# Direct CP asymmetry in exclusive charmless B decays and the pQCD approach

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**On behalf of the pQCD collaboration**

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## March 2002: Belle and Babar reported

the value of the direct CP asymmetry in $B \to \pi^+\pi^-$.

- **Master formula:**

$$a_f = C_f \cos \Delta M t + S_f \sin \Delta M t$$

$C_f$: direct CPV, $S_f$: mixing CPV

➥$C_f \neq 0$ occurs when there are two different kinds of contribution to the amplitude.

- **Let us start with a generic amplitude:**

$$\overline{A}(\overline{B}^0 \to f_{CP}) = e^{-i\theta_1} e^{i\delta_1} A_1 + e^{-i\theta_2} e^{i\delta_2} A_2$$

$$A(B^0 \to f_{CP}) = e^{+i\theta_1} e^{i\delta_1} A_1 + e^{+i\theta_2} e^{i\delta_2} A_2$$

$\delta_i$: CP Conserving phase (strong phase),

$\theta_i$: CP Violating phase (weak phase)

- **If one of the amplitudes (e.g. $A_1$) dominates and $\mathcal{O}((A_2/A_1)^2)$ is negligible, then**

M. Gronau, Phys. Lett. B300, (1993)

$$C_f = 2 \sin(\theta_1 - \theta_2) \sin(\delta_1 - \delta_2) A_2/A_1$$

$$S_f = \sin(2\beta + 2\theta_1) + 2 \cos(2\beta + 2\theta_1) \sin(\theta_1 - \theta_2) \cos(\delta_1 - \delta_2) A_2/A_1.$$

☛ **What does $C_f \neq 0$ mean?**

$C_f = 2\sin(\theta_1 - \theta_2)\sin(\delta_1 - \delta_2)A_2/A_1$

$$S_f = \sin(2\beta + 2\theta_1) + 2\cos(2\beta + 2\theta_1)\sin(\theta_1 - \theta_2)\cos(\delta_1 - \delta_2)A_2/A_1.$$

✍ $B \to \pi^+\pi^-$ **mode**

$A_1$: Tree $A_2$: Penguin

$\sin(2\beta + 2\theta_1)$ ➠ UT $\alpha(\phi_2)$ determination

Is there any penguin pollution?!

✍ $B \to K_s\pi$ **mode**

$A_1$: Penguin $A_2$: Tree

$\sin(2\beta - 2\theta_1)$ ➠ UT $\gamma(\phi_3)$ determination

Is there any tree pollution?!

✍ $B \to \eta' K_s$ $(B \to \phi K_s)$ **mode**

D.London & A.Soni, Y.Grossman & P.Worah, G.Hou

♣ If tree is negligible, $C_f \neq 0$ is signal of NP!

$A_1$: Standard Model $A_2$: New Physics

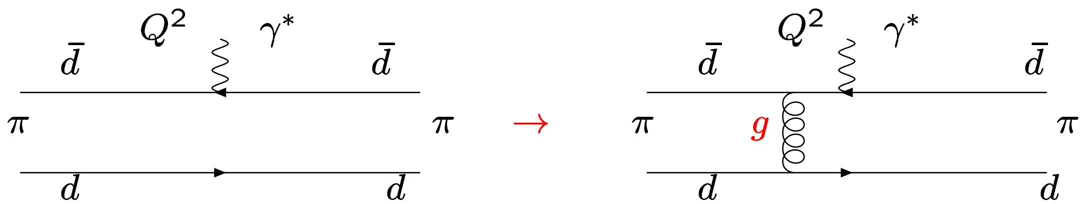
$\sin(\theta_1 - \theta_2)$ ➠ NP phase determination

Is tree contribution really small?!

☛ **Evaluation of the amplitudes including strong phase is crucial.↪ pQCD approach!**

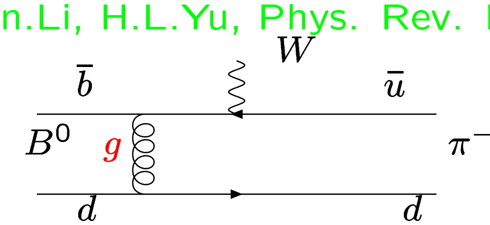
## ☛ Perturbative QCD approach for exclusive charmless B decays

➥ based on the calculation of electromagnetic pion form factor at large $Q^2$. P.Lepage, S.Brodsky, Phys. Rev. D22(1980) H.-n.Li, G.Sterman, Nucl. Phys. B381, (1992)

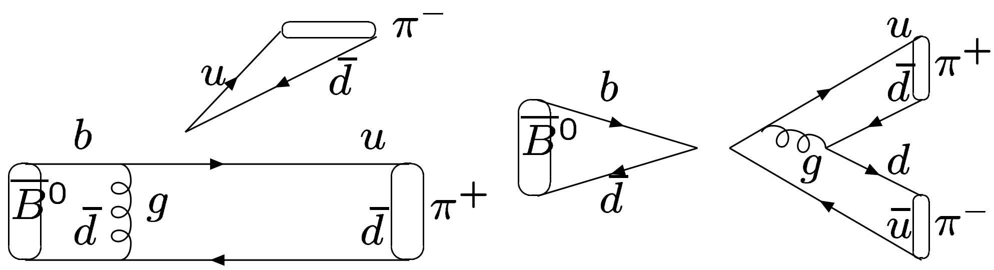



**Hard gluon exchange is crucial!**

➥ applied to $B \to \pi$ transition form factor
R.Akhoury, G.Sterman, Y.P.Yao, Phys. Rev. D50(1994)
H.-n.Li, H.L.Yu, Phys. Rev. D53(1996)




**Since the leading order diagrams include one gluon exchange, the annihilation diagram is same order of $\alpha_s$ as the emission type of diagrams.**




emission type annihilation type

**The strong phase is mainly coming from annihilation type of diagrams.**

## ☛ Form factor calculation in pQCD

The form factor is written as a convolution of distribution amplitude and hard scattering amplitude:

$$\langle \pi(P_2)|\bar{b} j_\mu u|B(P_1)\rangle = \int_0^1 dx_1 dx_2 \int_0^\infty db_1 db_2$$
$$\mathcal{P}_\pi(x_2, b_2, P_2, \mu) T_H(x_1, x_2, b_1, b_2, Q, \mu) \mathcal{P}_B(x_1, b_1, P_1, \mu)$$

where $x_i$ and $b_i$ are momentum fraction and impact parameter of the quark inside meson, respectively. $Q^2 = -(P_2 - P_1)^2$.

### ➪ Distribution Amplitude

$$\mathcal{P}_M(x, b, P, \mu) =$$
$$\exp\left[-s(x, b, Q) - s(1-x, b, Q) - 2\int_{1/b}^{\mu} \frac{d\bar{\mu}}{\bar{\mu}} \gamma_q(g(\bar{\mu}))\right] \Psi_M(x, 1/b, P)$$

where $s(x, b, Q)$ is Sudakov exponent. $\Psi_M$ denotes a wave function of meson M.

### ➪ Hard Scattering Amplitude

$$T_H(x_1, x_2, b_1, b_2, Q, \mu) \sim \int \frac{d^2\mathbf{k}_{\perp 1,2}}{(2\pi)^2} \exp[-i\mathbf{k}_{\perp 1,2} \cdot \mathbf{b_{1,2}}]$$
$$\frac{C_F}{[x_2 M_B^2 + \mathbf{k}_{\perp 2}^2][x_1 x_2 M_B^2 + (\mathbf{k}_{\perp 1} + \mathbf{k}_{\perp 2})^2]} \exp\left[4\int_\mu^t \frac{d\bar{\mu}}{\bar{\mu}} \gamma_q(g(\bar{\mu}))\right]$$

where $t$ is the largest scale appearing in $T_H$, $t = max(\sqrt{x} M_B, 1/b)$.

## ☛ Wave functions and input parameters

### Light meson wave functions

see e.g. P. Ball JHEP 9809(1998)

$$\Psi_M(P,x,\zeta) \equiv \not{P}\phi_M^A(x) + m_0^M\phi_M^P(x) + \zeta m_0^M(\not{v}\not{n} - v\cdot n)\phi_M^{\sigma\prime}(x)$$

where $P$ and $x$ are the momentum and the momentum fraction of meson $M$, respectively.

- ➥ $\phi_M^A$, $\phi_M^P$ and $\phi_M^\sigma$ represent the axial vector, pseudoscalar and tensor components of the wave function, respectively, for which we utilize the result from the Light-Cone sum rule including twist-3 contribution.

- ➥ The parameters $m_0^M$ are defined as:

$$m_0^\pi \equiv \frac{m_\pi^2}{(m_u+m_d)} = (1.4 \pm 0.3)\text{GeV},$$

$$m_0^K \equiv \frac{M_K^2}{m_{d(u)}+m_s} = (1.7 \pm 0.5)\text{GeV}.$$

### B meson wave function

see e.g. A.G.Grozin and M. Neubert, Phys. Rev. D55(1997)

$$\Psi_B(x,b) = N_B x^2(1-x)^2 exp[-\frac{1}{2}(\frac{xM_B}{\omega_B})^2 - \frac{\omega_B^2 b^2}{2}]$$

$$N_B = 91.7835 \text{ GeV},$$

- ➥ $\omega_B$ is a free parameter.

$$\omega_B = (0.4 \pm 0.2)\text{GeV}$$

✗ *There are 3 input parameters*

**These parameters will be constrained as experimental errors will decrease. (Universality of WF)**

## ☛ Numerical results of pQCD: part 1

$C_f = 2\sin(\theta_1 - \theta_2)\sin(\delta_1 - \delta_2)A_2/A_1$

$S_f = \sin(2\beta + 2\theta_1)$
$+2\cos(2\beta + 2\theta_1)\sin(\theta_1 - \theta_2)\cos(\delta_1 - \delta_2)A_2/A_1.$

### ✍ $B \to \pi^+\pi^-$ **mode**

$A_1$: Tree, $A_2$: Penguin ➠ UT angle $\alpha(\phi_2)$

➤ pQCD prediction of the penguin pollution is

$\frac{P}{T} = 0.09 \sim 0.1$ *see page*11

$\delta_P = -66^\circ \sim -56^\circ$

### ✍ $B \to K^\pm\pi^\mp$ **mode**

$A_1$: Penguin, $A_2$: Tree ➠ UT angle $\gamma(\phi_3)$

➤ pQCD prediction of the tree pollution is

$\frac{T}{P} = 0.11 \sim 0.14$ *not negligible*

$\delta_P = 150^\circ \sim 155^\circ$

### ✍ $B \to \eta' K_s$ $(B \to \phi K_s)$**modes**

D.Atwood & A.Soni, Y.Grossman & P.Worah, G.Hou

♣ If tree is negligible, $C_f \neq 0$ is signal of NP!

$A_1$: SM, $A_2$: NP ➠ NP phase

➤ pQCD prediction of the tree pollution is

$\frac{T}{P} = 0.0075 \sim 0.011$ $(B \to \eta' K)$ *negligible*!

$\delta_P = -45^\circ \sim -35^\circ$

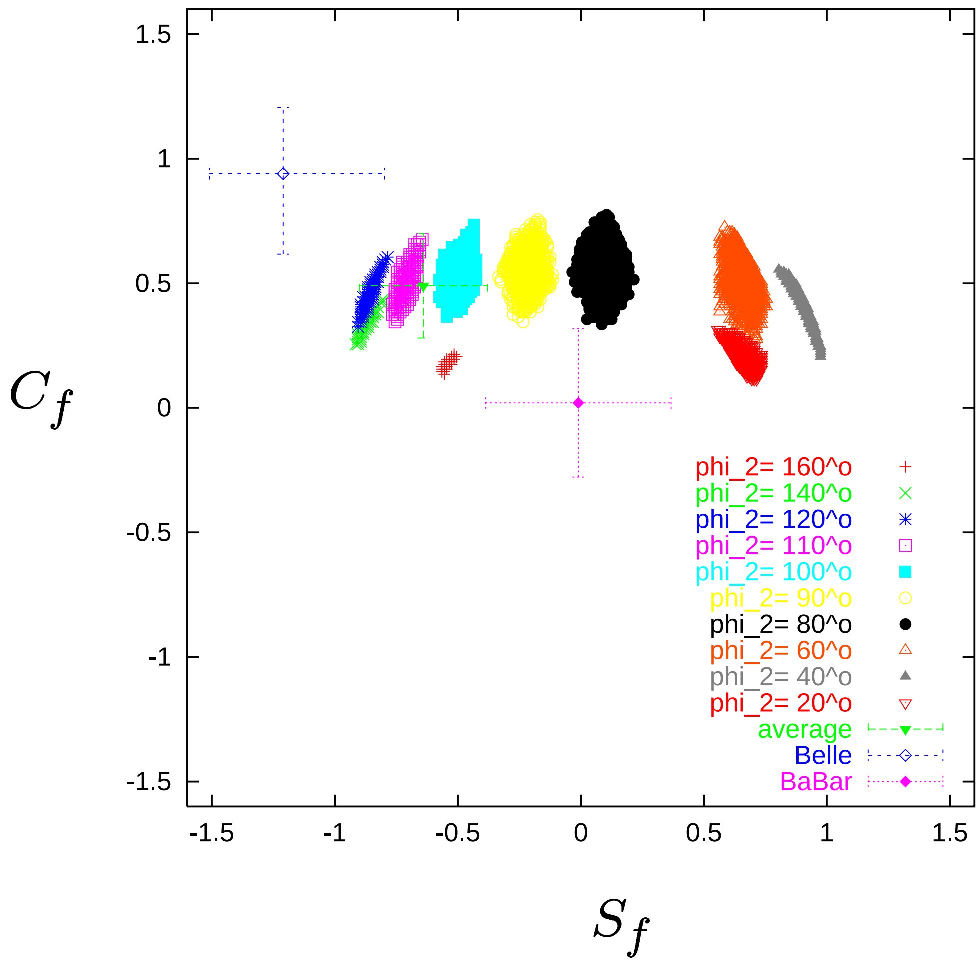
## ☛ Numerical results of pQCD: part2

## ✍ $B \to \pi\pi$ mode

➤ pQCD prediction of the strong phase is

$$\frac{P}{T} = 0.\not{0}9 \sim 0/\!\!\!1, \; see \; page 11$$
$$\delta_P = -66^\circ \sim -56^\circ$$

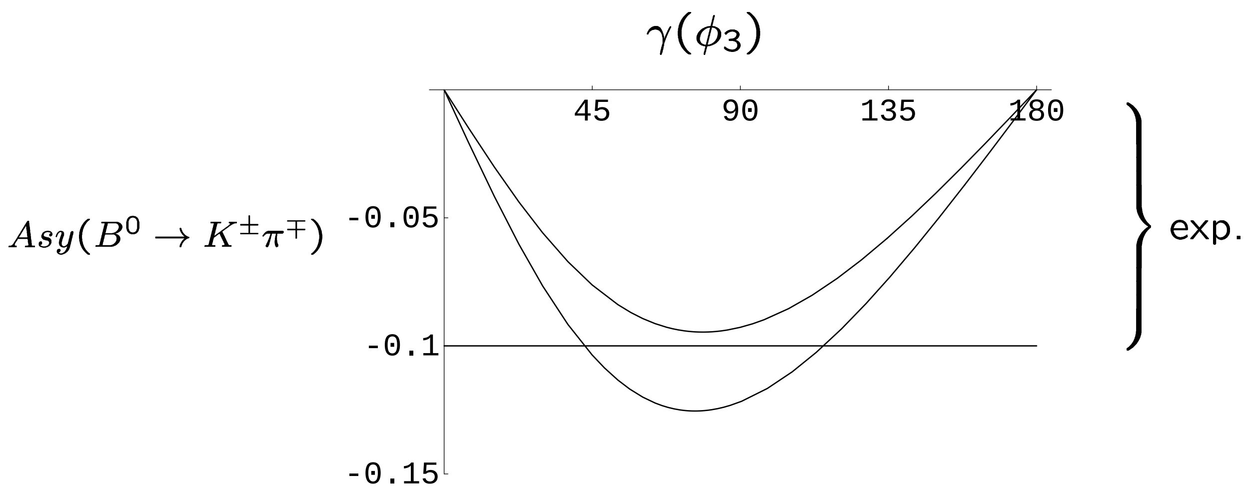
A.I. Sanda and K. Ukai (Prog.Theor.Phys. 107)



☛ **Numerical results of pQCD: part3**

✍$B \to K\pi$ **mode**

$$\frac{T}{P} = 0.11 \sim 0.14, \quad \delta_P = 150^\circ \sim 155^\circ$$




➤ Note that we are improving our calculation by including Higher Fock states.

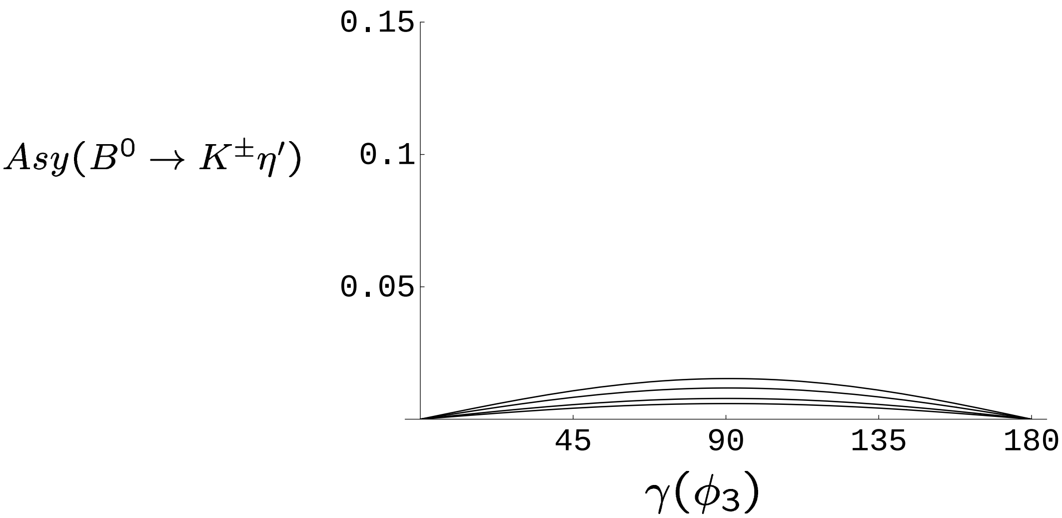
S.J. Brodsky and S. Gardner Phys.Rev.D65:054016,2002

☛ **Numerical results of pQCD: part4**

✍ $B \to K\eta'$ **mode**

➤ pQCD prediction of the strong phase is

$$\frac{T}{P} = 0.0075 \sim 0.011, \quad \delta_P = -45^\circ \sim -35^\circ$$




➤ $B^0 \to K\eta'$ process shows very large branching ratio. To be precise, Chromo-magnetic $O_{8g}$ contribution may need to be included.

➤ However, $O_{8g}$ contribution is penguin type of operator so that it does not increase the SM prediction of the direct CP asymmetry.

➤ Measurement of large direct CP asymmetry will indeed a signal of NP!

# CONCLUSIONS

- Brief review of the pQCD approach.

- The strong phase coming from annihilation type of diagram is calculated in the literature.

- The penguin pollution rate for $B \to \pi^+\pi^-$, $P/T$, is found to be 0.09 to 0.1(*see page*11).

- The tree pollution rate for $B \to K^\pm\pi^\mp$, $T/P$, is found to be 0.10.to 0.14 (not negligible).

- The tree pollution rate for $B \to K_s\eta'$, $T/P$, is found to be 0.0075.to 0.011 (negligible). NP search could be performed!

# ERRATUM

The value of the $P/T$ ratio for $B \to \pi\pi$ process shown during my talk ($P/T = 0.09 \sim 0.1$) was obtained by using the definition in the paper Prog. Theor. Phys. 107 (A.I Sanda and K. Ukai). In this paper, $P/T$ ratio is defined as the ratio of the penguin and tree amplitudes excluding the ratio of the absolute value of the CKM matrix element $|V_{tb}^* V_{td}/V_{ub}^* V_{ud}|$.

The definition of $P/T$ ratio in this talk was the one including the ratio of the CKM matrix element. Thus, the definition was not consistent. I apology for my rising a confusion during the talk.

Since the known value for $|V_{tb}^* V_{td}/V_{ub}^* V_{ud}|$ is about 3, we obtain $P/T \sim 0.3$, which might solve several questions which occurred after the talk.