + r_{EW}^C e^{i\delta^{EWC}} - (r_T e^{i\delta^T} + r_C e^{i\delta^C} + r_A e^{i\delta^A}) e^{i\phi_3}\right],
\end{aligned}
$$

where ϕ_3 is the weak phase of $V_{ub}^*V_{us}$, δ^X is the strong phase difference and

$$
\begin{aligned}
r_T = \frac{|TV_{ub}^*V_{us}|}{|PV_{tb}^*V_{ts}|}, \quad r_{EW} = \frac{|P_{EW}|}{|P|}, \quad &\sim \quad O(0.1) \\
r_C = \frac{|CV_{ub}^*V_{us}|}{|PV_{tb}^*V_{ts}|}, \quad r_{EW}^C = \frac{|P_{EW}^C|}{|P|} \quad &\sim \quad O(0.01) \\
r_A = \frac{|AV_{ub}^*V_{us}|}{|PV_{tb}^*V_{ts}|}.&
\end{aligned}
$$

Hierarchy Assumption

$$1 > r_T, r_{EW} > r_C, r^C_{EW} > r_A$$

- $r_T \equiv \frac{|TV^*_{ub}V_{us}|}{|PV^*_{tb}V_{ts}|} = \frac{1}{0.1}\lambda R_b \sim 0.2$

- $r_{EW} \equiv \frac{|P_{EW}|}{|P|} \sim 0.1$

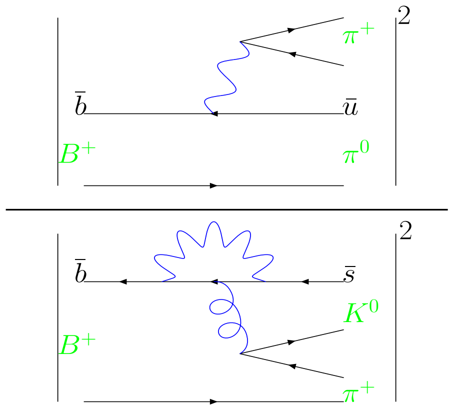
- $r_C \equiv \frac{|CV^*_{ub}V_{us}|}{|PV^*_{tb}V_{ts}|} = 0.1 r_T \sim 0.02$

- $r^C_{EW} \equiv \frac{|P^C_{EW}|}{|P|} \sim 0.1 r_{EW} \sim 0.01$

- $r_A \equiv \frac{|AV^*_{ub}V_{us}|}{|PV^*_{tb}V_{ts}|} = r_T \frac{A}{T} \sim r_T \frac{f_B}{M_B} \sim 0.005$

Rough estimation of r_T

by the factorization assumption,



$$\propto \frac{|T|^2}{|P|^2}$$

Extracting r_T from experimental data for $B \to \pi^+\pi^0$ and $B \to K^0\pi^+$.

$$\frac{2Br(B \to \pi^+\pi^0)}{Br(B \to K^0\pi^+)} \sim \frac{f_\pi^2 |T+C|^2 |V_{ub}^* V_{ud}|^2}{f_K^2 \ \ |P|^2 \ \ |V_{tb}^* V_{ts}|^2} \sim \frac{r_T^2}{1.5\lambda^2}$$

$$\|$$

(EXP.) $$\frac{2Br(B \to \pi^+\pi^0)}{Br(B \to K^0\pi^+)} = \frac{2 \times 5.3 \pm 0.8}{21.8 \pm 1.4} = 0.49 \pm 0.08$$

$$\Downarrow$$

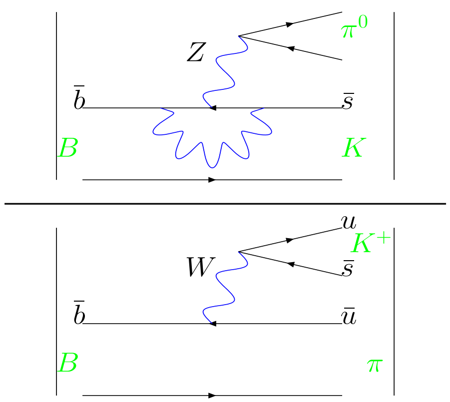
$$r_T \equiv \frac{|TV_{ub}^* V_{us}|}{|PV_{tb}^* V_{ts}|} = \frac{|T|}{|P|}\lambda^2 R_b \sim 0.2(\pm 0.017)$$

Rough estimation of r_{EW}

$$r_{EW} = \frac{|P_{EW}|}{|P_{QCD}|}$$

$$= \frac{|P_{EW} V_{tb}^* V_{ts}|}{|T V_{ub}^* V_{us}|} \frac{|T V_{ub}^* V_{us}|}{|P_{QCD} V_{tb}^* V_{ts}|} = \frac{|P_{EW} V_{tb}^* V_{ts}|}{|T V_{ub}^* V_{us}|} \, r_T$$

where



$$= \frac{|P_{EW} V_{tb}^* V_{ts}|}{|T V_{ub}^* V_{us}|} \simeq \frac{3}{2} \frac{|V_{cb}|}{\lambda |V_{ub}|} \left[\frac{C_9 + C_{10}}{C_1 + C_2} \right]$$

$$= 0.69$$

($\frac{P_{EW}}{T} \frac{|V_{tb}^* V_{ts}|}{|V_{ub}^* V_{us}|} = q e^{i\omega}$ Neubert and Rosner, Buras and Fleischer et.al)

Then

$$r_{EW} = 0.69 \times 0.2 = 0.14$$

Hierarchy Assumption

$$1 > r_T, r_{EW} > r_C, r_{EW}^C > r_A$$

- $r_T \equiv \frac{|TV_{ub}^* V_{us}|}{|PV_{tb}^* V_{ts}|} = \frac{1}{0.1} \lambda R_b \sim 0.2$

- $r_{EW} \equiv \frac{|P_{EW}|}{|P|} \sim 0.1$

- $r_C \equiv \frac{|CV_{ub}^* V_{us}|}{|PV_{tb}^* V_{ts}|} = 0.1 r_T \sim 0.02$

- $r_{EW}^C \equiv \frac{|P_{EW}^C|}{|P|} \sim 0.1 r_{EW} \sim 0.01$

- $r_A \equiv \frac{|AV_{ub}^* V_{us}|}{|PV_{tb}^* V_{ts}|} = r_T \frac{A}{T} \sim r_T \frac{f_B}{M_B} \sim 0.005$

The estimations by pQCD (Mishima)

(QCD) Factorization	VS	pQCD

- $r_T \equiv \frac{|TV_{ub}^* V_{us}|}{|PV_{tb}^* V_{ts}|} = \frac{1}{0.1} \lambda R_b \sim 0.2$
- $r_T = 0.21$
- $r_{EW} \equiv \frac{|P_{EW}|}{|P|} \sim 0.14$
- $r_{EW} = 0.14$
- $r_C \equiv \frac{|CV_{ub}^* V_{us}|}{|PV_{tb}^* V_{ts}|} = 0.1 r_T \sim 0.02$
- $r_C = 0.018$
- $r_{EW}^C \equiv \frac{|P_{EW}^C|}{|P|} \sim 0.1 r_{EW} \sim 0.01$
- $r_{EW}^C = 0.012$
- $r_A \equiv \frac{|AV_{ub}^* V_{us}|}{|PV_{tb}^* V_{ts}|} = r_T \frac{A}{T} \sim r_T \frac{f_B}{M_B} \sim 0.005$
- $r_A = 0.0048$

We start to consider about $B \to K\pi$ from these amplitudes and the hierarchy.

$$
\begin{aligned}
A^{0+} &= -P|V_{tb}^* V_{ts}| \left[1 - r_A e^{i\delta^A} e^{i\phi_3} \right], \\
\sqrt{2}A^{00} &= -P|V_{tb}^* V_{ts}| \left[1 - r_{EW} e^{i\delta^{EW}} + r_C e^{i\delta^C} e^{i\phi_3} \right], \\
A^{+-} &= P|V_{tb}^* V_{ts}| \left[1 - r_T e^{i\delta^T} e^{i\phi_3} + r_{EW}^C e^{i\delta^{EWC}} \right], \\
\sqrt{2}A^{+0} &= P|V_{tb}^* V_{ts}| \left[1 + r_{EW} e^{i\delta^{EW}} + r_{EW}^C e^{i\delta^{EWC}} - (r_T e^{i\delta^T} + r_C e^{i\delta^C} + r_A e^{i\delta^A}) e^{i\phi_3} \right],
\end{aligned}
$$

where δ^X is the strong phase difference between each diagram and QCD penguin. And the each parameters r are

$$
r_T = \frac{|T V_{ub}^* V_{us}|}{|P V_{tb}^* V_{ts}|}, \quad r_{EW} = \frac{|P_{EW}|}{|P|}, \quad \sim \quad O(0.1)
$$

$$
r_C = \frac{|C V_{ub}^* V_{us}|}{|P V_{tb}^* V_{ts}|}, \quad r_{EW}^C = \frac{|P_{EW}^C|}{|P|} \quad \sim \quad O(0.01)
$$

$$
r_A = \frac{|A V_{ub}^* V_{us}|}{|P V_{tb}^* V_{ts}|}.
$$

Branching Ratios

assumption of the hierarchy of the ratios : $1 > r_T, r_{EW} > r_C, r_{EW}^C > r_A$.

neglect the r^2 terms including r_C, r_{EW}^C and r_A. (smaller terms than $O(0.01)$)

Then, the branching ratios are $B = |P|^2 |V_{tb}^* V_{ts}|^2 (1 + O(0.1) + O(0.01))$

$$\bar{B}^{+-} \propto |P|^2 |V_{tb}^* V_{ts}|^2 \left[1 - 2 r_T \cos\delta^T \cos\phi_3 + r_T^2 + 2 r_{EW}^C \cos\delta^{EWC} \right],$$

$$2\bar{B}^{00} \propto |P|^2 |V_{tb}^* V_{ts}|^2 \left[1 - 2 r_{EW} \cos\delta^{EW} + r_{EW}^2 + 2 r_C \cos\delta^C \cos\phi_3 \right],$$

$$\begin{aligned} 2\bar{B}^{+0} \propto |P|^2 |V_{tb}^* V_{ts}|^2 \Big[& 1 + 2 r_{EW} \cos\delta^{EW} - 2 r_T \cos\delta^T \cos\phi_3 + r_{EW}^2 + r_T^2 \\ & + 2 r_{EW}^C \cos\delta^{EWC} - (2 r_C \cos\delta^C + 2 r_A \cos\delta^A) \cos\phi_3 \\ & - 2 r_{EW} r_T \cos(\delta^{EW} - \delta^T) \cos\phi_3 \Big]. \end{aligned}$$

$$\bar{B}^{0+} \propto |P|^2 |V_{tb}^* V_{ts}|^2 \left[1 - 2 r_A \cos\delta^A \cos\phi_3 \right],$$

There are several relations up to $O(r)$ among the branchings,

which are weakly relating to a relation among the decay amplitudes, $A^{+-}+\sqrt{2}A^{00}=\sqrt{2}A^{+0}+A^{0+}$.

As an example, see the following two ratios,

$$R_n \equiv \frac{\bar{B}^{+-}}{2\bar{B}^{00}} = \Big\{1+2r_{EW}\cos\delta^{EW}+2r^{C}_{EW}\cos\delta^{EWC} -2(r_T\cos\delta^{T}+r_C\cos\delta^{C})\cos\phi_3+r_T^2\Big\} -r_{EW}^2+4r_{EW}^2\cos^2\delta^{EW} \Leftarrow,$$

$$R_c \equiv \frac{2\bar{B}^{+0}}{\bar{B}^{0+}} = \Big\{1+2r_{EW}\cos\delta^{EW}+2r^{C}_{EW}\cos\delta^{EWC} -2(r_T\cos\delta^{T}+r_C\cos\delta^{C})\cos\phi_3+r_T^2\Big\} +r_{EW}^2-2r_{EW}r_T\cos(\delta^{EW}-\delta^{T})\cos\phi_3 \Leftarrow,$$

The terms in { } are same and the difference comes from r^2 term.

$\Downarrow$

Equal or not ?

The experimental data

	CLEO	Belle	BaBar	Average
$Br(B^0 \to K^+\pi^-) \times 10^6$	$18.0^{+2.3+1.2}_{-2.1-0.9}$	$18.5 \pm 1.0 \pm 0.7$	$17.9 \pm 0.9 \pm 0.7$	18.2 ± 0.8
$Br(B^0 \to K^0\pi^0) \times 10^6$	$12.8\ ^{+4.0+1.7}_{-3.3-1.4}$	$12.6 \pm 2.4 \pm 1.4$	$11.4 \pm 1.7 \pm 0.8$	11.9 ± 1.5
$Br(B^+ \to K^+\pi^0) \times 10^6$	$12.9^{+2.4+1.2}_{-2.2-1.1}$	$12.8 \pm 1.4\ ^{+1.4}_{-1.0}$	$12.8\ ^{+1.2}_{-1.1} \pm 1.0$	12.8 ± 1.1
$Br(B^+ \to K^0\pi^+) \times 10^6$	$18.8\ ^{+3.7+2.1}_{-3.3-1.8}$	$22.0 \pm 1.9 \pm 1.1$	$22.3 \pm 1.9 \pm 1.1$	21.8 ± 1.4

The ratios among the branchings are

$$\frac{\bar{B}^{+-}}{2\bar{B}^{00}} = 0.76 \pm 0.10, \qquad \frac{2\bar{B}^{+0}}{\bar{B}^{0+}} = 1.17 \pm 0.13,$$

$$\frac{\tau^+}{\tau^0}\frac{\bar{B}^{+-}}{\bar{B}^{0+}} = 0.90 \pm 0.07, \qquad \frac{\tau^0}{\tau^+}\frac{\bar{B}^{+0}}{\bar{B}^{00}} = 1.00 \pm 0.16,$$

$$\frac{\tau^+}{\tau^0}\frac{2\bar{B}^{00}}{\bar{B}^{0+}} = 1.18 \pm 0.17, \qquad \frac{\tau^0}{\tau^+}\frac{2\bar{B}^{+0}}{\bar{B}^{+-}} = 1.30 \pm 0.13.$$

Experimentally, $\frac{\bar{B}^{+-}}{2\bar{B}^{00}} \neq \frac{2\bar{B}^{+0}}{\bar{B}^{0+}}$.

$$\frac{\bar{B}^{+-}}{2\bar{B}^{00}} = \Big\{1 + 2r_{EW}\cos\delta^{EW} + 2r_{EW}^{C}\cos\delta^{EWC} - 2(r_T\cos\delta^T + r_C\cos\delta^C)\cos\phi_3 + r_T^2\Big\}$$
$$-r_{EW}^2 + 4r_{EW}^2\cos^2\delta^{EW} \Leftarrow,$$

$$\frac{2\bar{B}^{+0}}{\bar{B}^{0+}} = \Big\{1 + 2r_{EW}\cos\delta^{EW} + 2r_{EW}^{C}\cos\delta^{EWC} - 2(r_T\cos\delta^T + r_C\cos\delta^C)\cos\phi_3 + r_T^2\Big\}$$
$$+r_{EW}^2 - 2r_{EW}r_T\cos(\delta^{EW} - \delta^T)\cos\phi_3 \Leftarrow,$$

$$\frac{\tau^+}{\tau^0}\frac{\bar{B}^{+-}}{\bar{B}^{0+}} = 1 + 2r_{EW}^{C}\cos\delta^{EWC} - 2(r_T\cos\delta^T - r_A\cos\delta^A)\cos\phi_3 + r_T^2,$$

$$\frac{\tau^0}{\tau^+}\frac{\bar{B}^{+0}}{\bar{B}^{00}} = 1 + 2r_{EW}^{C}\cos\delta^{EWC} - 2(r_T\cos\delta^T + 2r_C\cos\delta^C + r_A\cos\delta^A)\cos\phi_3 + r_T^2$$
$$+ 4r_{EW}\cos\delta^{EW} - 2r_{EW}r_T\cos(\delta^{EW} - \delta^T)\cos\phi_3 + 4r_{EW}^2\cos^2\delta^{EW},$$

$$\frac{\tau^+}{\tau^0}\frac{2\bar{B}^{00}}{\bar{B}^{0+}} = 1 - 2r_{EW}\cos\delta^{EW} - 2(r_C\cos\delta^C + r_A\cos\delta^A)\cos\phi_3 + r_{EW}^2.$$

$$\frac{\tau^0}{\tau^+}\frac{2\bar{B}^{+0}}{\bar{B}^{+-}} = 1 + 2r_{EW}\cos\delta^{EW} - 2(r_C\cos\delta^C + r_A\cos\delta^A)\cos\phi_3 + r_{EW}^2$$
$$- 2r_{EW}r_T\cos(\delta^{EW} - \delta^T)\cos\phi_3 + 4r_T^2\cos^2\delta^T\cos^2\phi_3.$$

We have a few relations up to $O(r)$!!

$$\frac{\bar{B}^{+-}}{2\bar{B}^{00}} = \frac{2\bar{B}^{+0}}{\bar{B}^{0+}},$$

$$\frac{2\bar{B}^{+0}}{\bar{B}^{0+}} - \frac{\tau^+}{\tau^0}\frac{\bar{B}^{+-}}{\bar{B}^{0+}} + \frac{\tau^+}{\tau^0}\frac{2\bar{B}^{00}}{\bar{B}^{0+}} - 1 = 0.$$

$\Downarrow$

But, the experimental data do not satisfy these relations (sum rules) !!

The discrepancy come from $r_{EW}^2 \sim O(0.01)$ terms. $\quad$ ($r_{EW}^2 \sim 0.14^2 = 0.02$)

But The differences are about 0.4,

$$\frac{2\bar{B}^{+0}}{\bar{B}^{0+}} - \frac{\bar{B}^{+-}}{2\bar{B}^{00}} = 2r_{EW}^2 - 2r_{EW}r_T\cos(\delta^{EW} - \delta^T)\cos\phi_3 - 4r_{EW}^2\cos^2\delta^{EW} = 0.41 \pm 0.16,$$

$$\frac{2\bar{B}^{+0}}{\bar{B}^{0+}} - \frac{\tau^+}{\tau^0}\frac{\bar{B}^{+-}}{\bar{B}^{0+}} + \frac{\tau^+}{\tau^0}\frac{2\bar{B}^{00}}{\bar{B}^{0+}} - 1 = 2r_{EW}^2 - 2r_{EW}r_T\cos(\delta^{EW} - \delta^T)\cos\phi_3 = 0.45 \pm 0.21,$$

To explain the ratios from experimental data, we may need

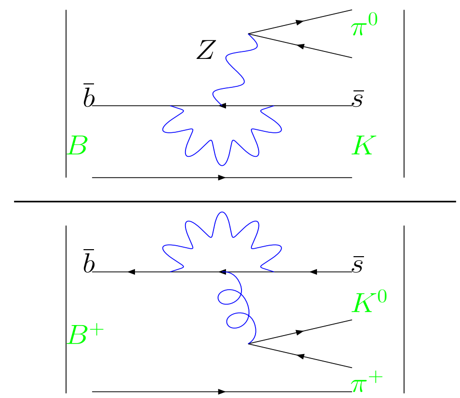
quite Large r_{EW}

$\Downarrow$

An evidence of NEW PHYSICS ????

How large is r_{EW} to expain the experimental results ?

$$r_{EW} = \frac{|P_{EW}|}{|P|} =$$



$\Rightarrow$ Z Penguin contribution

Relations (Sum rules) are

$$\frac{2\bar{B}^{+0}}{\bar{B}^{0+}} - \frac{\bar{B}^{+-}}{2\bar{B}^{00}} = 2r_{EW}^2 - 2r_{EW}r_T\cos(\delta^{EW} - \delta^T)\cos\phi_3 - 4r_{EW}^2\cos^2\delta^{EW} = 0.41 \pm 0.16,$$

$$\frac{2\bar{B}^{+0}}{\bar{B}^{0+}} - \frac{\tau^+}{\tau^0}\frac{\bar{B}^{+-}}{\bar{B}^{0+}} + \frac{\tau^+}{\tau^0}\frac{2\bar{B}^{00}}{\bar{B}^{0+}} - 1 = 2r_{EW}^2 - 2r_{EW}r_T\cos(\delta^{EW} - \delta^T)\cos\phi_3 = 0.45 \pm 0.21,$$

Adding the other relation as following

$$\frac{\bar{B}^{+-}}{2\bar{B}^{00}} - \frac{\tau^0}{\tau^+}\frac{\bar{B}^{+0}}{\bar{B}^{00}} + \frac{\tau^+}{\tau^0}\frac{2\bar{B}^{00}}{\bar{B}^{0+}} - 1$$
$$= -4r_{EW}\cos\delta^{EW} + 2r_{EW}r_T\cos(\delta^{EW} - \delta^T)\cos\phi_3 = -0.05 \pm 0.21,$$

$$\longrightarrow Im(P_{EW}) > Re(P_{EW})$$

we can solve about r_{EW} from the 3 Eqs. and if we can respect the central values, the solutions are

$$(r_{EW},\ \cos\delta^{EW},\ r_T\cos(\delta^{EW} - \delta^T)\cos\phi_3)$$
$$= (0.63, 0.16, 0.28).$$

But this r_{EW} is too large because r_{EW} should be about 0.14.

From experimental data with the error, we can find the allowed region of r_{EW}.

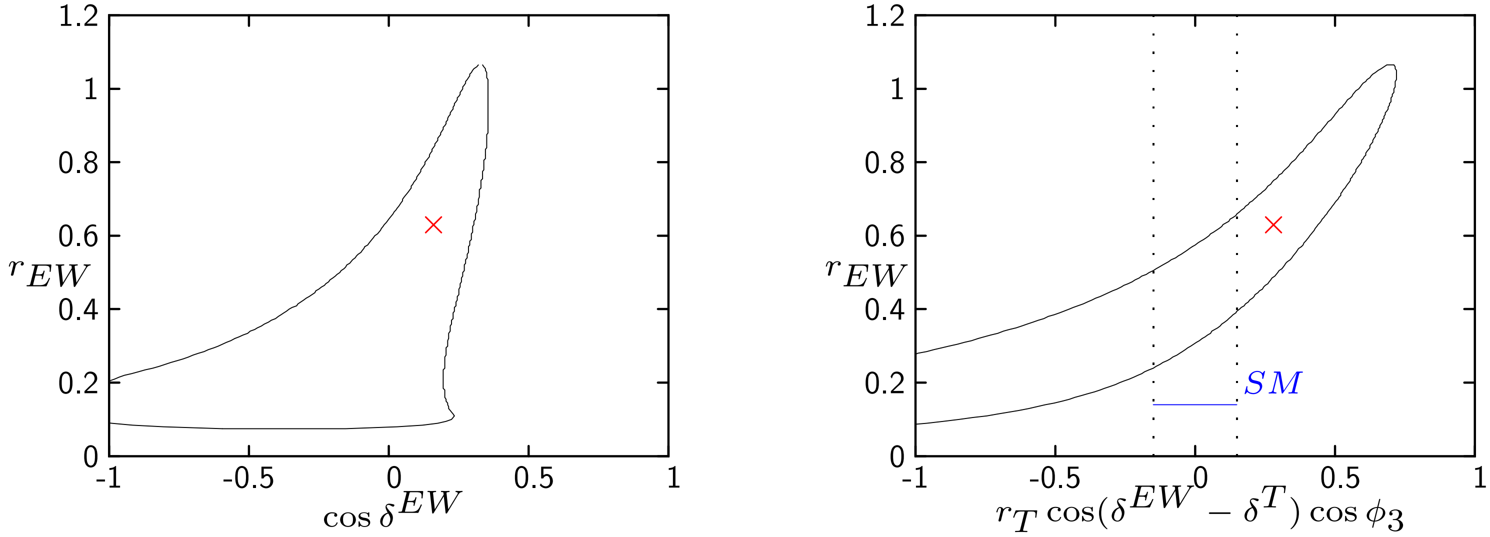


Figure 1: The allowed region on $(r_{EW},\ \cos\delta^{EW})$ and $(r_{EW},\ r_T\cos(\delta^{EW} - \delta^T)\cos\phi_3)$ plane at 1σ level.

Large EW penguin contribution and Large strong phase δ^{EW} are favored !!!

Larger r_{EW} seems to be favored and $\delta^{EW} = 0$ is disfavored.

If r_T is about 0.2, from Figs, r_{EW} have to be larger than r_T.

$$\Downarrow$$

Large electroweak penguin contribution $=$ Discrepancy from the SM ?

$$\Downarrow$$

An Hint of NEW PHYSICS ????

$$\Downarrow$$

Good test of the SM !

Consider more detail about the strong phases.

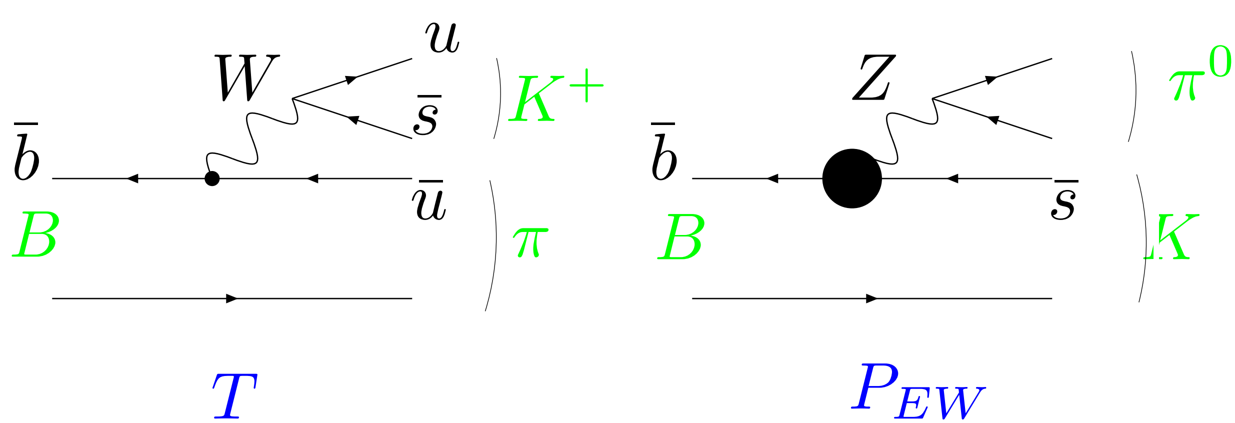
What we can expect.

1) $40^\circ < \phi_3 < 80^\circ$ $\Leftarrow$ CKM fitting OK.
2) $r_T \sim 0.2 \pm 0.018 \Leftarrow$ EXP. OK.
3) No phase difference between tree and EW(Z) penguin ??

$$\omega \equiv \delta^{EW} - \delta^{T} \to 0 \qquad \text{(Buras and Fleischer, Gronau et.al.)}$$

$$\to 0 \qquad \text{(pQCD (Mishima))}$$

$\to$ free parameter (my case).



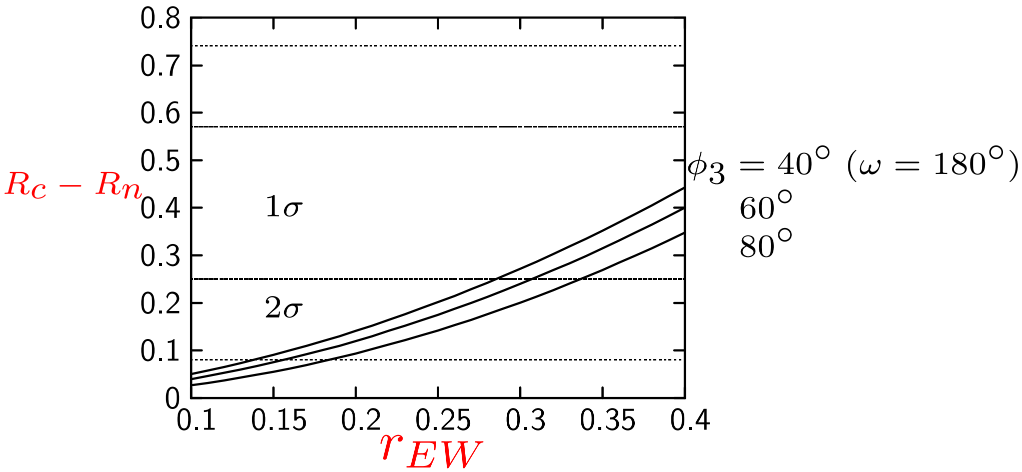
Under $SU(3)$ Symmetry, the strong phases should be same because the topology of the diagrams is same except for the weak gauge boson.

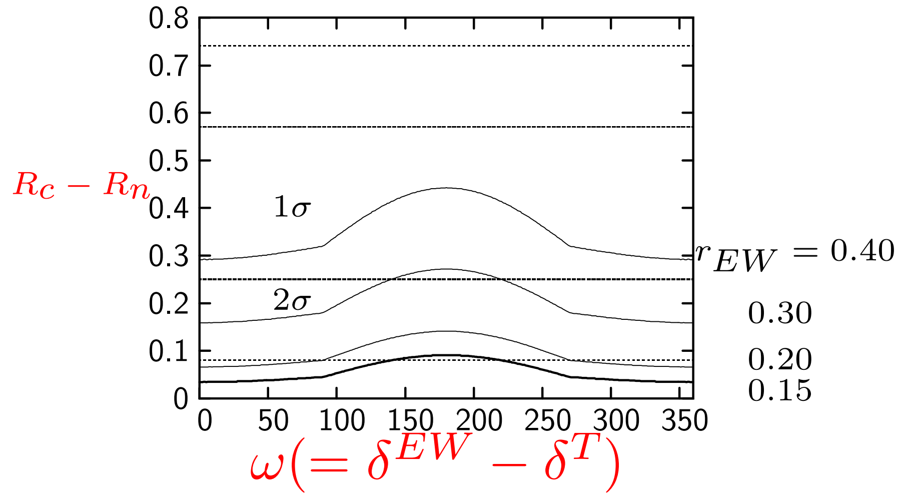
$$\Rightarrow \quad \omega = \delta^{EW} - \delta^{T} \simeq 0 \qquad \text{Correct or Not ?}$$

$$R_c - R_n \equiv \frac{2\bar{B}^{+0}}{\bar{B}^{0+}} - \frac{\bar{B}^{+-}}{2\bar{B}^{00}} = 0.41 \pm 0.16$$
$$= 2r_{EW}^2 - 2r_T r_{EW}\cos(\delta^{EW} - \delta^T)\cos\phi_3 - 4r_{EW}^2\cos^2\delta^{EW}$$

3 parameters are still remaining. $r_{EW}, \quad \delta^{EW}, \quad \omega = \delta^{EW} - \delta^T$

$R_c - R_n$ VS r_{EW} and ω





The lines show the maximum bound of $R_c - R_n$ for r_{EW} and $\omega(= \delta^{EW} - \delta^T)$ when $r_T = 0.2$and δ^T is taken as free parameters for $40^\circ < \phi_3 < 80^\circ$.

$$R_c - R_n = 2r_{EW}^2 - 2r_T r_{EW}\cos(\delta^{EW} - \delta^T)\cos\phi_3 - 4r_{EW}^2\cos^2(\delta^{EW})$$
$$= -2r_{EW}^2\cos 2(\delta^{EW}) - 2r_T r_{EW}\cos(\delta^{EW} - \delta^T)\cos\phi_3$$

To get the larger and positive value, We need

1) larger r_{EW} $\Rightarrow$ $r_{EW} >$ **0.3**

2) smaller $\cos\delta^{EW}$ **,** $\Rightarrow$ $\delta^T + \omega = \delta^{EW} \to \pm 90^\circ$

Positive $R_c - R_n \Rightarrow \cos 2\delta^{EW}) < 0 \Rightarrow 45^\circ < |\delta^{EW}| < 135^\circ$.

3) $\cos\omega\cos\phi_3$ **should be negative.**

$\Rightarrow$ **if** $\omega \sim 0$, $\boxed{\phi_3 > 90^\circ}$ **and** $\boxed{45^\circ < |\delta^{EW}|(= |\delta^T|) < 135^\circ}$

$\Rightarrow$ **Large Strong Phase !** $\rightarrow \sin\delta \sim O(1)$

$\Rightarrow$ **Need check the direct CP asymmetries !!!**

Direct CP Violations

We can also do same discussion about direct CP violation.

	CLEO	Belle	BaBar	Average
A_{CP}^{0+}	0.18$\pm$ 0.24$\pm$0.02	0.07 $^{+0.09+0.01}_{-0.08-0.03}$	-0.05 $\pm$ 0.08 $\pm$ 0.01	0.02 $\pm$ 0.06
A_{CP}^{00}	-	-	0.03 $\pm$ 0.036 $\pm$ 0.09	0.03 $\pm$ 0.37
A_{CP}^{+-}	-0.04 $\pm$0.16 $\pm$0.02	-0.088 $\pm$ 0.035 $\pm$ 0.018	-0.107 $\pm$ 0.041 $\pm$ 0.013	-0.095 $\pm$ 0.028
A_{CP}^{+0}	-0.29 $\pm$0.24 $\pm$ 0.02	0.23 $\pm$ 0.11 $^{+0.01}_{-0.04}$	-0.09 $\pm$0.09 $\pm$0.01	0.00 $\pm$ 0.07

The experimental data of the direct CP asymmetry and the average.

The Direct CP asymmetries under the same assumption are

$$A_{CP}^{0+} \equiv \frac{|A^{0-}|^2 - |A^{0+}|^2}{|A^{0-}|^2 + |A^{0+}|^2} = -2r_A \sin\delta^A \sin\phi_3 \sim 0.0,$$

$$A_{CP}^{00} \equiv \frac{|\bar{A}^{00}|^2 - |A^{00}|^2}{|\bar{A}^{00}|^2 + |A^{00}|^2} = 2r_C \sin\delta^C \sin\phi_3 \quad \sim O(0.01),$$

$$A_{CP}^{+-} \equiv \frac{|A^{-+}|^2 - |A^{+-}|^2}{|A^{-+}|^2 + |A^{+-}|^2} = -2r_T \sin\delta^T \sin\phi_3 - r_T^2 \sin 2\delta^T \sin 2\phi_3,$$

$$A_{CP}^{+0} \equiv \frac{|A^{-0}|^2 - |A^{+0}|^2}{|A^{-0}|^2 + |A^{+0}|^2} = -2(r_T \sin\delta^T + r_C \sin\delta^C + r_A \sin\delta^A)\sin\phi_3$$

$$+2r_{EW} r_T \cos\delta^T \sin\delta^{EW} \sin\phi_3 - r_T^2 \sin 2\delta^T \sin 2\phi_3.$$

Up to the first order of r, there is a relation among the CP asymmetries as follows:

$$A_{CP}^{+0} - A_{CP}^{+-} + A_{CP}^{00} - A_{CP}^{0+} = 0.$$

$$\Downarrow$$

The discrepancy of this relation is also caused by the cross term of r_T and r_{EW}.

$$A_{CP}^{+0} - A_{CP}^{+-} + A_{CP}^{00} - A_{CP}^{0+} = 2 r_T r_{EW} \cos\delta^T \sin\delta^{EW} \sin\phi_3.$$

$$\Downarrow$$

If we can have more accurate data,
this may also give us some useful informations about r_{EW} and the strong phase δ^{EW}.

Up to O(0.01) on our notation,

$$A_{CP}^{+0} + A_{CP}^{00} - A_{CP}^{0+} = -2r_T \sin\delta^T \sin\phi_3 - r_T^2 \sin 2\delta^T \sin 2\phi_3 + 2r_T r_{EW} \cos\delta^T \sin(\omega + \delta^T) \sin\phi_3$$

$$A_{CP}^{+-} = -2r_T \sin\delta^T \sin\phi_3 - r_T^2 \sin 2\delta^T \sin 2\phi_3$$

Under our assumption, the discrepancy from the relation is

$$A_{CP}^{+0} - A_{CP}^{+-} + A_{CP}^{00} - A_{CP}^{0+} = 2r_T r_{EW} \cos\delta^T \sin\delta^{EW} \sin\phi_3.$$

Using higher accurate data, we will be able to get some useful informations from this relation.

However the experimental data have still large errors which mainly comes from $B \to K^0\pi^0$,

$$A_{CP}^{+0} + A_{CP}^{00} - A_{CP}^{0+} = 0.01 \pm 0.38$$

$$A_{CP}^{+-} = -0.095 \pm 0.028$$

$$A_{CP}^{+0} - A_{CP}^{+-} + A_{CP}^{00} - A_{CP}^{0+} = 0.11 \pm 0.38$$

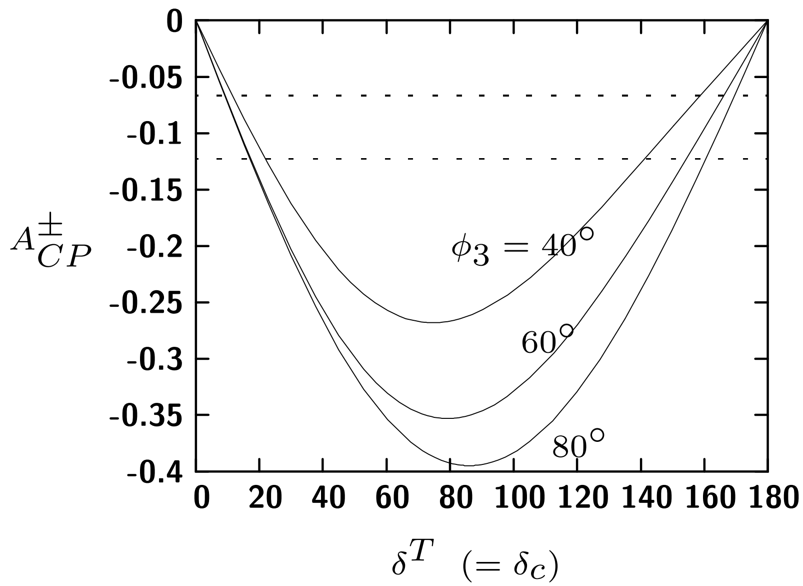
$$\Downarrow$$

So we consider to use A_{CP}^{+-} because it is accurate measurement and will give some constraint to δ^T.

$$\boxed{A_{CP}^{+-} = -2r_T \sin\delta^T \sin\phi_3 - r_T^2 \sin 2\delta^T \sin 2\phi_3}$$

$$A_{CP}^{+-} = -2 r_T \sin\delta^T \sin\phi_3 - r_T^2 \sin 2\delta^T \sin 2\phi_3$$

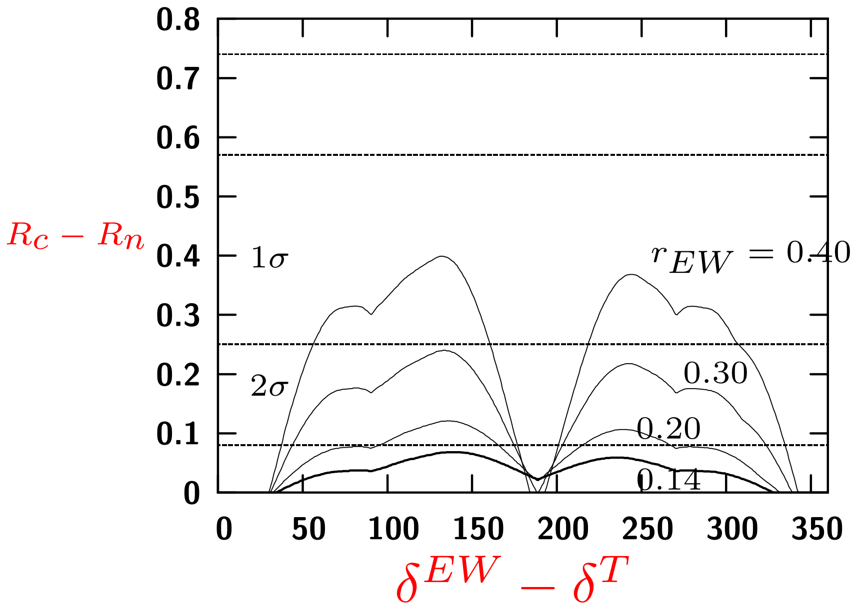
We plot A_{CP}^{+-} as a function of δ^T. From it, we can find the constraint for δ^T at $-0.123 < A_{CP}^{+-} < -0.067$. It tells us that the small δ^T is favored and δ^T should be around 20° or 150°.

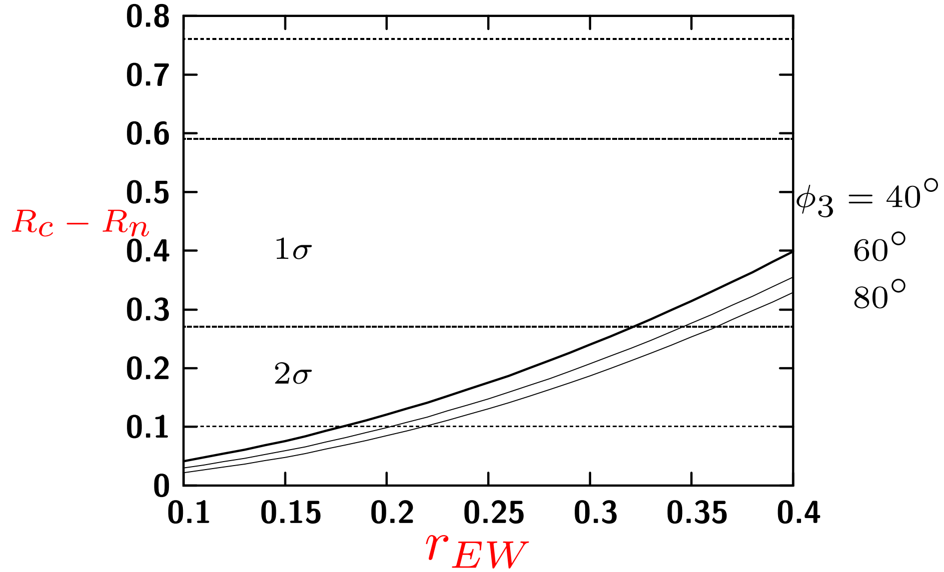


$\Downarrow$

replot the figures about $R_c - R_n$
under the constraint to δ^T from $-0.123 < A_{CP}^{+-} < -0.067$.

the figures about $R_c - R_n$ under the constraint to δ^T from $-0.123 < A_{CP}^{+-} < -0.067$.





The lines show the maximum bound of $R_c - R_n$ for r_{EW} and ω when $r_T = 0.2$ for each ϕ_3 under constraint $-0.123 < A_{CP}^{+-} < -0.067$

$$\Downarrow$$

$\omega = \delta^{EW} - \delta^T = 0 \ \ (180^\circ)$ **is disfavored !!**

Discrepancy from our expectation which is $\delta^{EW} = \delta^T$ under $SU(3)$ sym. !!

Summary

1) The allowed region of r_{EW} should be larger than about 0.3.

The theoretical estimation is $r_{EW} = 0.14$.

2) To keep positive $R_c - R_n$, at least we need $\cos 2\delta^{EW} < 0$
so that $45^\circ < |\delta^{EW}| < 135^\circ$. Large strong phase differences are requested.

3) The constraint from $A_{CP}^{\pm} = -0.095 \pm 0.028$ is inconsistent
with $\omega = \delta^{EW} - \delta^{T} = 0$. Large ω is favored. $\Rightarrow SU(3)$ breaking !

$\Downarrow$

Large EW penguin, Large strong phase difference

$\Downarrow$

New Physics or Not ?

Next Steps

We need consistency checks to know whether some new physics are hiding in these decay modes.

1) need more accurate data! $B^0 \to K^0\pi^0$ **is important.**

2) A relation among the direct CP asymmetries:

$$A_{CP}^{+0} - A_{CP}^{+-} + A_{CP}^{00} - A_{CP}^{0+} = 2 r_T r_{EW} \cos\delta^T \sin\delta^{EW} \sin\phi_3.$$

$\Rightarrow$ **An information about** $r_{EW}\sin\delta^{EW}$**.**

3) The other decay modes like $b \to s l^+ l^-, B \to l^+ l^-, B \to \phi K_s$ **et.al.**