Higher Order Strong Penguin Effects in:

Semi-inclusive Decay $B \to \phi X_s$

&

Nonleptonic Decays $B \to \pi\pi,\ \pi K$

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Short presentation at Seminar on Heavy Flavor Physics– Aug. 16, 2005

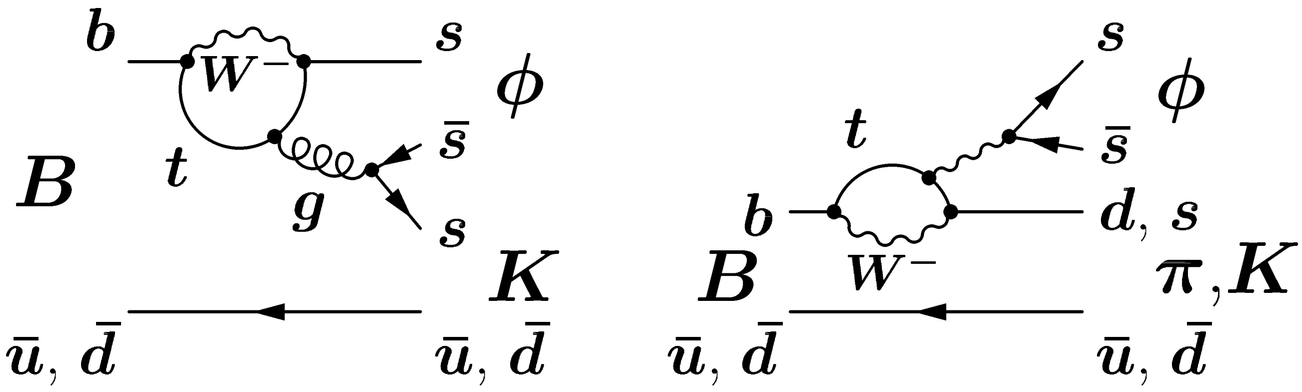
Where we stand so far

- The Standard Model has been established to be the theory for electro-weak interactions already more than 30 years.
- The SM is known to be unsatisfactory from the (perfect) theoretical standpoint.
- Yet, it is tremendously successful at predicting all known particle physics phenomena so far...
- However, searching for physics beyond the SM is never-ending
- Many models of New Physics predict new particles.

- **Penguin** dominant processes, which are very sensitive to **New Particles**, have been serving as powerful probes for the SM and for scenarios beyond the SM

Say, $b \to s\gamma$, $b \to s\mu^+\mu^-$, $b \to sg^*$.

- B-meson factories **Belle** and **BaBar** operating at $\Upsilon(4S)$ have the sensitivity to discover effects of New Physics in Penguin induced decays $\cdots\cdots$ and are already constraining the New Physics's parameter space.



The example of penguin dominant B decays

Why $B \to \phi X_s$ is interesting

♣ A Pure penguin process

♣ Clear signature of ϕ, via, $\phi \to K^+K^-$, two charge tracks and $Br(\phi \to K^+K^-) = 49.2\%$

How about $B \to \eta\prime X_s$?

⇒ Surely, it is very interesting! It has been observed by **CLEO** and refined by **BaBar** and **Belle**

⇒ its abnormal large branching ratio has risen tough challenge for theoretical explanation.

⇒ Reliable theoretical predictions hindered by poor knowledge of content of η', mixing angles, $gg - \eta'$ coupling, and so on.

⇒ Strong penguin enhanced by New Physics?

$B \to \phi X_s$: theoretical clean probe of the strength of Strong penguin

⋆ **Thanks to my collaborator Gad Eilam**

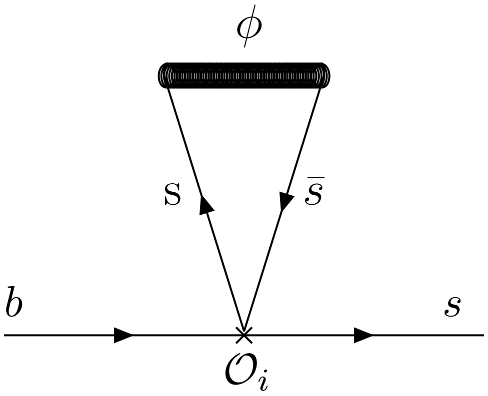
G.Eilam and Yadong Yang, Phys.Rev. D66, 074010(2002)

♣ ϕ is almost a pure $s\bar{s}$ state and does not couple to two gluons. Moreover ϕ coupling to three gluons is highly suppressed by OZI rule.

We start from the H_{eff} of the SM

$$\boxed{\mathcal{H}_{eff} = \frac{4G_F}{\sqrt{2}}\left[V_{cb}V_{cs}^* \sum_{i=1}^{2} C_i O_i - V_{tb}V_{ts}^* \left(C_g O_g + \sum_{j=3}^{10} C_j O_i\right)\right]. \qquad (1)}$$

$B \to \phi X_s$ induced by $b \to \phi s$



Leading diagram for $(B \to \phi X_s)_2$. $\mathcal{O}_i$ are strong penguin operators in which top penguin effects are embedded.

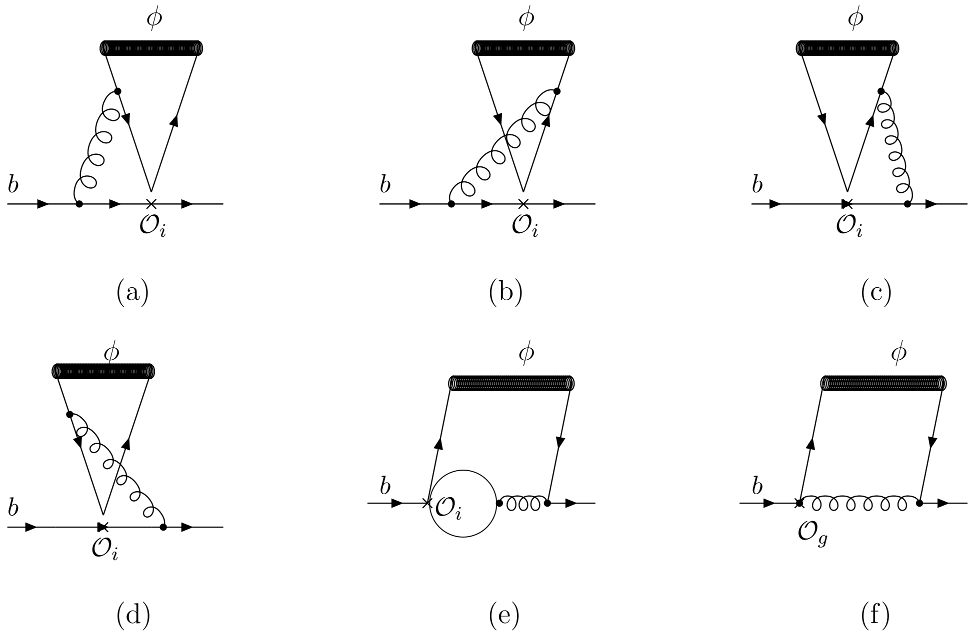
With Naive Factorization, we get

$$\Rightarrow \mathcal{B}\left[(B \to \phi X_s)_2\right] = 4.9 \times 10^{-5}$$

Naive Factorization(NF) works for color-allowed processes since Bjorken's color transparency argument applies,

while for color-suppressed processes, we must go beyond NF.

In QCD factorization, including sub-leading corrections



$$\Rightarrow \mathcal{B}\left[(B \to \phi X_s)_2\right] = 6.7 \times 10^{-5}$$

To study the momentum spectrum of ϕ, we include the Fermi Motion of b quark by ACCMM model

- b quark is off-shell, has a momentum dependent mass

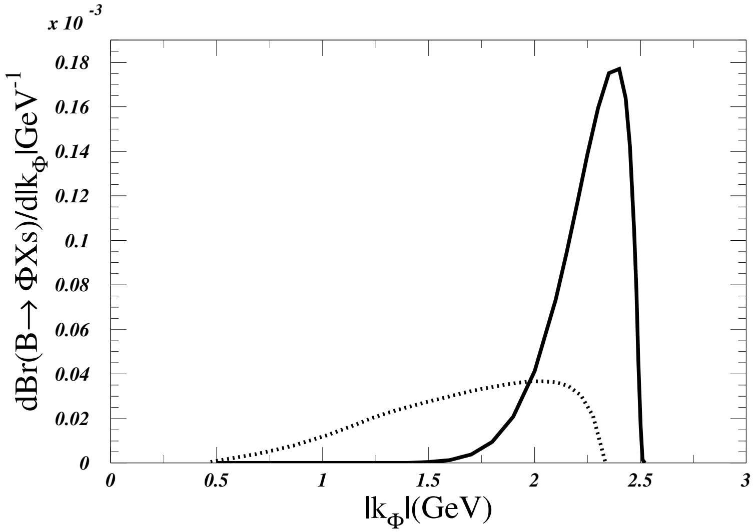
$$W^2(p) = M_B^2 + m_{sp} - 2M_B\sqrt{m_{sp}^2 + p^2}, \tag{2}$$

- the momentum of b quark is modelled by a Gaussian

$$\phi_F(p) = \frac{4}{\sqrt{\pi}}\frac{1}{p_F^3}\exp\left(-\frac{p^2}{p_F^2}\right). \tag{3}$$

- p_F=410MeV, $\langle m_b \rangle$=4.690GeV, $m_{sp} = 298$ MeV from fitting $B \to X_s\gamma$ by CLEO.

We get the momentum spectrum of ϕ



√ **the spectrum peaking near $|\mathrm{k}_\phi| = 2.4$ GeV which corresponds to $M_{X_s} = 1.15$ GeV.**

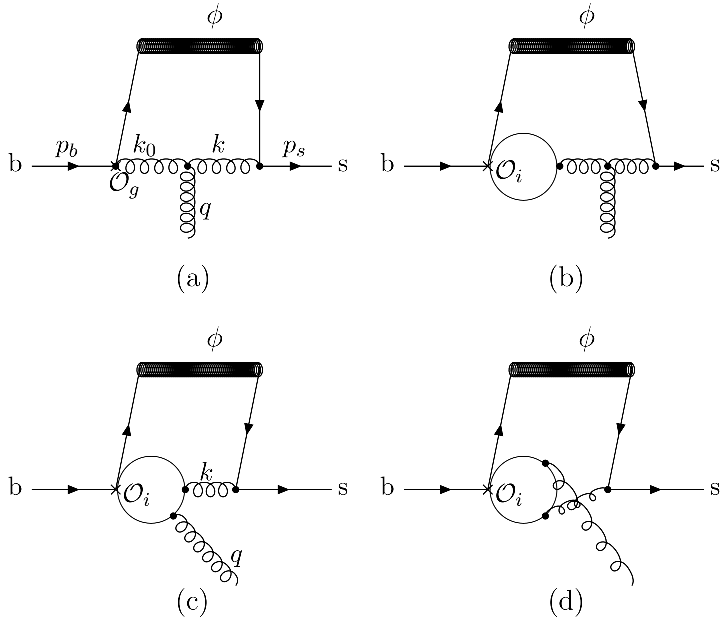
To suppress indirect ϕ production, we impose a momentum cut $|\mathrm{k}_\phi| \geq 2.0$ GeV. With this cut, the branching ratio is

$$\boldsymbol{\mathcal{B}}\left[(B \to \phi X_s)_2\right] = 6.1 \times 10^{-5} \tag{4}$$

$B \to \phi X_s$ induced by $b \to \phi s g$

- ✓ gluon radiating from external quarks effect is rather small, $\mathcal{B}(b \to \phi s g)/\mathcal{B}(b \to \phi s) \approx 3\%$. (Deshpande et al., PLB366,300(1996))

- ✓ "inner bremsstrahlung" effect could be large



- ✓ The effect entered by power of g_s^2, not by $\frac{g_s^2}{16\pi^2}$

Results and Arguments for $B \to \phi X_s$

✓ The contribution of $b \to \phi s g$ is quite substantial,

$$\mathcal{B}\left[(B \to \phi X_s)_3\right] = 3.8 \times 10^{-5}, \tag{5}$$

After cut $|\mathrm{k}_\phi| \geq 2.0$ GeV,

$$\mathcal{B}\left[(B \to \phi X_s)_3\right] = 1.0 \times 10^{-5} \quad (|\mathrm{k}_\phi| \geq 2.0 \text{ GeV}). \tag{6}$$

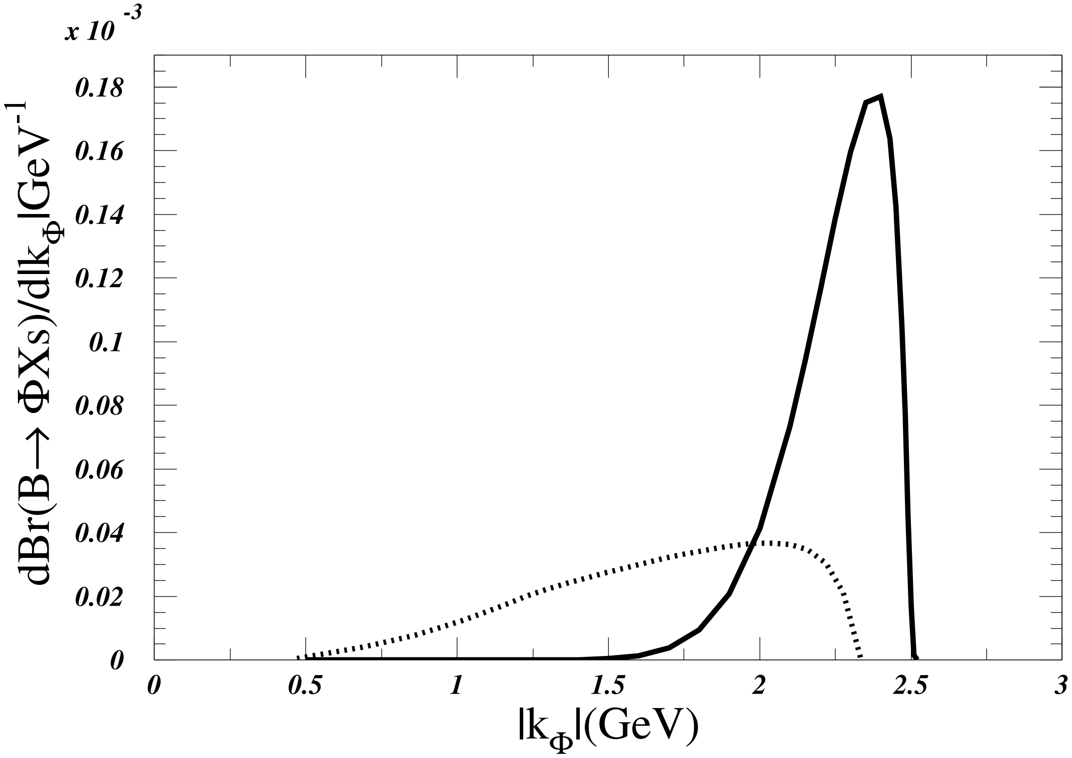
which is about 16% of $\mathcal{B}(b \to \phi s)$.

Sum up these contributions

$$\boxed{\mathcal{B}(B \to \phi X_s) = 10.5 \times 10^{-5}}$$

$$\boxed{\mathcal{B}(B \to \phi X_s) = 7.1 \times 10^{-5} \qquad (|\mathrm{k}_\phi| \geq 2.0 \text{ GeV}).}$$

The final shot of the momentum spectrum of ϕ



- Theoretical prediction for $B \to \phi X_s$ is rather clean
- ϕ has a clear experimental signature
- Large rate

$\Rightarrow$ render detailed studies at BaBar and Belle.

$\Rightarrow$ good ground for testing the SM and searching for New Physics.

♣ How large are these contributions in charmless exclusive decays?

Let's go to $B \to \pi\pi, \pi K$ decays

Already, we have met many tough challenges from beautiful measurements at BABAR and BELLE, say

√The large $B \to \pi^0\pi^0$ rate

√ The ratios between the CP average branching fractions

$$R_{+-} \equiv 2\left[\frac{\mathrm{BR}(B^+ \to \pi^+\pi^0) + \mathrm{BR}(B^- \to \pi^-\pi^0)}{\mathrm{BR}(B_d^0 \to \pi^+\pi^-) + \mathrm{BR}(\bar{B}_d^0 \to \pi^+\pi^-)}\right]\frac{\tau_{B_d^0}}{\tau_{B^+}} = (2.20 \pm 0.31)_{exp} = (1.12)_{th} \quad (7)$$

$$R_{00} \equiv 2\left[\frac{\mathrm{BR}(B_d^0 \to \pi^0\pi^0) + \mathrm{BR}(\bar{B}_d^0 \to \pi^0\pi^0)}{\mathrm{BR}(B_d^0 \to \pi^+\pi^-) + \mathrm{BR}(\bar{B}_d^0 \to \pi^+\pi^-)}\right] = (0.67 \pm 0.14)_{exp} = (0.04)_{th} \quad (8)$$

$$R \equiv \left[\frac{\mathrm{BR}(B_d^0 \to \pi^-K^+) + \mathrm{BR}(\bar{B}_d^0 \to \pi^+K^-)}{\mathrm{BR}(B^+ \to \pi^+K^0) + \mathrm{BR}(B^- \to \pi^-\bar{K}^0)}\right]\frac{\tau_{B^+}}{\tau_{B_d^0}} = (0.82 \pm 0.06)_{exp} = (0.84)_{th} \quad (9)$$

$$R_c \equiv 2\left[\frac{\mathrm{BR}(B^+ \to \pi^0K^+) + \mathrm{BR}(B^- \to \pi^0K^-)}{\mathrm{BR}(B^+ \to \pi^+K^0) + \mathrm{BR}(B^- \to \pi^-\bar{K}^0)}\right] = (1.00 \pm 0.09)_{exp} = (1.09)_{th} \quad (10)$$

$$R_n \equiv \frac{1}{2}\left[\frac{\mathrm{BR}(B_d^0 \to \pi^-K^+) + \mathrm{BR}(\bar{B}_d^0 \to \pi^+K^-)}{\mathrm{BR}(B_d^0 \to \pi^0K^0) + \mathrm{BR}(\bar{B}_d^0 \to \pi^0\bar{K}^0)}\right] = (0.79 \pm 0.08)_{exp} = (1.10)_{th} \quad (11)$$

exp. values by HFAG

Possible implications:

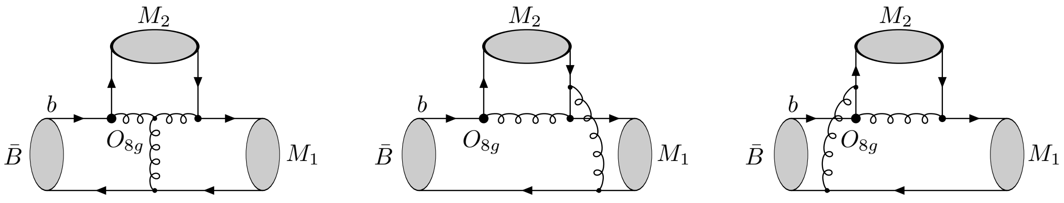
⇒ Insufficient understanding of hadronic dynamics.

⇒ New physics playing in the electro-weak penguin sector.

We present a study of higher order strong penguin effects

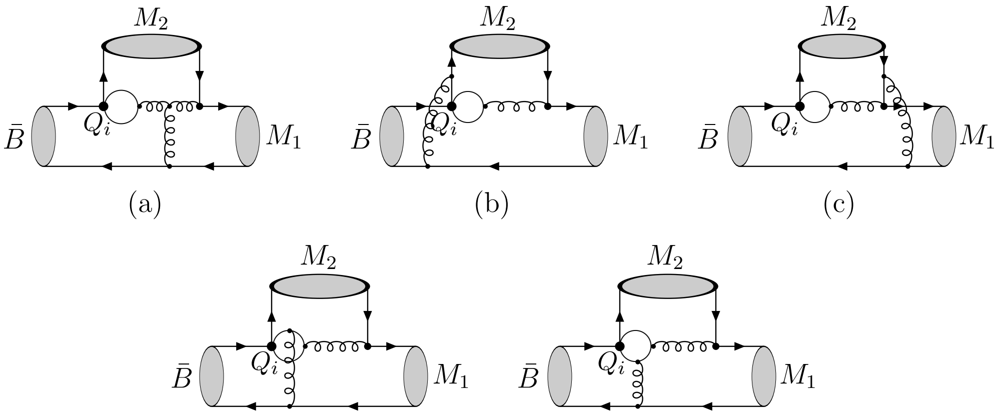
induced by $b \to s(d)g^*g^*$[X.Q. Li, YD hep-ph/0508079]

Feynman diagrams to be calculated:



(a) (b) (c)

Chromo-magnetic operator Q_{8g} contributions induced by $b \longrightarrow sg^*g^*$

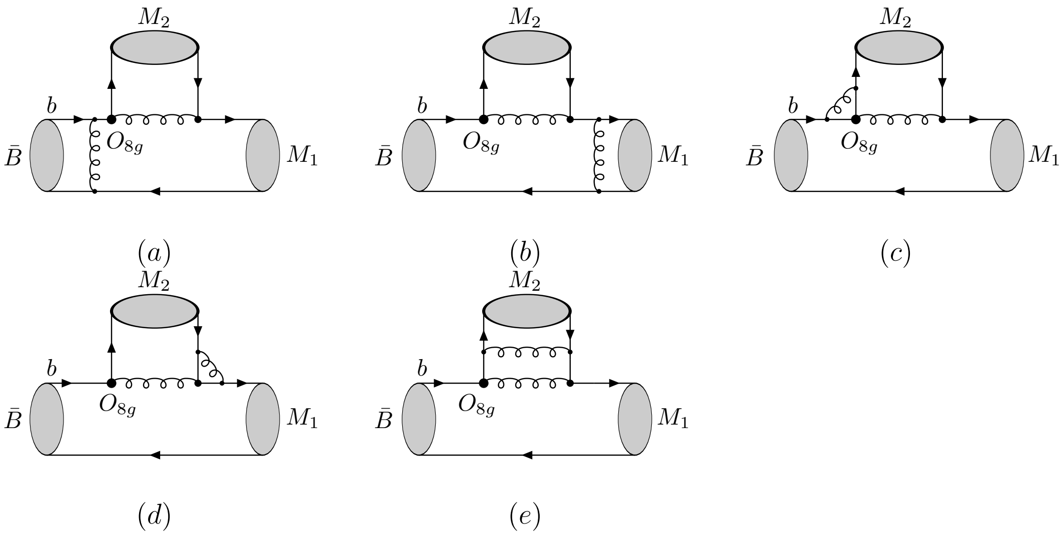


(a) (b) (c)

(d) (e)

Penguin contributions induced by $b \longrightarrow sg^*g^*$

Feynman diagrams not included:



(a) (b) (c)

(d) (e)

Representative diagrams not evaluated. For others $\mathcal{O}_{8g} \to \mathcal{O}_i$.

♣ Figs like (a), (b) could be factorized in formfactors

♣ Figs like (c),(d) or (e) are further suppressed by $1/16\pi^2$ compared to the Figs in last page.

The CP-averaged branching ratios. $\bar{\mathcal{B}}^f$ and $\bar{\mathcal{B}}^{f+a}$ denote the results without and with the annihilation contributions, respectively. The NF results, which are of order $\mathcal{O}(\alpha_s^0)$, are also shown for comparison. $\bar{\rho} = 0.20$ and $\bar{\eta} = 0.33$.

$F_0^{B\to\pi}(0) = 0.258, \quad F_0^{B\to K}(0) = 0.331$

Decay Mode	NF	$\bar{\mathcal{B}}^f$		$\bar{\mathcal{B}}^{f+a}$		Exp.
		$\mathcal{O}(\alpha_s)$	$\mathcal{O}(\alpha_s+\alpha_s^2)$	$\mathcal{O}(\alpha_s)$	$\mathcal{O}(\alpha_s+\alpha_s^2)$	
$B^- \longrightarrow \pi^-\overline{K}^0$	10.07	13.28	17.31	16.04	20.44	24.1 ± 1.3
$B^- \longrightarrow \pi^0 K^-$	5.69	7.30	9.37	8.72	10.97	12.1 ± 0.8
$\overline{B}^0 \longrightarrow \pi^+ K^-$	7.71	10.25	13.61	12.46	16.15	18.2 ± 0.8
$\overline{B}^0 \longrightarrow \pi^0\overline{K}^0$	3.38	4.63	6.26	5.70	7.50	11.5 ± 1.0
$\overline{B}^0 \longrightarrow \pi^+\pi^-$	7.41	7.69	7.99	8.32	8.63	4.5 ± 0.4
$B^- \longrightarrow \pi^-\pi^0$	5.12	5.06	5.06	—	—	5.5 ± 0.6
$\overline{B}^0 \longrightarrow \pi^0\pi^0$	0.15	0.16	0.19	0.17	0.21	1.45 ± 0.29

- ✓ For penguin-dominated $B \to \pi K$ decays,
  $\sim 30\%$ enhancement found,
  the consistency between the TH predictions
  and the EXP data improved much.

- ✓ For tree-dominated $B \to \pi\pi$ decays,
  the higher order $b \to d g^* g^*$ contributions
  play only a minor role.
  $Br(B^\pm \to \pi^\pm \pi^0)$ agrees with the data quite well
  $Br(B^0 \to \pi^\pm \pi^\mp)_{TH}$ is rather large
  $Br(B^0 \to \pi^0 \pi^0)_{TH}$ is too large

TOUGH!

Let's have a look at the puzzling ratios

We show the situations for the ratios. The values in the parentheses are the ones without the annihilation contributions.

	NF	$\mathcal{O}(\alpha_s)$	$\mathcal{O}(\alpha_s + \alpha_s^2)$	Exp.
R_{+-}	1.272	1.119 (1.209)	1.077 (1.163)	2.20 ± 0.31
R_{00}	0.040	0.041 (0.042)	0.048 (0.047)	0.67 ± 0.14
R	0.833	0.845 (0.840)	0.860 (0.855)	0.82 ± 0.06
R_c	1.130	1.087 (1.100)	1.074 (1.083)	1.00 ± 0.09
R_n	1.140	1.092 (1.106)	1.077 (1.087)	0.79 ± 0.08

The $\pi\pi$, πK puzzles still persist!

The direct CP asymmetries (in units of 10^{-2}) for $B \longrightarrow \pi K, \pi\pi$ decays with the default input parameters. A_{CP}^{f} and A_{CP}^{f+a} denote the results without and with the annihilation contributions, respectively.

Decay Mode	A_{CP}^{f}		A_{CP}^{f+a}		Exp.
	$\mathcal{O}(\alpha_s)$	$\mathcal{O}(\alpha_s+\alpha_s^2)$	$\mathcal{O}(\alpha_s)$	$\mathcal{O}(\alpha_s+\alpha_s^2)$	
$B^- \longrightarrow \pi^- \overline{K}^0$	0.73	0.52	0.65	0.46	-2.0 ± 3.4
$B^- \longrightarrow \pi^0 K^-$	7.59	6.94	6.56	6.07	4 ± 4
$\overline{B}^0 \longrightarrow \pi^+ K^-$	5.31	4.83	4.39	4.08	-10.9 ± 1.9
$\overline{B}^0 \longrightarrow \pi^0 \overline{K}^0$	-3.08	-2.84	-2.71	-2.54	-9 ± 14
$\overline{B}^0 \longrightarrow \pi^+ \pi^-$	-4.73	-5.51	-4.54	-5.27	37 ± 10
$B^- \longrightarrow \pi^- \pi^0$	-0.30	-0.31	–	–	-2 ± 7
$\overline{B}^0 \longrightarrow \pi^0 \pi^0$	55.52	58.53	55.03	55.50	28 ± 39

In a recent interesting study of ”next-to-leading” corrections in PQCD by H.n Li et al.[hep-ph/0508041], they find the puzzles could be solved but the large rate of $B^0 \to \pi^0\pi^0$.

We note that the contributions calculated here are not included in [hep-ph/0508041].

Wrong sign in the imaginary of QCDF calculations of hard-scattering?

But it could be traced rightly by the causalities of propagators.

Anyway, higher order corrections deserve further systematical studies in both PQCD and QCDF frameworks.

In conclusion, there are tough challenges by recent measurements at BABAR and BELLE.

Abnormal CP in $B \longrightarrow \phi K_s$ has faded way.

But the polarization puzzles in $B \longrightarrow \phi K^*$ and $B^+ \longrightarrow \rho^+ K^{*0}$ are still there.

And maybe the puzzles in $B \longrightarrow \pi\pi, \pi K$ decays

Is new physics there and dancing with EW-penguins?

New Physics can do anything but make coffee?

But we can not sleep with the puzzles!

Searching for possible solutions without bias!