Resolving New Physics Puzzle in B to K π

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In Progressing

OUT Line

- $B \to K\pi$ Puzzle
- Model Independent Analysis
- Numerical Analysis(In progressing)
- Summary

Experimental Data of B → K π

- HFAG since ICHEP06

$Br(10^{-6})$

	BABAR	Belle	CLEO	PDG2006 Avg.	New Avg.
$K^0\pi^+$	$23.9 \pm 1.1 \pm 1.0$	$22.9^{+0.8}_{-0.7} \pm 1.3$	$18.8^{+3.7+2.1}_{-3.3-1.8}$	24.1 ± 1.7	23.1 ± 1.0
$K^+\pi^0$	$13.3 \pm 0.6 \pm 0.6$	$12.4 \pm 0.5^{+0.7}_{-0.6}$	$12.9^{+2.4+1.2}_{-2.2-1.1}$	12.1 ± 0.8	12.8 ± 0.6
$K^+\pi^-$	$19.7 \pm 0.6 \pm 0.6$	$20.0 \pm 0.4 \pm 0.8$	$18.0^{+2.3+1.2}_{-2.1-0.9}$	18.2 ± 0.8	19.7 ± 0.6
$K^0\pi^0$	$10.5 \pm 0.7 \pm 0.5$	$9.2^{+0.7+0.6}_{-0.8-0.7}$	$12.8^{+4.0+1.7}_{-3.3-1.4}$	11.5 ± 1.0	10.0 ± 0.6

Blue color: Preliminary

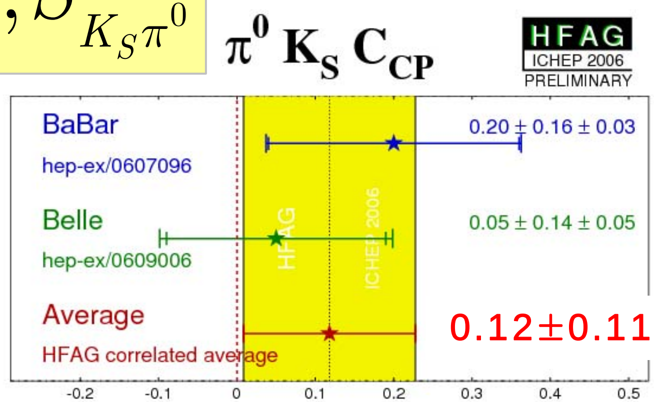
Experimental Data of B → K π

- HFAG since ICHEP06

A_{CP}

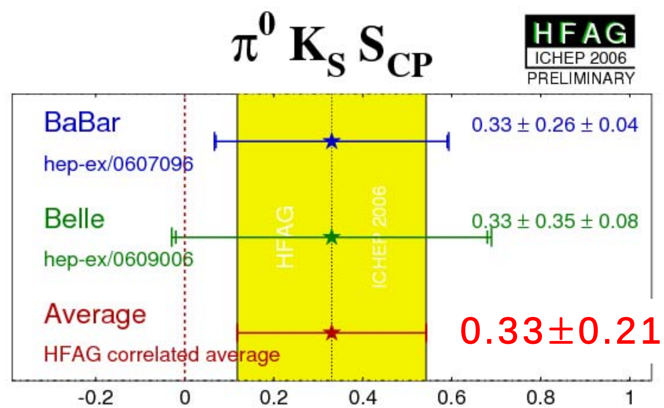
	BABAR	Belle	CLEO	PDG2006 Avg.	New Avg.
$K^0\pi^+$	$-0.029 \pm 0.039 \pm 0.010$	$0.03 \pm 0.03 \pm 0.01$	$0.18 \pm 0.24 \pm 0.02$	-0.02 ± 0.07	0.009 ± 0.025
$K^+\pi^0$	$0.016 \pm 0.041 \pm 0.012$	$0.07 \pm 0.03 \pm 0.01$	$-0.29 \pm 0.23 \pm 0.02$	0.04 ± 0.04	0.047 ± 0.026
$K^+\pi^-$	$-0.108 \pm 0.024 \pm 0.008$	$-0.093 \pm 0.018 \pm 0.008$	$-0.04 \pm 0.16 \pm 0.02$	-0.113 ± 0.020	-0.093 ± 0.015

$C_{K_S\pi^0}, S_{K_S\pi^0}$



0.12±0.11

PDG 2006 Avg. 0.08±0.14



0.33±0.21

PDG 2006 Avg. 0.34±0.28

Model Independent Analysis

Diagram approach B → K π

- Amplitude parameterization

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

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

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

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

- Adjust Parameter

$$\tilde{P} \equiv |V_{tb}{}^* V_{ts}|\left(P_t + EP_t - P_c - EP_c - \frac{1}{3}P_{EW}^C + \frac{2}{3}EP_{EW}^C\right)$$

$$\tilde{P}_{EW} \equiv |V_{tb}^* V_{ts}|\left(P_{EW} + EP_{EW}^C\right)$$

$$\tilde{P}_{EW}^C \equiv |V_{tb}^* V_{ts}|\left(P_{EW}^C - EP_{EW}^C\right)$$

$$\tilde{T} \equiv |V_{ub}^* V_{us}|(T + P_u + EP_u - P_c - EP_c)$$

$$\tilde{C} \equiv |V_{ub}^* V_{us}|(C - P_u - EP_u + P_c + EP_c)$$

$$\tilde{A} \equiv |V_{ub}^* V_{us}|(A + P_u + EP_u - P_c - EP_c)$$

Diagram approach B → K π

- Final form

$$\mathcal{A}\left(B^+ \to K^0\pi^+\right) \equiv \mathcal{A}^{0+} = -P$$

$$\mathcal{A}\left(B^0 \to K^+\pi^-\right) \equiv \mathcal{A}^{+-}e^{i\alpha^{+-}} = P - Te^{i\gamma}e^{i\delta_T}$$

$$\mathcal{A}\left(B^+ \to K^+\pi^0\right) \equiv \mathcal{A}^{+0}e^{i\alpha^{+0}} = \frac{1}{\sqrt{2}}\left(P - Te^{i\gamma}e^{i\delta_T} - Ce^{i\gamma}e^{i\delta_C} + P_{EW}e^{i\delta_{EW}}\right)$$

$$\mathcal{A}\left(B^0 \to K^0\pi^0\right) \equiv \mathcal{A}^{00}e^{i\alpha^{00}} = \frac{1}{\sqrt{2}}\left(-P - Ce^{i\gamma}e^{i\delta_C} + P_{EW}e^{i\delta_{EW}}\right)$$

- We Neglect P_{EW}^C, A
- We set the δ_P the strong phase of P as 0 → all phase is relative to δ_P
- There are 7 unknown parameters $P, T, C, P_{EW}, \delta_T, \delta_C, \delta_{EW}$
- we consider γ is given by other analysis
- $\mathcal{A}^{ij}$ are real, α^{ij} are phases of their amplitude

New Physics comes in

- Botella's arguments — Botella, Silva 2005
  - For weak phase φ, always

$$e^{i\phi} = \frac{\sin(\phi-\eta)}{\sin(\theta-\eta)} e^{i\theta} - \frac{\sin(\phi-\theta)}{\sin(\theta-\eta)} e^{i\eta}$$

  - We can choose arbitrary θ, η at will, for any given φ
- We assume NP comes into P_{EW} part(or C part) only

$$\frac{P_{EW}^N}{\sqrt{2}} e^{i\phi_{EW}^N} e^{i\delta_{EW}^N} = \frac{P_{EW}^N}{\sqrt{2}} \frac{\sin\phi_{EW}^N}{\sin\gamma} e^{i\delta_{EW}^N} e^{i\gamma} - \frac{P_{EW}^N}{\sqrt{2}} \frac{\sin(\phi_{EW}^N-\gamma)}{\sin\gamma} e^{i\delta_{EW}^N}$$

$$\begin{pmatrix} \theta = \gamma \\ \eta = 0 \end{pmatrix}$$

Absorbed into C

Absorbed into EW

New Physics comes in

- NP term is absorbed

$$\mathcal{A}^{+0}, \mathcal{A}^{00} \supset \frac{1}{\sqrt{2}}\left(-\boldsymbol{C} e^{i\gamma} \boldsymbol{e}^{i\delta_C} + \boldsymbol{P}_{EW} \boldsymbol{e}^{i\delta_{EW}} + \boldsymbol{P}_{EW}^{N} \boldsymbol{e}^{i\phi_{EW}^{N}} \boldsymbol{e}^{i\delta_{EW}^{N}}\right)$$

$$= \frac{1}{\sqrt{2}}\left[-\boldsymbol{C} e^{i\gamma} \boldsymbol{e}^{i\delta_C} + \boldsymbol{P}_{EW} \boldsymbol{e}^{i\delta_{EW}} + \boldsymbol{P}_{EW}^{N} \frac{\sin \boldsymbol{\phi}_{EW}^{N}}{\sin \gamma} \boldsymbol{e}^{i\delta_{EW}^{N}} \boldsymbol{e}^{i\gamma} - \boldsymbol{P}_{EW}^{N} \frac{\sin(\boldsymbol{\phi}_{EW}^{N} - \gamma)}{\sin \gamma} \boldsymbol{e}^{i\delta_{EW}^{N}}\right]$$

$$= \frac{1}{\sqrt{2}}\left(-\boldsymbol{C}' e^{i\gamma} \boldsymbol{e}^{i\delta'_C} + \boldsymbol{P}'_{EW} \boldsymbol{e}^{i\delta'_{EW}} \right)$$

$$\boldsymbol{C}' \boldsymbol{e}^{i\delta'_C} = -\boldsymbol{P}_{EW}^{N} \frac{\sin \boldsymbol{\phi}_{EW}^{N}}{\sin \gamma} \boldsymbol{e}^{i\delta_{EW}^{N}} + \boldsymbol{C} \boldsymbol{e}^{i\delta_C}$$

$$\boldsymbol{P}'_{EW} \boldsymbol{e}^{i\delta'_{EW}} = -\boldsymbol{P}_{EW}^{N} \frac{\sin(\boldsymbol{\phi}_{EW}^{N} - \gamma)}{\sin \gamma} \boldsymbol{e}^{i\delta_{EW}^{N}} + \boldsymbol{P}_{EW} \boldsymbol{e}^{i\delta_{EW}}$$

The analytic solution

- Original Form does not change

$$\mathcal{A}\left(B^{+} \to K^{0}\pi^{+}\right) \equiv \mathcal{A}^{0+} = -P$$

$$\mathcal{A}\left(B^{0} \to K^{+}\pi^{-}\right) \equiv \mathcal{A}^{+-}e^{i\alpha^{+-}} = P - Te^{i\gamma}e^{i\delta_T}$$

$$\mathcal{A}\left(B^{+} \to K^{+}\pi^{0}\right) \equiv \mathcal{A}^{+0}e^{i\alpha^{+0}} = \frac{1}{\sqrt{2}}\left(P - Te^{i\gamma}e^{i\delta_T} - C'e^{i\gamma}e^{i\delta'_C} + P'_{EW}e^{i\delta'_{EW}}\right)$$

$$\mathcal{A}\left(B^{0} \to K^{0}\pi^{0}\right) \equiv \mathcal{A}^{00}e^{i\alpha^{00}} = \frac{1}{\sqrt{2}}\left(-P - C'e^{i\gamma}e^{i\delta'_C} + P'_{EW}e^{i\delta'_{EW}}\right)$$

- If there Is NP $C' \neq C_{SM}$, $\delta'_C \neq \delta_{C,SM}$

  $P'_{EW} \neq (P_{EW})_{SM}$, $\delta'_{EM} \neq (\delta_{SM})_{SM}$

The analytic solution

- Step 1 - P, T, δ_T

$$\mathcal{A}^{0+} = -P$$

$$\mathcal{A}^{+-} e^{i\alpha^{+-}} = P - T e^{i\gamma} e^{i\delta_T}$$

$$P = \sqrt{Br^{0+}}$$

$$\cot \delta_T = \frac{\sin 2\gamma}{A_{CP}^{+-}} \frac{Br^{0+}}{Br^{+-}} \left[1 \pm \sqrt{1 + \frac{1}{\cos^2 \gamma} \left(\frac{Br^{+-}}{Br^{0+}} - 1 \right)} \right]$$

$$T = \sqrt{Br^{+-} - Br^{0+} + A_{CP}^{+-} Br^{+-} \cot \gamma \cot \delta_T}$$

We neglect

$$\left(\frac{A_{CP}^{+-}}{2 \sin \gamma} \frac{Br^{+-}}{Br^{0+}} \right)^2 \approx 0.0008$$

The analytic solution

- Step 2 - $\alpha^{00}, \bar{\alpha}^{00}$

$$\sqrt{2}\left(\mathcal{A}^{+0} e^{i\alpha^{+0}} - \mathcal{A}^{00} e^{i\alpha^{00}}\right) = 2P - Te^{i\gamma} e^{i\delta_T} \equiv X e^{i\zeta}$$

$$\sqrt{2}\left(\bar{\mathcal{A}}^{+0} e^{i\bar{\alpha}^{+0}} - \bar{\mathcal{A}}^{00} e^{i\bar{\alpha}^{00}}\right) = 2P - Te^{-i\gamma} e^{i\delta_T} \equiv \bar{X} e^{i\bar{\zeta}}$$

$$\cos(\alpha^{00} - \zeta) = \frac{2\left|\mathcal{A}^{+0}\right|^2 - 2\left|\mathcal{A}^{00}\right|^2 - X^2}{2\sqrt{2}\left|\mathcal{A}^{00}\right| X}$$

$$\cos(\bar{\alpha}^{00} - \bar{\zeta}) = \frac{2\left|\bar{\mathcal{A}}^{+0}\right|^2 - 2\left|\bar{\mathcal{A}}^{00}\right|^2 - \bar{X}^2}{2\sqrt{2}\left|\bar{\mathcal{A}}^{00}\right| \bar{X}}$$

The analytic solution

- Step 3 - $C', EW', \delta'_C, \delta'_{EW}$

$$-C' e^{i\gamma} e^{i\delta'_C} + P'_{EW} e^{i\delta'_{EW}} = \sqrt{2}\mathcal{A}^{00} e^{i\alpha^{00}} + P \equiv y$$

$$-C' e^{-i\gamma} e^{i\delta'_C} + P'_{EW} e^{i\delta'_{EW}} = \sqrt{2}\bar{\mathcal{A}}^{00} e^{i\bar{\alpha}^{00}} + P \equiv \bar{y}$$

$$C'^2 = \frac{1}{4\sin^2\gamma}\left[|y|^2 + |\bar{y}|^2 - 2\,\mathrm{Re}\left(y^*\bar{y}\right)\right] = \frac{1}{\sin^2\gamma}\left[Br^{00} - \mathcal{A}^{00}\bar{\mathcal{A}}^{00}\cos\left(\alpha^{00} - \bar{\alpha}^{00}\right)\right]$$

$$P'^{\,2}_{EW} = \frac{1}{4\sin^2\gamma}\left[|y|^2 + |\bar{y}|^2 - 2\,\mathrm{Re}\left(y^*\bar{y}e^{2i\gamma}\right)\right]$$

$$\tan\delta'_C = -\frac{\mathrm{Re}(y - \bar{y})}{\mathrm{Im}(y - \bar{y})} \qquad \tan\delta'_{EW} = -\frac{\mathrm{Re}(ye^{-i\gamma} - \bar{y}e^{i\gamma})}{\mathrm{Im}(ye^{-i\gamma} - \bar{y}e^{i\gamma})}$$

New Physics Test

- Hierarchy Test

$$EW'^2 > C'^2 \quad \Rightarrow \mathrm{Im}\left(y^* \bar{y}\, e^{i\gamma}\right) > 0$$

$$T^2 > EW'^2 \quad \Downarrow$$

$$Br^{+-} - Br^{0+} + A_{CP}^{+-} Br^{+-} \cot\gamma \cot\delta_T > \frac{1}{4\sin^2\gamma}\left[|y|^2 + |\bar{y}|^2 - 2\,\mathrm{Re}\left(y^* \bar{y} e^{2i\gamma}\right)\right]$$

- Strong phase Test

$$\delta_C = \delta_P \quad \Rightarrow \quad \mathcal{A}^{00} \cos\alpha^{00} = \bar{\mathcal{A}}^{00} \cos\bar{\alpha}^{00}$$

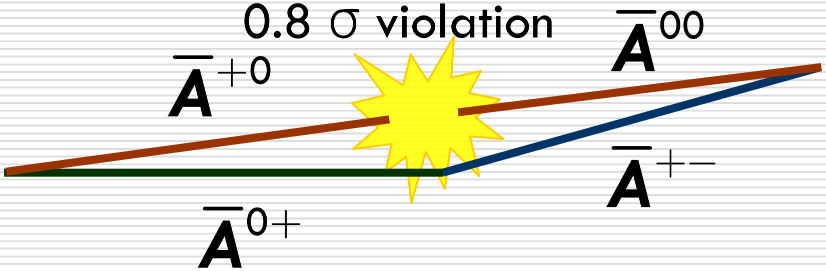
$$\delta_T = \delta_{EW} \quad \Downarrow$$

$$\frac{\sin 2\gamma}{A_{CP}^{+-}} \frac{Br^{0+}}{Br^{+-}}\left[1 \pm \sqrt{1 + \frac{1}{\cos^2\gamma}\left(\frac{Br^{+-}}{Br^{+0}} - 1\right)}\right] = -\frac{\mathrm{Im}(y e^{-i\gamma} - \bar{y} e^{i\gamma})}{\mathrm{Re}(y e^{-i\gamma} - \bar{y} e^{i\gamma})}$$

Numerical Analysis

Numerical Analysis

Isospin quadrangle



The solution within 0.8 σ variation

$$P = 4.79 \quad T = 0.96 \quad \delta_T = -0.22$$

$$\left[\begin{array}{l} C' = 1.05,\ P'_{EW} = 1.54,\ \delta'_C = 2.89,\quad \delta'_{EW} = 1.52 \\ C' = 2.10,\ P'_{EW} = 0.63,\ \delta'_C = 3.01,\quad \delta'_{EW} = 2.12 \\ C' = 1.22,\ P'_{EW} = 1.10,\ \delta'_C = 0.06,\quad \delta'_{EW} = -0.49 \\ C' = 0.14,\ P'_{EW} = 1.62,\ \delta'_C = -0.19,\quad \delta'_{EW} = -1.22 \end{array}\right.$$

Summary

- Even there is New Physics, by using botella's argument they changed into SM form.
- We can get each topological amplitude analytically step by step.
- For given Theoretical calculations, such as QCDF, pQCD we can resolve New physics part analytically – so we can resolve NP puzzle through hierarchical test and Strong phase comparison.