Large CP violation in Nonleptonic B meson decays: Application of k_T factorization in B-meson Physics

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Part-I

Non-leptonic B-meson decays

Nonleptonic B-meson Decays

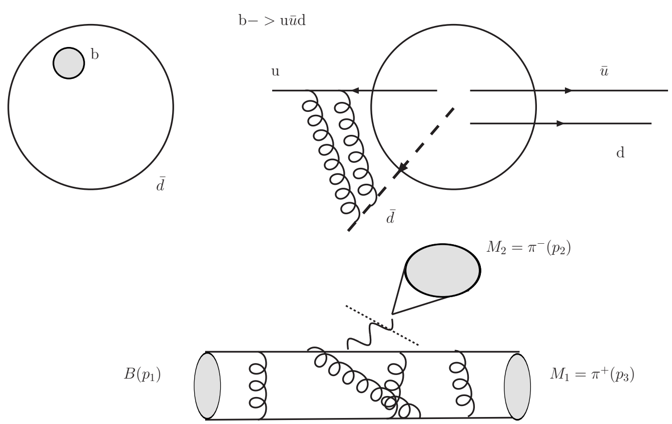
The aim of the study of weak decays in B-meson;

1. To determine the elements of CKM matrix and to explore the origin of CP-violation in low-energy scale,
2. To study the strong interaction dynamics related to the confinement of quarks and gluons inside hadrons,
3. To explore the possibility of the New Physics beyond SM.

All tasks complement each other:
An understanding of the connection between quarks and hadron properties is a necessary prerequiste for a precise dtermination of CKM matrix elements and CP-violating phase (Kobayashi-Maskawa phase).

Color-Transparancy Argument and Factorization

Since b-quark decays into light quarks energetically($> 1\ GeV$), the produced quark-antiquark pair doesn't have enough time to evolve to the real size hadronic entity, but remians a small size bound state with a correspondingly small chromomagnetic moment which suppress the QCD interaction between final state mesons. [Bejorken,Bordsky and Lepage;1980].



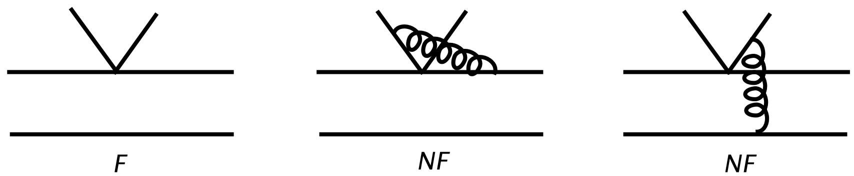
The matrix elements of 0_1 is expressed by

$$< \pi(p_2)\pi(p_3)|0_1(\mu)|B(p_1) > \quad \sim \quad < \pi(p_2)|(d_i q_i)_{V-A}|0 >< \pi(p_3)|(q_j b_j)_{V-A}|B(p_1) >$$
$$f_\pi \qquad \otimes \qquad F^{B\pi}(q^2 = M_\pi^2) \tag{1}$$

Models for the exclusive B-decays

1. Naive Factorization Approach[Bauer,Stech,Wirbel;1985]
   - consider only factorized part
2. Generalized Factorization Approach[Kamal, Cheng et al.,Ali et al.;1998]

- consider non-factorizable contributions
- but can not calculable
- asuume that $NF = \chi \otimes F$

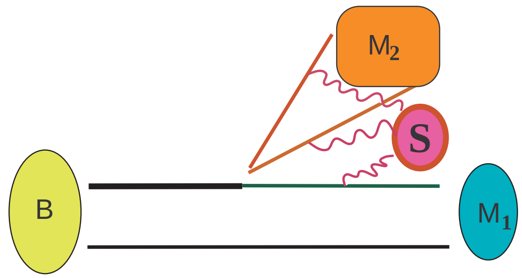


$$
\begin{aligned}
(a_1)_{eff} &= C_1 + C_2 \left(\frac{1}{N_c} + \chi_1 \right) : \qquad \text{color} - \text{favored modes} \\
(a_2)_{eff} &= C_2 + C_1 \left(\frac{1}{N_c} + \chi_2 \right) : \qquad \text{color} - \text{suppressed modes}
\end{aligned}
$$

- putting $\chi_1 = \chi_2 = \chi$(universal real parameter)
- Weak points: Can't predict CP-Asymmetry correctly !!

3. QCD-Factorization Approach[BBNS;1999]

- Consider $B \longrightarrow M_1 M_2$ with recoiled M_1 and emitted M_2 (light or quarkonium)



- Because energies of $M_1, M_2 \sim m_B/2$,
  soft gluons with momentum of oder $\Lambda_{\rm QCD}$ decouple in $\Lambda_{\rm QCD}/m_b$.

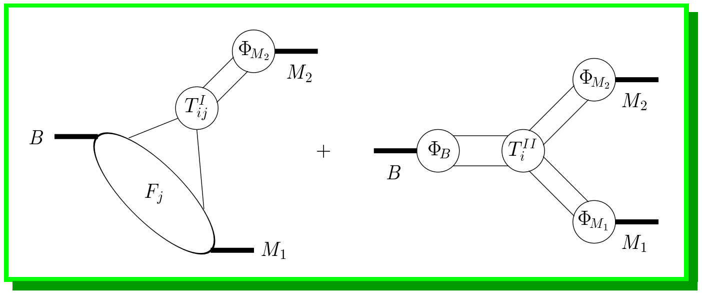
QCD factorization implies that

- only hard interactions between (BM_1) and M_2 survive in $m_b \longrightarrow \infty$ limit, soft effects are confined to (BM_1) system.
- decay amplitude= naive fact. $[1+\mathcal{O}(\alpha_s) + \mathcal{O}(\frac{\Lambda_{\rm QCD}}{m_b})]$
- nonfactorizable effects and a_i are calculable in heavy quark limit.

- strong phases $\sim \mathcal{O}(\alpha_s)$, soft phases $\sim \mathcal{O}(\Lambda_{\rm QCD}/m_b)$
  Factorization formula:

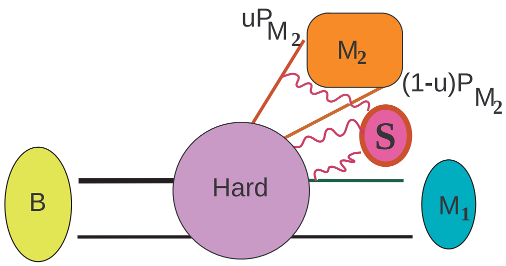
$$\begin{aligned}
& \langle M_1 M_2 | O_i | B \rangle \\
= & \; F^{BM_1}(m_2^2) \int_0^1 du T^I(u) \Phi_{M_2}(u) \\
+ & \int_0^1 d\xi \, du \, dv \, T^{II}(\xi, u, v) \Phi_B(\xi) \Phi_{M_1}(v) \Phi_{M_2}(u),
\end{aligned}$$

  T^I, T^{II}: hard scattering functions



- Divergence of the twist-3 contribution

$$\int_0^1 \frac{d\bar{u}}{\bar{u}} \frac{\Phi_\sigma^{M_2}(\bar{u})}{6\bar{u}} \sim \int_0^1 \frac{d\bar{u}}{\bar{u}} - 1 \quad \text{logarithmic divergence}$$



- Here the calculation is based on the collinear expansion, i.e., the parton's momentum $\propto u p_{M_2}$ or $\bar{u} p_{M_2} = (1-u) p_{M_2}$.
- Since the result is divergent due to the integral of the end point region, it means the collinear expansion should be modified.
  $\Longrightarrow$ the hadronic size effect plays an important role, especially in the end point region, i.e.,

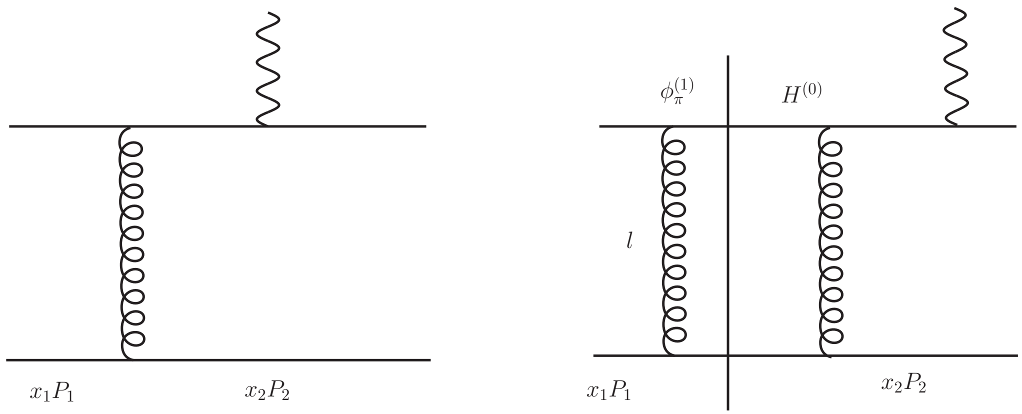
$$\int_0^1 \frac{d\bar{u}}{\bar{u}} \frac{\Phi_\sigma^{M_2}(\bar{u})}{6\bar{u}} \sim \int_0^1 \frac{d\bar{u}}{\bar{u} + \langle 2k \rangle / m_b} - 1$$

$$= \ln(m_B/\mu_h)(1+\rho) - 1$$

- $0 < |\rho| < 1$ by BBNS from $K\pi, \pi\pi$ fitting.
- $|\rho| \sim 1.5$ by H.-Y. Cheng and K.-C.Yang from $J/\psi K$ fitting.

Collinear Factorization vs k_T Factorization(1)

Ex: Pion form factor:



1. at $O(\alpha_s)$: $H^{(0)}(x_1, x_2) \propto 1/(x_1P_1 - x_2P_2)^2 = -1/x_1x_2Q^2 \qquad (Q^2 = 2P_1^+P_2^-)$
2. at $O(\alpha_s^2)$:

$$\begin{aligned} H^{(0)}(x_1, x_2) &\propto 1/(x_1P_1 - x_2P_2 + l)^2 \\ &= \frac{1}{(x_1P_1 - x_2P_2)^2 + 2x_1P_1^+l^- - 2x_2P_2^-l^+ + 2l^+l^- - l_T^2} \end{aligned} \tag{2}$$

- $l||P_1 \Rightarrow l^+ \sim P_1^+ >> l_T \sim \Lambda >> l^- \sim \Lambda^2/P_1^+, P_1^2 \sim l^2 \sim O(\Lambda^2)$

Collinear Factorization vs k_T Factorization(2)

• Collinear Factorization ⇒ dropping l^- and l_T

$$H^{(0)}(\xi_1, x_2) \propto \frac{1}{2x_1x_2P_1^+P_2^- + 2x_2P_2^-l^+} = \frac{1}{2(x_1 + l^+/P_1^+)x_2P_1^+P_2^-} \equiv \frac{1}{\xi x_2 Q^2} \qquad (3)$$

⇒ convolution only in the longitudinal component of parton momentum

$$\Rightarrow \qquad F_\pi = \int d\xi_1 d\xi_2 \; \phi_\pi(\xi_1) \; H(\xi_1, \xi_2) \; \phi_\pi(\xi_2) \qquad (4)$$

♠ Soft-collinear effective theory(SCET), light-cone sum rules(LCSR), and QCD-improved factorization(QCDF) are based on collinear factorization.

• k_T Factorization ⇒ In the small x region, $x_1x_2Q^2$ is small;
⇒ dropping only l^-, but keeping l_T

$$H^{(0)}(\xi_1, x_2, l_T) \propto \frac{1}{2(x_1 + l^+/P_1^+)x_2P_1^+P_2^- + l_T^2} \equiv \frac{1}{\xi x_2 Q^2 + l_T^2} \qquad (5)$$

⇒ convolution in both the longitudinal and transverse components of parton momentum:

$$\Rightarrow \qquad F_\pi = \int d\xi_1 d\xi_2 d^2k_{1T} d^2k_{2T} \; \phi_\pi(\xi_1, k_{1T}) \; H(\xi_1, \xi_2, k_{1T}, k_{2T}) \; \phi_\pi(\xi_2, k_{2T}) \qquad (6)$$

♡ k_T factorization is more general, suitable also in the small x region.
PQCD is based on k_T factorization.

k_T-factorization

Perturbative QCD Approach[Keum,Li,Sanda;2000]

a. Factorization (Hard part vs Soft part)

b. Sudakov Suppression Effects

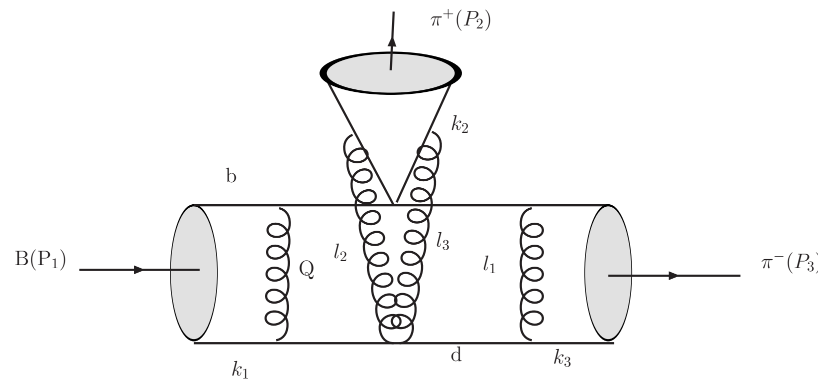
c. Threshold resummation Effects

d. Higher Twist LCDAs

—— Important theoretical Issues in Nonleptonic B-decays: ——

- End point singularity vs Form Factors
- Dynamical Penguin Enhancement vs Chiral Penguin Enhancement
- Soures of Strong Phases and CP Violation
- Important Role of Annihilation Diagram

Factorization picture in PQCD method



1. Soft pole from soft gluon l_1 is absorbed into pion wave-function,
2. Finite piece of them is absorbed into the Hard part H_T,
3. Soft divergences from $l_2 \sim l_3 \sim 0$ is cancelled at the leading power of α_s ($\Leftarrow$ Soft gluon is global object)
   $\Rightarrow$ Nonfactorizable gluons are infrared finite !!!

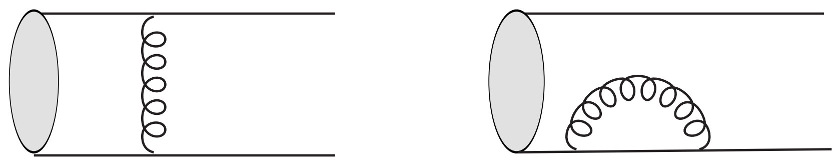
Factorization

Natually we can factorize amplitudes into two pieces:

$$
\begin{array}{llcl}
G = & H(Q,\mu) & \otimes & \Phi(m,\mu) \\
 & \mathrm{Perturbative} & & \mathrm{Non-perturbative} \\
 & (> 1\ GeV) & & (< 1\ GeV) \\
 & \mathrm{Hard-Part} & & \mathrm{Soft-Part:LCDAs} \\
 & \mathrm{Process-Dependent} & & \mathrm{Universal}
\end{array}
\tag{7}
$$

Sudakov Suppression Factor

Including $k_T \Rightarrow$ (Radiative corrections) $\Rightarrow \alpha_s \ln^2\left(\frac{k_T}{M_B}\right)$ [Large double Logarithms]



$\Rightarrow k_T$ resummation give a distribution of k_T, which exhibits suppression in the region with

$$< k_T^2 > \sim 0(\bar{\Lambda} M_B) >> \bar{\Lambda}^2 \quad (8)$$

Strategies for curing singularities: *N-n. Li and Sterman, NPB381, 129 (1992); H-n. Li, PRD64, 014019 (2001)*

• Include parton transverse momentum, k_T, and the corresponding Sudakov factor to remove end-point singularities such that $< |\vec{k}_T|^2 >$ is from $\bar{\Lambda}^2$ scale to

$$\left\langle \left|\vec{\mathrm{k}}_T\right|^2 \right\rangle \sim m_B \bar{\Lambda}, \ \bar{\Lambda} = m_B - m_b$$ *C.-H Chen, YYK, H-n Li, PRD64,112002 (2001)*

$$\int dx_2 \frac{1}{(k_2-k_1)^2} \frac{\Phi_{M2}^{tw2,3}(x_2)}{(p_1-k_2)^2 - m_B^2} \sim \int dx_2 \frac{1}{x_1 x_2 m_B^2 + \left|\vec{\mathrm{k}}_{1T} - \vec{\mathrm{k}}_{2T}\right|^2} \frac{\Phi_{M2}^{tw2,3}(x_2)}{x_2 m_B^2 + \left|\vec{\mathrm{k}}_{2T}\right|^2}$$

Threshold Resummation Effect

- When we consider radiative corrections for $B \to P/V$ transitions:

- Finally we have the threshold resummation factor (universal factor)

$$S_t(x) = 1.78[x(1-x)]^c$$

- Threshold resummation for non-factorizable diagrams is weaker and negligible in charmless B-decays.
- Include threshold resummation, parametrized by $[x(1-x)]^c$, to smear $\ln^2 x$

Sudakov factors make pQCD approach reliable

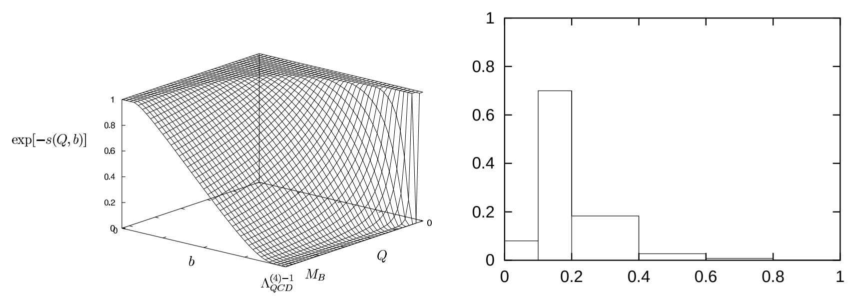


Figure 1: (a) Sudakov effects (b): α_s/π vs fractions

Characters of pQCD approach

- Improved PQCD factorization formalism:

$$\langle M_1 M_2 | C_k(t) \mathcal{O}_k | B \rangle = \int [dx] \int \left[\frac{d^2\vec{b}}{4\pi} \right] \Phi^*_{M_1}(x_2, \vec{b}_2)\, \Phi^*_{M_2}(x_3, \vec{b}_3)\, C_k(t)$$
$$\times\ H_k(\{x\}, \{\vec{b}\}, M_B) \Phi_B(x_1, \vec{b}_1)\, \underbrace{S_t(\{x\})}\, \underbrace{e^{-S(\{x\},\{\vec{b}\},M_B)}}$$

$$S = S_B(x_1 P_1^+, b_1) + S_{M_1}(x_2 P_2^-, b_2) + S_{M_1}((1-x_2) P_2^-, b_2) + ...$$

- Few theoretical parameters involve except the wave functions, decay constants

ω_B: Shape parameter for B meson wave function, $0.38 < \omega_B < 0.42$

m_0 : Chiral symmetry breaking parameter, $1.2 < m_\pi^0 < 1.6$, $1.4 < m_K^0 < 1.8$

c: Parametrization of threshold resummation,
$[x(1-x)]^c$, $c = 0.3$ for charmless decays,
$c = 0.35$ for charmful decays

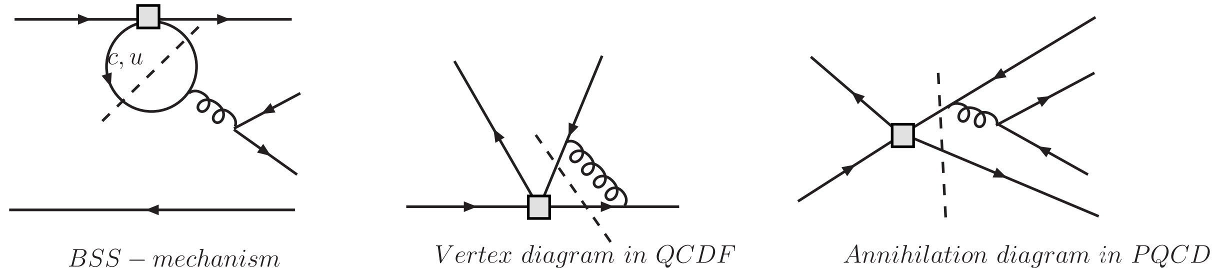
- Three scales:

M_W: Electroweak scale

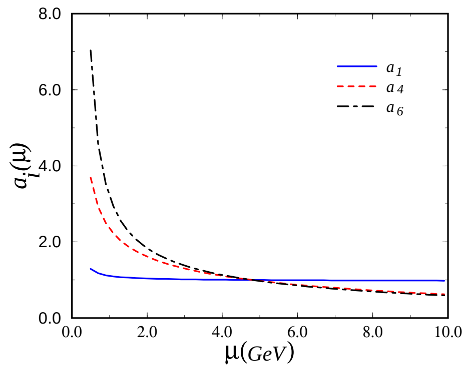
t: hard scale $\sim \sqrt{\bar{\Lambda} M_B}$

Λ_{QCD}: factorization scale

- New sourse of Strong Phase: YYK , H.N. Li, PRD63, 074006 (2001)



- Dynamical enhancement vs chiral enhancement: YYK, H.N. Li, A.I. Sanda, PLB 504,6; PRD63, 054008 (2001)



In general, the amplitude can be expressed as

$$Amp \sim [a_{1,2} \pm a_4 \pm m_0^{P,V}(\mu)\, a_6] \otimes < M_1 M_2 | O | B > \tag{9}$$

with the chiral factors $m_0^P = m_P^2/[m_1(\mu) + m_2(\mu)]$ for pseudoscalar meson and $m_0^V = m_V$.

Figure 8:

For $\mu = 1.5GeV$, $m_0^P \sim 1.5GeV$, however $m_0^P \sim 3.0GeV$ at $\mu = 4.8GeV$. So it is difficult to distinguish tow different methods in $B \to PP$ decays, however, we can do it in $B \to VP, VV$ modes.

- Large absorptive parts from annihilation topologies in two-body decays

$$emission \quad : \quad anni. \ : \ nonfact. = 1 : \frac{2m_K^0}{M_B} : \frac{\bar{\Lambda}}{M_B}$$

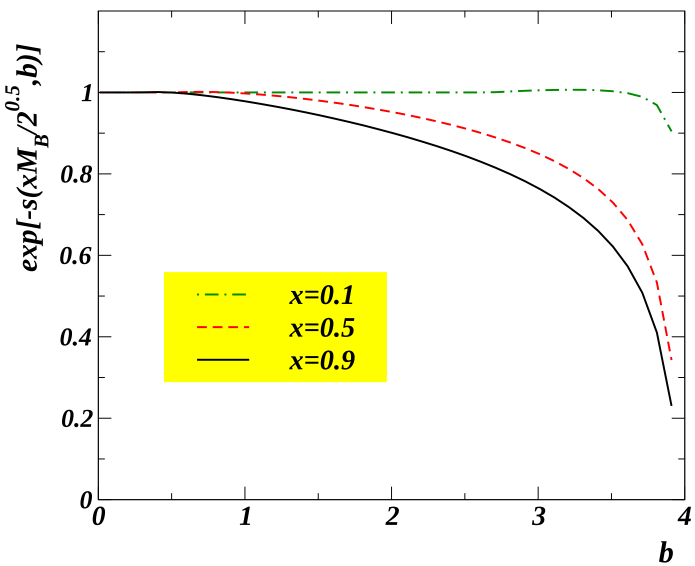
Sudakov factor

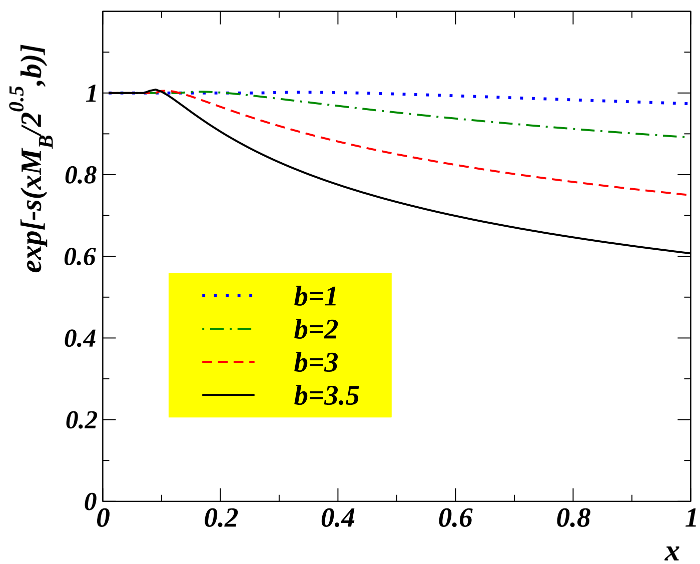
$$S_{k_T} = \exp\left[- s(x_2 P_2^-, b_2) \right] \quad (10)$$

$$s(Q,b) = \int_{1/b}^{Q} \frac{d\mu}{\mu} \left[\ln\left(\frac{Q}{\mu}\right) A(\alpha_s(\mu)) + B(\alpha_s(\mu)) \right]; \quad \frac{\alpha_s(\mu)}{\pi} = \frac{4}{\beta_0} \frac{1}{\ln \frac{\mu^2}{\Lambda^2}} \quad (11)$$

$$A = \frac{4}{3}\frac{\alpha_s}{\pi} + \left[\frac{67}{9} - \frac{\pi^2}{3} - f\frac{10}{27} + \frac{2}{3}\beta_0 \ln\left(\frac{e^{\gamma_E}}{2}\right) \right] \left(\frac{\alpha_s}{\pi}\right)^2 \quad (12)$$

$$B = \frac{2}{3}\frac{\alpha_s}{\pi} \ln\left(\frac{e^{2\gamma_E - 1}}{2}\right); \quad \beta_0 = \frac{33-2f}{3}; \quad f = 4 \quad (13)$$





Spin structures and wave functions

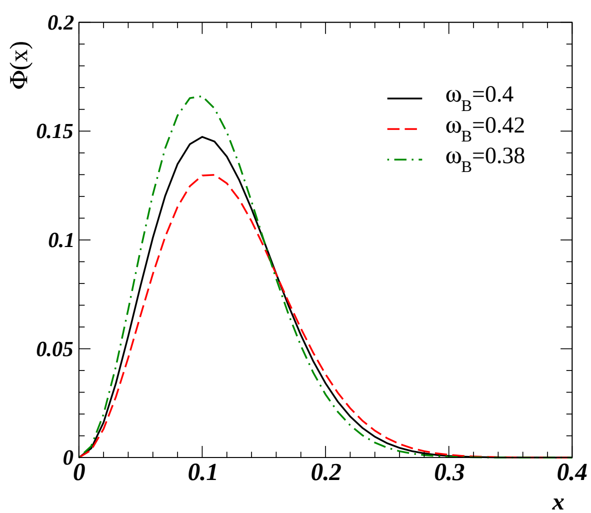
- Procedure for form factor

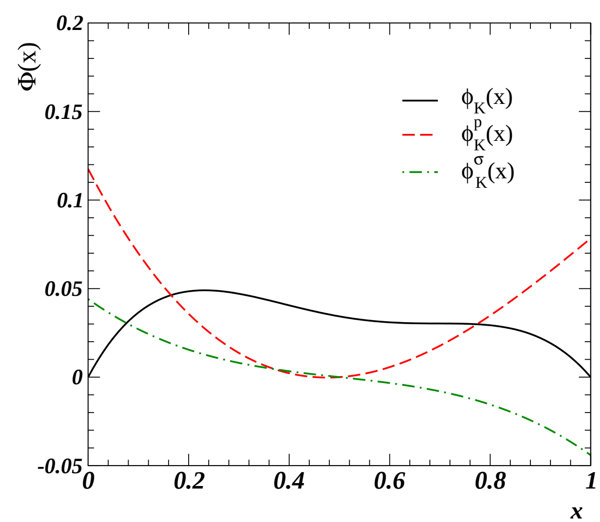
$$\langle K|\bar{b}\gamma_\mu s|B\rangle \propto Tr\Big[\gamma_\alpha T^a \frac{\not p_B - \not k_2 + M_B}{(p_B-k_2)^2 - M_B^2}\gamma_\mu \langle K|\bar{q}s|0\rangle \gamma^\alpha T^a \langle 0|\bar{b}q|B\rangle\Big]\frac{-1}{(k_2-k_1)^2}$$

Spin structures (up to twist-3)

$$\begin{aligned}
\langle 0|\bar{b}(z)_j q(0)_l|B\rangle &\sim ([\not P]_{jl} + M_B[I]_{jl})\gamma_5\phi_B(x)\\
\langle K|\bar{q}(z)_j s(0)_l|0\rangle &\sim [\gamma_5 \not P]_{jl}\phi_K(x) + m_K^0([\gamma_5]_{jl}\phi_K^p(x) + [\gamma_5(\not n_- \not n_+ - 1)]_{jl}\phi_K^\sigma(x))\\
\langle K^*(\varepsilon_L)|\bar{q}(z)_j s(0)_l|0\rangle &\sim M_{K^*}[\not\varepsilon_L]_{lj}\phi_{K^*}(x) + [\not\varepsilon_L \not P]_{lj}\phi_{K^*}^t(x) + M_{K^*}[I]_{lj}\phi_{K^*}^s(x)\\
\langle K^*(\varepsilon_T)|\bar{q}(z)_j s(0)_l|0\rangle &\sim M_{K^*}[\not\varepsilon_T]_{lj}\phi_{K^*}^v(x) + [\not\varepsilon_T \not P]_{lj}\phi_{K^*}^T(x) + M_{K^*}[\gamma_5 \not V]_{lj}\phi_{K^*}^a(x)
\end{aligned}$$

$V_\mu = i\epsilon_{\mu\nu\rho\sigma}\varepsilon_T^\nu P^\rho n_-^\sigma / P\cdot n_-$





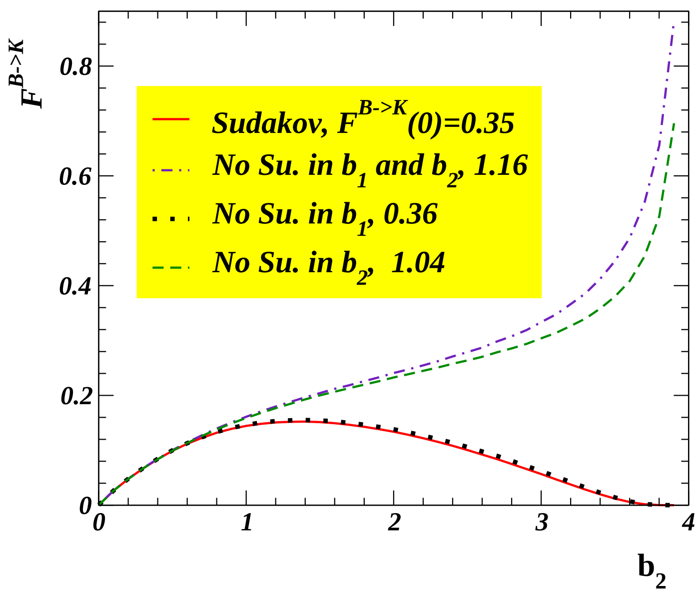
Sudakov factors on form factor

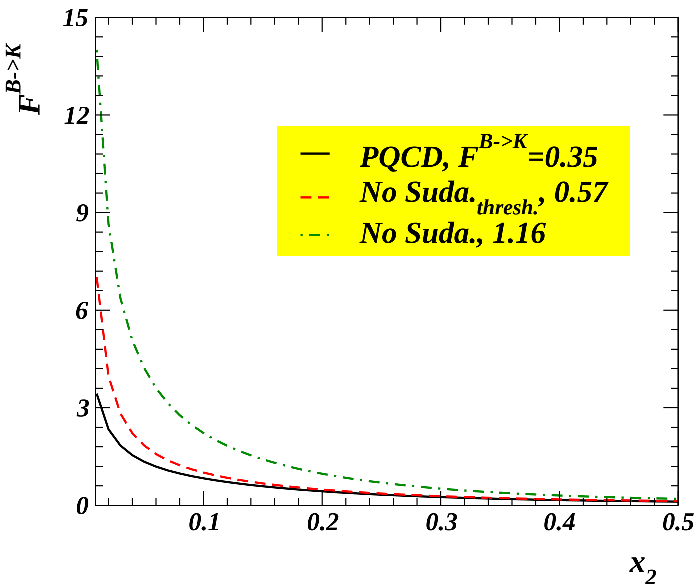
B meson wave function

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

- What are the suppressed effects of Sudakov factors?

$$S_{k_T} \;=\; S_B \otimes S_K = \exp\Big[-s(x_1 P_1^-, b_1) - s(x_2 P_2^-, b_2) - s((1-x_2)P_2^-, b_2)\Big]$$





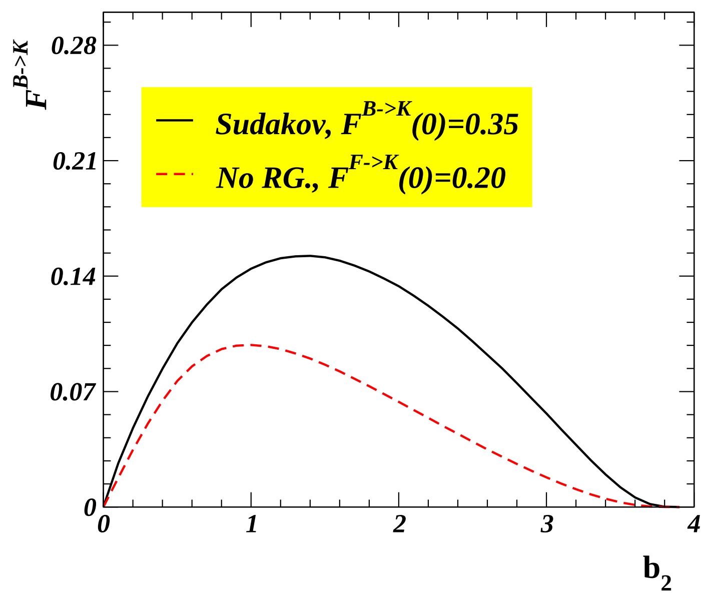
RG factor for Λ scale to hard scale

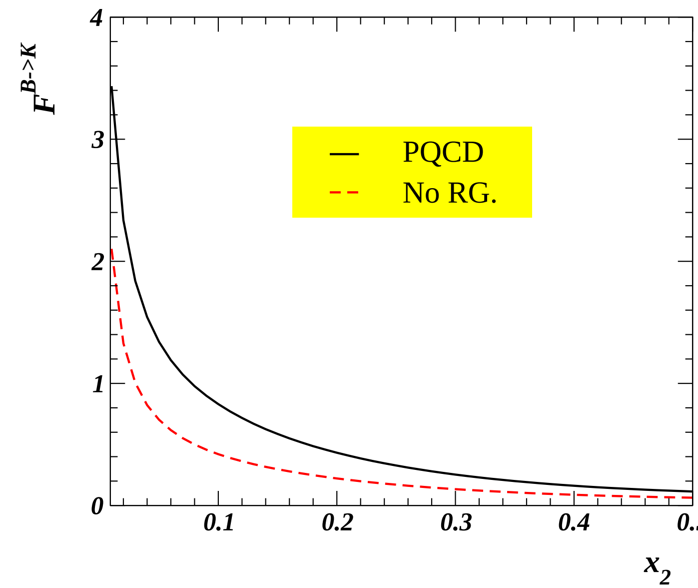
- Renormalization group effects on wave function

$$S_{RG} = \exp\Big[-2\int_{1/b}^{t} \frac{d\bar{\mu}}{\bar{\mu}} \gamma(\alpha_s(\bar{\mu}^2)) \Big]$$

where $\gamma = -\alpha_s/\pi$ is the quark anomalous dimension. The hard scale t could be determined by the condition

$$t_i = max(x_i P_i, 1/b_1, 1/b_2)$$





Summary of LO calculations in PQCD approach

(A) CP Asymmetry of $B \to \pi\pi, K\pi$ decays:

$DCPA(\%)$	BELLE	BABAR	PQCD
$\pi^+ K^-$	$-10.1 \pm 2.5 \pm 0.5$	$-13.3 \pm 3.0 \pm 0.9$	$-12.9 \sim -21.9$
$\pi^0 K^-$	$4 \pm 5 \pm 2$	$6 \pm 6 \pm 1$	$-10.0 \sim -17.3$
$\pi^- \bar{K}^0$	$5 \pm 5 \pm 1$	$-8.7 \pm 4.6 \pm 1.0$	$-0.6 \sim -1.5$
$\pi^+ \pi^-$	$58 \pm 15 \pm 7$	$9 \pm 15 \pm 4$	$16.0 \sim 30.0$
$\pi^+ \pi^0$	$-2 \pm 10 \pm 1$	$1 \pm 10 \pm 2$	0.0
$\pi^0 \pi^0$	$43 \pm 51 \pm 17$	$12 \pm 56 \pm 6$	$20 \sim 40$

World averaged value of DCPV of $B \to K^+ \pi^-$ is $-(11.4 \pm 2.0)\%$ (3.9σ)

Numerical Results (Comparsion with Experimantal data)

(B) Branching ratios of PP,VP and VV decays:

Decay Channel	World Av.	PQCD
$\pi^+\pi^-$	4.6 ± 0.4	$5.93 - 10.99$
$\pi^+\pi^0$	5.5 ± 0.6	$2.72 - 4.79$
$\pi^0\pi^0$	1.51 ± 0.28	$0.10 - 0.65$
$K^\pm\pi^\mp$	18.2 ± 0.8	$12.67 - 19.30$
$K^0\pi^\mp$	24.1 ± 1.3	$14.43 - 26.26$
$K^\pm\pi^0$	12.1 ± 0.8	$7.87 - 14.21$
$K^0\pi^0$	11.5 ± 1.0	$4.46 - 8.06$
$K^\pm K^\mp$	< 0.6	0.06
$K^\pm \bar{K}^0$	< 2.4	1.4
$K^0 \bar{K}^0$	$1.19^{+0.42}_{-0.37}$	1.4
$\phi K^\pm$	9.4 ± 0.7	$9.6 - 14.1$
ϕK^0	$8.3^{+1.2}_{-1.0}$	$7.6 - 11.0$
$\phi K^{*\pm}$	9.7 ± 1.5	$12.6 - 21.2$
ϕK^{*0}	9.5 ± 0.9	$11.5 - 19.8$
$K^{*0}\pi^\pm$	9.76 ± 1.2	$10.2 - 14.6$
$K^{*\pm}\pi^\mp$	12.6 ± 1.8	$8.0 - 11.6$

PQCD:Keum and Sanda,PRD67,054009(2003); Chen, Keum and Li,PRD66,054013(2003)

Comments on large Br. of $\pi^0\pi^0$ in SCET:

$$A(\bar{B} \to M_1 M_2) = A_0^{cc}$$
$$+\frac{G_F m_B^2}{\sqrt{2}}\{f_{M_1}\int_0^1 du\, dz\, T_{1J}(u,z)\ \xi_J^{BM_2}(z)\ \phi^{M_1}(u) \quad :\leftarrow \text{[Factorized piece(T\&P)]}$$
$$+f_{M_2}\ \xi^{BM_2}\ \int_0^1 du T_{1\xi}(u)\ \phi^{M_1}(u)\} \quad :\leftarrow \text{[Non − factorizable term(T\&P)]}$$
$$+\{1 \leftrightarrow 2\}\,.$$

- SCET is more careful in scale separation
- Free parameters $\xi, \xi_J, A_0^{cc} e^{i\phi_{cc}}$ need to be fitted on data
- No annihilation contribution
- Nonperturbative charming penguin term provides large strong phases (from $C_{\pi\pi}$ and $S_{\pi\pi}$);
- T + P is determined from $Br(B^0 \to \pi^+\pi^-)$ and T + C from $Br(B^\pm \to \pi^\pm\pi^0)$:
  $\Longrightarrow$ Large $Br(B^0 \to \pi^0\pi^0) = P - C$ is obtained automatically from isospin relation.
  $\Longrightarrow$ Predicted one ???
- How can we treat high-twist LCDAs contributions in SCET ?

$$A(B \to \pi^0\pi^0) \sim [C_1 + \frac{C_2}{N_c}][\xi^{B\pi} + \xi_J^{B\pi}] + \frac{C_1}{N_c}\ [\int_0^1 dx \frac{\phi_\pi(x)}{x}]\ \xi_J^{B\pi}$$

Comments on large Br. of $\pi^0\pi^0$ and $K^0\pi^0$

How can we understand large Brs. of $B \to \pi^0\pi^0$ and $K^0\pi^0$?

- From global-fit analyis with new experimental data by considering 30% SU(3) flavour symmetry breaking, we have solutions for $K\pi$ decays:[YY Charng, H-n.Li]

$$[\mathrm{Sol-A}] : \frac{T}{P}|_K = 0.26 \cdot e^{-168^o i}; \quad \frac{P_{ew}}{P}|_K = 0.17 \cdot e^{34^o i}; \quad \frac{C}{T}|_K = 1.01 \cdot e^{-18^o i}; \quad \gamma = 61^o$$

$$[\mathrm{Sol-B}] : \frac{T}{P}|_K = 0.28 \cdot e^{-11^o i}; \quad \frac{P_{ew}}{P}|_K = 0.37 \cdot e^{98^o i}; \quad \frac{C}{T}|_K = 0.94 \cdot e^{171^o i}; \quad \gamma = 118^o$$

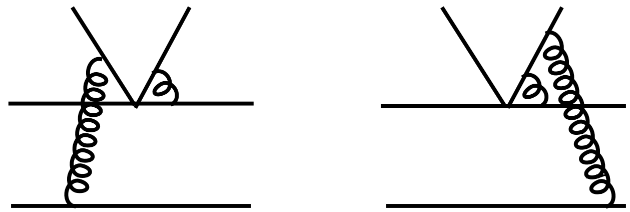
- For $B \to \pi\pi$ with $\phi_2 = 90^o$, we have a solution:

$$\frac{P}{T}|_\pi = 0.38 \cdot e^{150^o i}; \quad \frac{P_{ew}}{P}|_\pi = 0.26 \cdot e^{54^o i}; \quad \frac{C}{T}|_\pi = 0.81 \cdot e^{-43^o i};$$

$$\Longrightarrow \quad \begin{aligned} Br(B^\pm \to \pi^\pm\pi^0) &= 5.7 \cdot 10^{-6}; \\ Br(B^0 \to \pi^\pm\pi^\mp) &= 4.2 \cdot 10^{-6}; \\ Br(B^0 \to \pi^0\pi^0) &= 1.43 \cdot 10^{-6}; \end{aligned}$$

- For Sol.-A, we need a new mechanism to enhance color-suppressed Amps.
- For Sol.-B, we need an enhancement of electroweak-penguin Amps. via extra Z-penguin contributions beyond SM.

- Including Full NLO-corrections in pQCD, we can easily enhance Non-factorizable contributions in both magnitude and strong phases: [YYK:ICFP-2003]



$$Amp(B \to \pi^+\pi^-) = V_u f_\pi F_e a_2 + V_u M_e c_1/3 + ... \quad (14)$$

$$Amp(B \to \pi^+\pi^0) = V_u f_\pi F_e (a_1 + a_2) + V_u M_e (c_1 + c_2)/3 + ... \quad (15)$$

$$Amp(B \to \pi^0\pi^0) = V_u f_\pi F_e a_1 - V_u M_e c_2/3 + ... \quad (16)$$

with $c_2 > 0$, $c_1 < 0$ and $|c_2| > |c_1|$.

- Four or Five times enhanced $M_e \sim F_e$ can accomodate experimental data.

Determination of UT-angle of α in $B \to \pi\pi$:

- Time dependent measurements :

$$A_{cp} \equiv \frac{\Gamma(\bar{B}^0(t) \to f_{cp}) - \Gamma(B^0(t) \to f_{cp})}{\Gamma(\bar{B}^0(t) \to f_{cp}) + \Gamma(B^0(t) \to f_{cp})} = S_f \; sin\Delta m_d t - C_f \; cos\Delta m_d t$$

$$C_f = \frac{1-|\lambda_f|^2}{1+|\lambda_f|^2}; \quad \lambda_f = \frac{q}{p} \cdot \frac{\bar{A}(B^0 \to f)}{A(B^0 \to f)}$$

$$S_f = \frac{2\; Im\lambda_f}{1+|\lambda_f|^2};$$

$$D_f = \frac{2\; Re\lambda_f}{1+|\lambda_f|^2}; \quad \text{measurable if} \Delta\Gamma \neq 0.$$

$$S_f^2 + C_f^2 + D_f^2 = 1 \quad \Rightarrow \quad S_f^2 + C_f^2 \leq 1$$

- In $B^0 \to J/\psi K_s$, Tree/Penguin carry same weak phase :

  $\Rightarrow$ can measure clean $sin2\beta = 0.736 \pm 0.049$:

  $[\beta = (23.8 \pm 2.0)^o]$

- $Br(B^0 \to K^+\pi^-) >> Br(B^0 \to \pi^+\pi^-)$

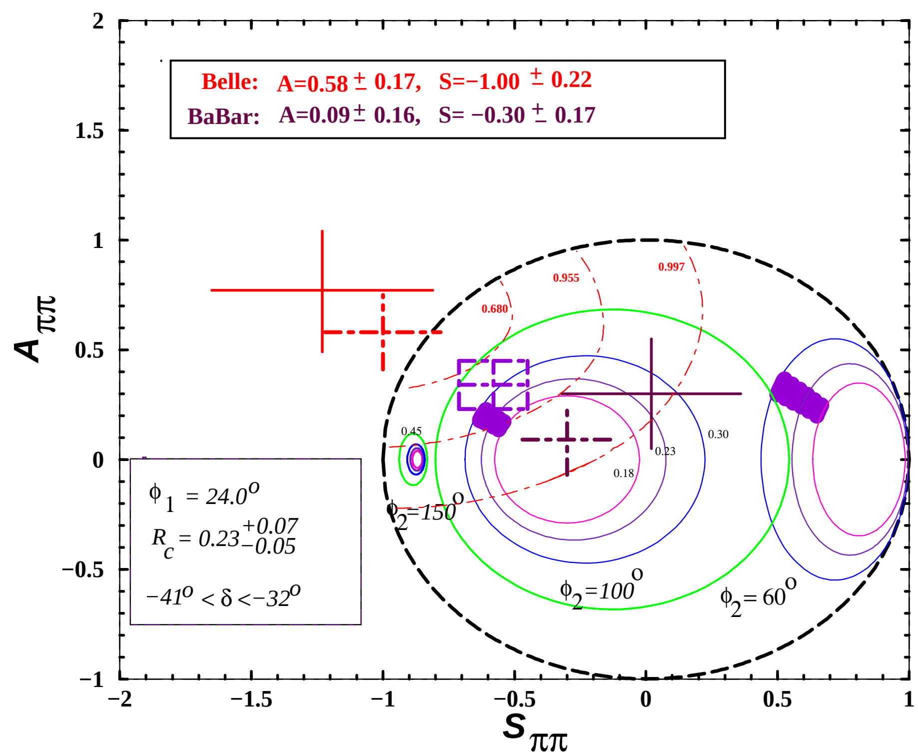
  $\Rightarrow$ Large penguin contribution.

- Theoretical predictions:

$$|P/T| = 0.23^{+0.07}_{-0.05} \qquad \delta = -(37 \pm 5)^o \qquad \text{PQCD[YYK]}$$
$$|P/T| = 0.29 \pm 0.09 \qquad \delta = (9 \pm 15)^o \qquad \text{QCDF[Buchalla \& Safir]}$$

- Data supports large penguin contribution and large strong phase difference:

$$S_{\pi\pi} = -0.58 \pm 0.13 \qquad A_{\pi\pi} = 0.34 \pm 0.11$$



Determination of UT-angle γ in $B \to K\pi$:

- Fleischer and Mannel: tree-penguin interference in $B^0 \to K^+\pi^-(\sim T' + P')$ vs $B^+ \to K^0\pi^+(\sim P')$.

$$
\begin{aligned}
R_K &\equiv \frac{\bar{B}(B^0 \to K^+\pi^-)}{\bar{B}(B^+ \to K^0\pi^+)} \frac{\tau_+}{\tau_0} \\
&= 1 - 2\, r_K \, cos\delta_0 \, cos\phi_3 + r_K^2 \\
&\geq sin^2\phi_3.
\end{aligned}
$$

$\Longrightarrow$ Useful if $R_K < 1$.

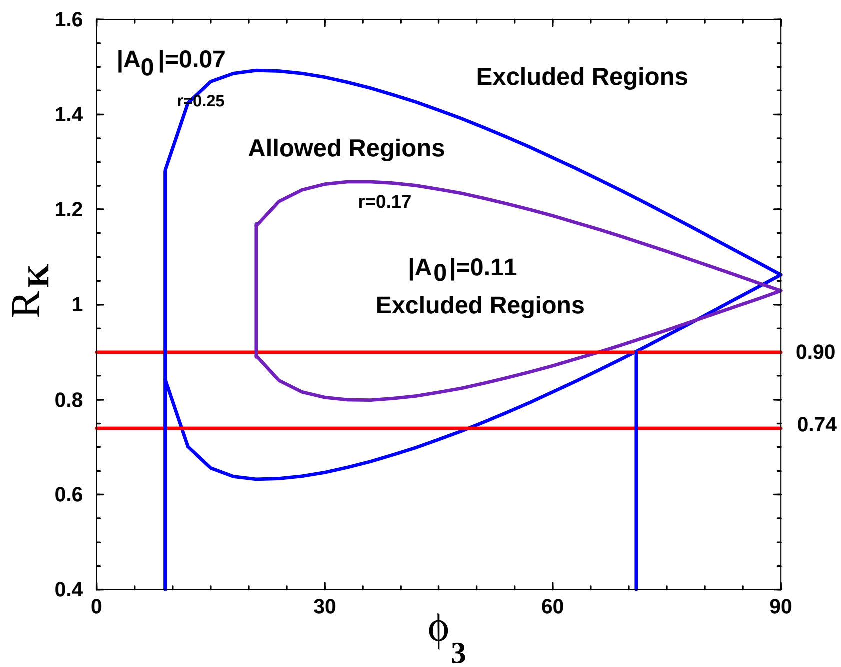
- Grounau and Rosner: [PRD65, 013004(2002)]

$$
\begin{aligned}
A_0 &= \frac{\Gamma(\bar{B}^0 \to K^-\pi^+) - \Gamma(B^0 \to K^+\pi^-)}{\Gamma(B^- \to \bar{K}^0\pi^-) + \Gamma(B^+ \to K^0\pi^+)} \\
&= A_{CP}(B^0 \to K^+\pi^-)\, R_K \\
&= -2\, r_K \; sin\phi_3 \, sin\delta_0, \\
&= -0.09 \pm 0.02
\end{aligned}
$$

After eliminate $sin\delta_0$, we have

$$
R_K = 1 + r_K^2 \pm \sqrt{(4 r_K^2 \; cos^2\phi_3 - A_0^2 \; cot^2\phi_3)}
$$

- Input parameters:
  P' from $B^+ \to K^0\pi^+$, T' from $\Delta S = 0$ decays (e.g. $B \to \pi\ell\nu$) and Flavour SU(3).
  $\Longrightarrow r_K = 0.184 \pm 0.044$ in QCDF.
  PQCD provides 0.21 ± 0.04 $\Longrightarrow$ $9^o < \gamma(\phi_3) < 72^o$.



CP violations in $B \to \rho\pi$:

- Charge Asymmetry:

$$A_{\rho\pi} = \frac{N(\rho^+\pi^-) - N(\rho^-\pi^+)}{N(\rho^+\pi^-) + N(\rho^-\pi^+)}$$

- CP Asymmetry from Time-dependent CPV analysis:

$$A_{\rho^+\pi^-} = \frac{\Gamma(\bar{B}^0 \to \rho^+\pi^-) - \Gamma(B^0 \to \rho^-\pi^+)}{\Gamma(\bar{B}^0 \to \rho^+\pi^-) + \Gamma(B^0 \to \rho^-\pi^+)} = \frac{A_{\rho\pi} - C_{\rho\pi} - A_{\rho\pi} \cdot \Delta C_{\rho\pi}}{1 - \Delta C_{\rho\pi} - A_{\rho\pi} \cdot C_{\rho\pi}};$$

$$A_{\rho^-\pi^+} = \frac{\Gamma(\bar{B}^0 \to \rho^+\pi^-) - \Gamma(B^0 \to \rho^-\pi^+)}{\Gamma(\bar{B}^0 \to \rho^+\pi^-) + \Gamma(B^0 \to \rho^-\pi^+)} = -\frac{A_{\rho\pi} + C_{\rho\pi} + A_{\rho\pi} \cdot \Delta C_{\rho\pi}}{1 + \Delta C_{\rho\pi} + A_{\rho\pi} \cdot C_{\rho\pi}};$$

- CP asymmetry in $B \to \rho\pi$ $(\gamma = 60^o; m_0^\pi = 1.3\ GeV)$

	$DCPA(\%)$	PQCD	BaBar	Belle	W.A. data
**	$A_{\rho\pi}$	-10.3 ± 1.3	$-11.4 \pm 6.2 \pm 2.7$	–	-11.4 ± 0.7
O	A_{-+}	$11.6^{+2.0}_{-1.5}$	$-21 \pm 11 \pm 4$	$-2 \pm 16^{+5}_{-2}$	-15 ± 9
O	A_{+-}	$-7.1^{+0.1}_{-0.2}$	$-47 \pm 15 \pm 6$	$-53 \pm 29^{+9}_{-4}$	-48^{+14}_{-15}
**	A_{-0}	$17.5^{+2.7}_{-2.6}$	$24 \pm 16 \pm 6$	$6 \pm 19^{+4}_{-6}$	16 ± 13
**	A_{0-}	-23.2 ± 3.0	$-19 \pm 11 \pm 2$	$--$	-19 ± 11

(**: Direct CPV measurements; O: Time-dependent CPV analysis)

Polarization in VV modes

Pol. fraction	Belle	BaBar
$R_L(\phi K^{*+})$		$0.46 \pm 0.12 \pm 0.03$
$R_L(\phi K^{*0})$	$0.43 \pm 0.09 \pm 0.04$	$0.52 \pm 0.07 \pm 0.02$
$R_\perp(\phi K^{*0})$	$0.41 \pm 0.10 \pm 0.02$	$0.27 \pm 0.07 \pm 0.02$
$R_L(\rho^0 K^{*+})$		$0.96^{+0.04}_{-0.15} \pm 0.04$
$R_L(\rho^0 \rho^+)$	$0.95 \pm 0.11 \pm 0.02$	$0.97^{+0.03}_{-0.07} \pm 0.04$
$R_L(\rho^+ \rho^-)$		$0.98^{+0.02}_{-0.08} \pm 0.03$

Table 1: Polarization fractions in $B \to VV$ transitions.

The power counting rules for the emission topologies are:

$$R_L \sim 1 \; , \quad R_\parallel \sim R_\perp \sim O(m_\phi^2/m_B^2) \; , \tag{17}$$

and those for the annihilation topologies from $O_{5,6}$ are

$$R_L \sim R_\parallel \sim R_\perp \sim O(m_{K^*}^2/m_B^2, m_\phi^2/m_B^2) \; . \tag{18}$$

PQCD results

Mode	$\|A_0\|^2$	$\|A_\parallel\|^2$	$\|A_\perp\|^2$	$\phi_\parallel(rad.)$	$\phi_\perp(rad.)$
ϕK^{*0}(I)	0.923	0.040	0.035	π	π
(II)	0.860	0.072	0.063	3.30	3.33
(III)	0.833	0.089	0.078	2.37	2.34
(IV)	0.750	0.135	0.115	2.55	2.54
ϕK^{*+}(I)	0.923	0.040	0.035	π	π
(II)	0.860	0.072	0.063	3.30	3.33
(III)	0.830	0.094	0.075	2.37	2.34
(IV)	0.748	0.133	0.111	2.55	2.54

Table 2: (I) Without nonfactorizable and annihilation contributions, (II) add only nonfactorizable contribution, (III) add only annihilation contribution, (IV) add both nonfactorizable and annihilation contributions.

A solution within SM

- How can we reduce the branching ratios about 10×10^{-6} from 15×10^{-6} and longitudial fraction from 0.75 to 0.52 ?

Since H_{00} and $H_{\pm\pm}$ are given by:

$$H_{00} = \frac{G_F}{\sqrt{2}} \frac{a^n(\phi K^*) f_\phi}{2m_{K^*}} \left[\left(m_B^2 - m_{K^*}^2 - m_\phi^2 \right) (m_B + m_{K^*}) A_1^{BK^*}(m_\phi^2) - \frac{4m_B^2 p_c^2}{m_B + m_{K^*}} A_2^{BK^*}(m_\phi^2) \right.$$

$$H_{\pm\pm} = \frac{G_F}{\sqrt{2}} a^n(\phi K^*) m_\phi f_\phi \left[(m_B + m_{K^*}) A_1^{BK^*}(m_\phi^2) \mp \frac{2m_B p_c}{m_B + m_{K^*}} V^{BK^*}(m_\phi^2) \right]$$

where, $a^n(\phi K^*) = a_3^n + a_4^n + a_5^n - (a_7^n + a_9^n + a_{10}^n)/2$.

It is possible when we can enhance A_2 form factor value.
$\Rightarrow$ Longitudinal LCDAs have to be changed.
Recent paper by Braun and Lenz argued that the LCDAS of K^* by P. Ball is not correct even in twist-2 contributions.

We have to wait the further calculation for twist-3 contributions by Braun and Lenz.

New Physics Contributions

The SM-effective Hamiltonian describing the decay $b \to s\bar{s}s$ is given as

$$\mathcal{H}_{eff} = \frac{G_F}{\sqrt{2}} V_{qb} V_{qd}^* \Big[\sum_{j=3}^{10} C_j O_j + C_g O_g \Big], \tag{19}$$

where $q = u,\ c$. $O_3, \cdots, O_6$ and $O_7, \cdots, O_{10}$ are the standard model QCD and electroweak penguin operators respectively, and O_g is the gluonic magnetic penguin operator.

The NP Hamiltonian is given

$$\mathcal{H}_{eff}^{NP} \propto \left[\sum_i (C_i^{NP} O_i + \tilde{C}_i^{NP} \tilde{O}_i) + C_g O_g + \tilde{C}_g \tilde{O}_g \right] , \tag{20}$$

where O_i (O_g), are the standard model like QCD (magnetic) penguin operators with current structure $(\bar{s}b)_{V-A}(\bar{s}s)_{V\pm A}$ and C_i^{NP}, C_g^{NP} are the new Wilson coefficients. The operators $\tilde{O}_i$ $(\tilde{O}_g)$ are obtained from O_i (O_g) by exchanging $L \leftrightarrow R$.

The NP contributions to the different helicity amplitudes are given as

$$\begin{aligned} A^{NP}(\bar{B}_d^0 \to \phi K^{*0})_{0,\|} &\propto C_i^{NP} - \tilde{C}_i^{NP} , \\ A^{NP}(\bar{B}_d^0 \to \phi K^{*0})_{\perp} &\propto C_i^{NP} + \tilde{C}_i^{NP} . \end{aligned} \tag{21}$$

New Physics-II

Thus in the presence of new physics, the different amplitudes can be given as

$$\begin{aligned} A_{0,\parallel} &= A_{0,\parallel}^{SM} + A_{0,\parallel}^{NP} = A_{0,\parallel}^{SM}\left[1 + e^{i\phi_N}(r_{0,\parallel} - \tilde{r}_{0,\parallel}\right] \ , \\ A_{\perp} &= A_{\perp}^{SM} + A_{\perp}^{NP} = A_{\perp}^{SM}\left[1 + e^{i\phi_N}(r_{\perp} + \tilde{r}_{\perp})\right] \ , \end{aligned} \tag{22}$$

where r_λ,$\tilde{r}_\lambda$ with $(\lambda = 0, \|, \perp)$ are the ratio of NP to SM amplitudes.

Gluino Mediated SUSY FCNC

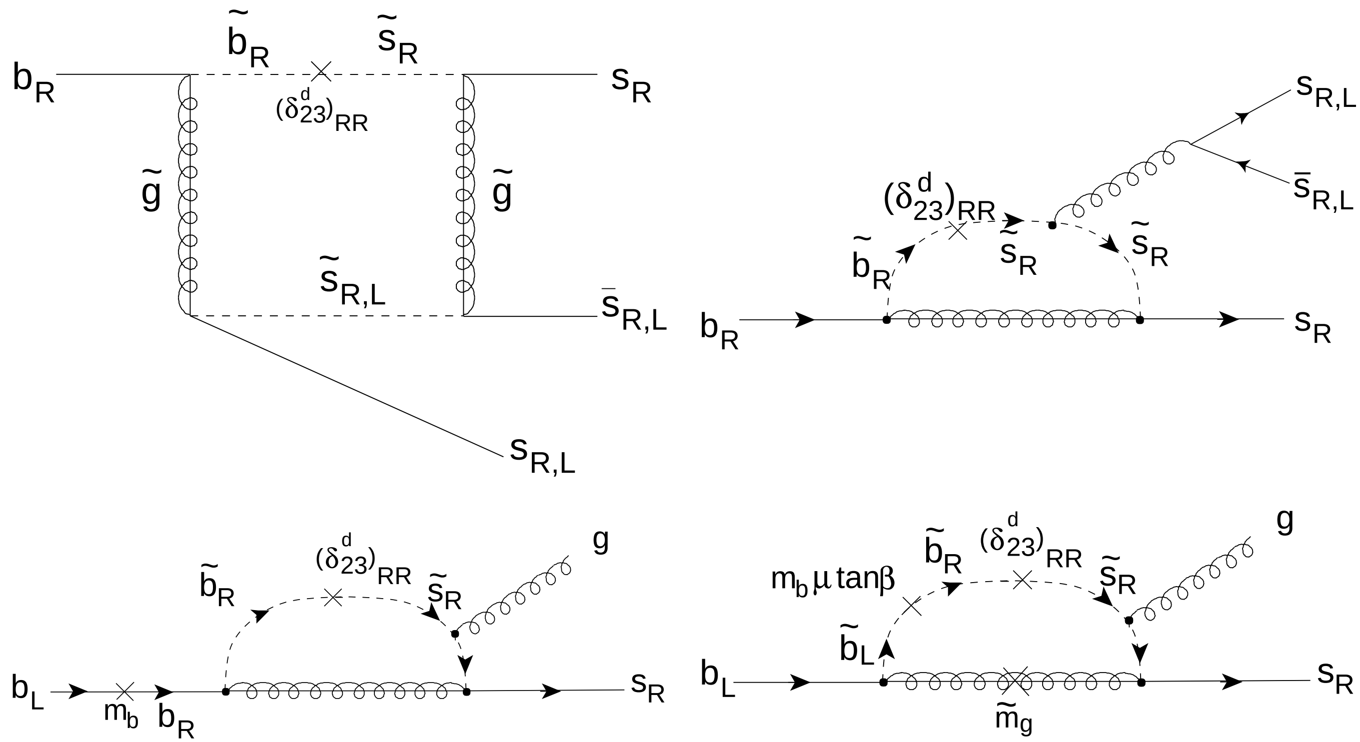


Figure 2: Box and penguin contributions to the $b \to s\bar{s}s$ transition. The bottom row shows contributions to the chromo-dipole operator. We show the mass insertions for pedagogical purposes but perform calculations in the mass eigenbasis.

SUSY-I

The new effective $\Delta B = 1$ Hamiltonian relevant for the $\bar{B}_d^0 \to \phi K^*$ process arising from new penguin/box diagrams with gluino-squark in the loops is given as

$$\mathcal{H}_{eff}^{SUSY} = -\frac{G_F}{\sqrt{2}} V_{tb} V_{ts}^* \left[\sum_{i=3}^{6} \left(C_i^{NP} O_i + \tilde{C}_i^{NP} \tilde{O}_i \right) + C_g^{NP} O_g + \tilde{C}_g^{NP} \tilde{O}_g \right] , \qquad (23)$$

with $x = m_{\tilde{g}}^2 / m_{\tilde{q}}^2$;

$$\begin{aligned}
C_3^{NP} &\simeq -\frac{\sqrt{2}\alpha_s^2}{4G_F V_{tb} V_{ts}^* m_{\tilde{q}}^2} \left(\delta_{LL}^d\right)_{23} \left[-\frac{1}{9} B_1(x) - \frac{5}{9} B_2(x) - \frac{1}{18} P_1(x) - \frac{1}{2} P_2(x) \right] , \\
C_4^{NP} &\simeq -\frac{\sqrt{2}\alpha_s^2}{4G_F V_{tb} V_{ts}^* m_{\tilde{q}}^2} \left(\delta_{LL}^d\right)_{23} \left[-\frac{7}{3} B_1(x) + \frac{1}{3} B_2(x) + \frac{1}{6} P_1(x) + \frac{3}{2} P_2(x) \right] , \\
C_5^{NP} &\simeq -\frac{\sqrt{2}\alpha_s^2}{4G_F V_{tb} V_{ts}^* m_{\tilde{q}}^2} \left(\delta_{LL}^d\right)_{23} \left[\frac{10}{9} B_1(x) + \frac{1}{18} B_2(x) - \frac{1}{18} P_1(x) - \frac{1}{2} P_2(x) \right] , \\
C_6^{NP} &\simeq -\frac{\sqrt{2}\alpha_s^2}{4G_F V_{tb} V_{ts}^* m_{\tilde{q}}^2} \left(\delta_{LL}^d\right)_{23} \left[-\frac{2}{3} B_1(x) + \frac{7}{6} B_2(x) + \frac{1}{6} P_1(x) + \frac{3}{2} P_2(x) \right] \\
C_g^{NP} &\simeq -\frac{2\sqrt{2}\pi\alpha_s}{2G_F V_{tb} V_{ts}^* m_{\tilde{q}}^2} \left[\left(\delta_{LL}^d\right)_{23} \left(\frac{3}{2} M_3(x) - \frac{1}{6} M_4(x) \right) \right. \\
&\qquad \left. + \left(\delta_{LR}^d\right)_{23} \left(\frac{m_{\tilde{g}}}{m_b} \right) \frac{1}{6} \left(4B_1(x) - \frac{9}{x} B_2(x) \right) \right] . \qquad (24)
\end{aligned}$$

SUSY-II

1. For the numerical analysis, we fix the SUSY parameter as $m_{\tilde{q}} = m_{\tilde{g}} = 500$ GeV, $\alpha_s(M_W) = 0.119$, $\alpha_s(m_b = 4.4$ GeV$)$=0.221, $\alpha_s(m_t = 175$ GeV$)$=0.107.
2. Assuming that all the mass insertion parameters $(\delta^d_{AB})_{23}$ have a common weak phase, we obtain the fraction of new physics amplitudes as

$$\begin{aligned} R_0 &= 0.18\left[(\delta^d_{LL})_{23} - (\delta^d_{RR})_{23}\right] + 90.65\left[(\delta^d_{LR})_{23} - (\delta^d_{RL})_{23}\right] \ , \\ R_{\parallel} &= 0.074\left[(\delta^d_{LL})_{23} - (\delta^d_{RR})_{23}\right] + 71.50\left[(\delta^d_{LR})_{23} - (\delta^d_{RL})_{23}\right] \ , \\ R_{\perp} &= 0.07\left[(\delta^d_{LL})_{23} + (\delta^d_{RR})_{23}\right] + 70.14\left[(\delta^d_{LR})_{23} + (\delta^d_{RL})_{23}\right] \ . \end{aligned} \tag{25}$$

3. $(\delta^d_{AB})_{23}$, with $A, B = (L, R)$ are constrained by the experimental value of $B \to X_s\gamma$ decay:

$$|(\delta^d_{LL,RR})_{23}| < 1 \quad \text{and} \quad |(\delta^d_{LR,RL})_{23}| \le 1.6 \times 10^{-2} \tag{26}$$

4. The new physics parameters arising from the LR and RL mass insertions;

$$\begin{aligned} r_0 = \tilde{r}_0 \le 1.45 \ , \\ r_{\parallel} = \tilde{r}_{\parallel} \le 1.14 \ , \\ r_{\perp} = \tilde{r}_{\perp} \le 1.12 \ . \end{aligned} \tag{27}$$

SUSY-Plot

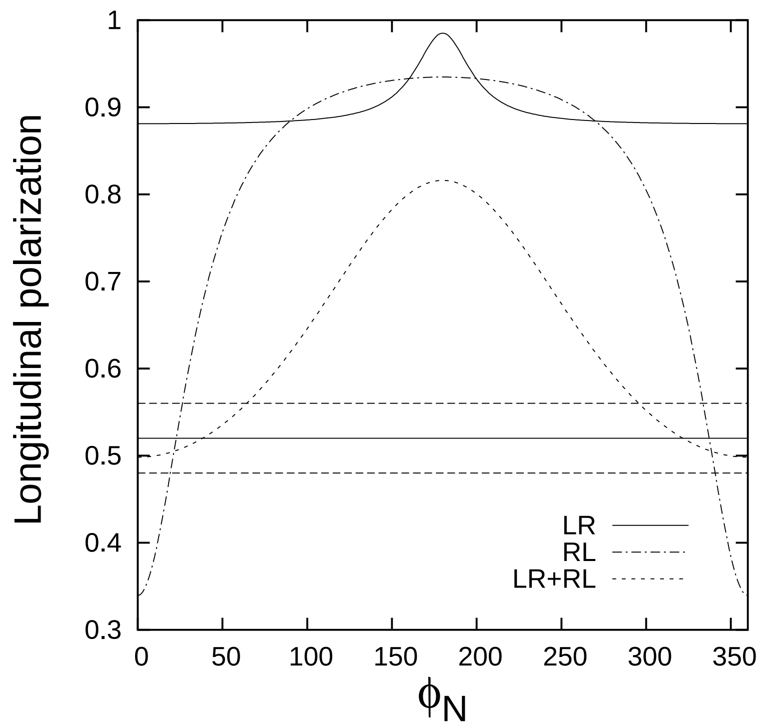


Figure 3: The longitudinal polarization fraction (f_L) of $\bar{B}_d^0 \rightarrow \phi K^{*0}$ process versus the weak phase ϕ_N (in degree). The horizontal solid line represents the experimental central value and the dashed lines represent the 1σ range.

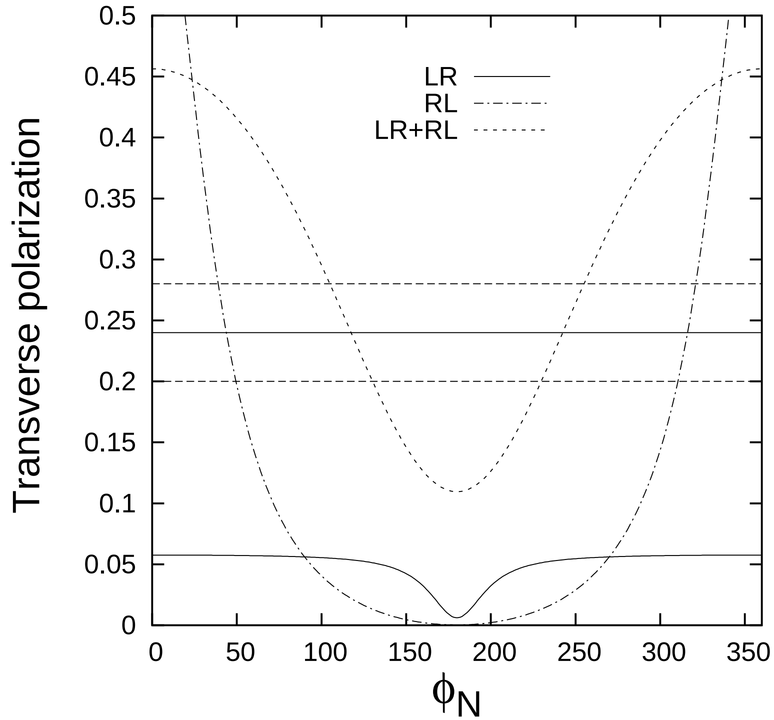


Figure 4: The transverse polarization fraction ($f_\perp$) of the $\bar{B}_d^0 \to \phi K^{*0}$ process versus the weak phase ϕ_N (in degree). The horizontal solid line represents the experimental central value and the dashed lines represent the 1σ range.

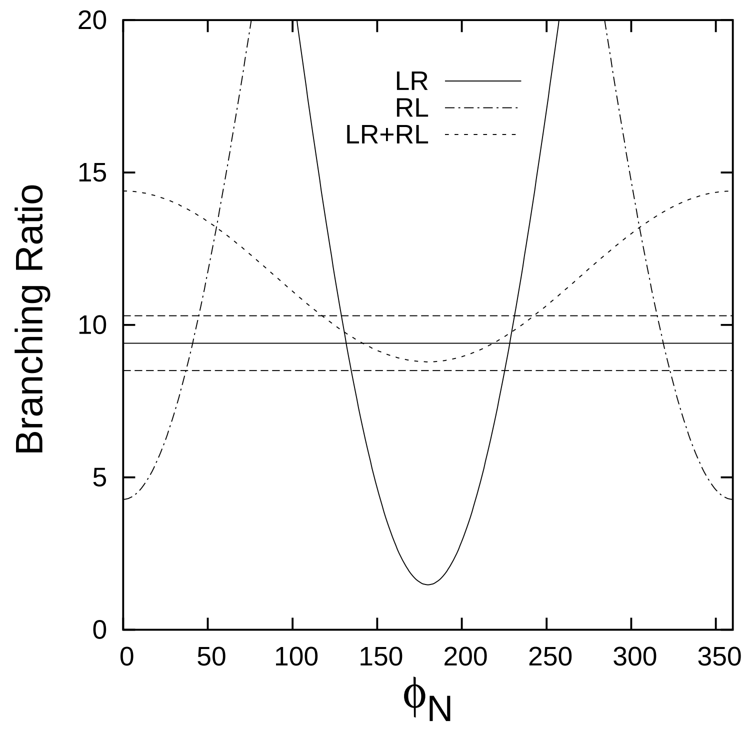


Figure 5: The branching ratio of $\bar{B}_d^0 \to \phi K^{*0}$ process (in units of 10^{-6}) versus the phase ϕ_N (in degree). The horizontal solid line represents the experimental central value and the dashed lines represent the 1σ range.

Part-II

Charmful B-decays and determination UT-angle γ

$B \to D^{(*)}M$ *Decays*

Table 3: Branching Ratios, Amplitudes and a_2/a_1 in the $B \to D\pi$ decays.

Quantities	PQCD	Exp. Data
C_D	0.7 ± 0.2	World Ave.
Branching ratios (Unit: 10^{-3})		
$B^- \to D^0\pi^-$	4.54 – 5.48	5.3 ± 0.5
$\overline{B^0} \to D^+\pi^-$	2.37 – 3.16	3.0 ± 0.4
$\overline{B^0} \to D^0\pi^0$	0.24 – 0.22	0.29 ± 0.05
Amplitudes (Unit: 10^{-2})		
$\mathcal{T}$	$12.00 + 2.18$ i	-
$\mathcal{C}$	$2.89 - 5.07$ i	-
$\mathcal{E}$	$-0.43 - 1.66$ i	-
a_2/a_1 without anni.		
$\lvert(a_2/a_1)_{eff}\rvert$	0.42 – 0.50	$0.35 \sim 0.60$ (HYCheng)
$arg(a_2/a_1)$	-68.8^0 – -73.4^0	$\pm 59^0$
a_2/a_1 with anni.		
$\lvert(a_2/a_1)_{eff}\rvert$	0.37 – 0.45	
$arg(a_2/a_1)$	-47.9^0 – -49.1^0	

- $\mathcal{T}$ = the color-allowed external W-emission Amplitude; $\mathcal{T} = f_\pi \xi_{ext} + \mathcal{M}_{ext}$,

- $\mathcal{C}$ = the color-suppressed internal W-emission Amplitude; $\mathcal{C} = f_D \xi_{int} + \mathcal{M}_{int}$,
- $\mathcal{E}$ = the W-exchanged Amplitude (Annihilation Amplitude) $\mathcal{E} = f_B \xi_{exc} + \mathcal{M}_{exc}$.

We have the following relations with $\omega_B = 0.4\,GeV$, $m_0^\pi = 1.4\,GeV$;

$$\frac{\mathcal{C}-\mathcal{E}}{\mathcal{T}+\mathcal{C}}\Big|_{D\pi} = 0.31 \cdot e^{-i\,56.8^0}, \quad \frac{\mathcal{C}-\mathcal{E}}{\mathcal{T}+\mathcal{E}}\Big|_{D\pi} = 0.41 \cdot e^{-i\,48.2^0}, \quad \frac{\mathcal{T}+\mathcal{E}}{\mathcal{T}+\mathcal{C}}\Big|_{D\pi} = 0.76 \cdot e^{+i\,13.6^0}$$

Table 4: Branching Ratios, Amplitudes and a_2/a_1 in the $B \to D^*\pi$ decays.

Quantities	PQCD	Exp. Data
C_D	0.7 ± 0.2	World Ave.
Branching ratios (Unit: 10^{-3})		
$B^- \to D^{*0}\pi^-$	4.44 – 5.33	4.60 ± 0.40
$\overline{B^0} \to D^{*+}\pi^-$	2.34 – 3.14	2.76 ± 0.21
$\overline{B^0} \to D^{*0}\pi^0$	0.21 – 0.24	0.17 ± 0.05
a_2/a_1 without anni.		
$\lvert(a_2/a_1)_{eff}\rvert$	0.40 – 0.48	
$arg(a_2/a_1)$	-78.3^0 – -69.0^0	

Extraction of $2\alpha + \gamma$ from $B \to D^*\pi$:

Extraction of γ from $Im\lambda = r\ sin(2\beta + \gamma - \delta)$

- Theoretical Input:

$$\text{Right sign}\ :(CFD) \qquad A = Amp(B^0 \to D^{*-}\pi^+) = |V_{cb}^* V_{ud}|\ e^{i\delta_a}\ |\tilde{A}|$$

$$\text{Wrong sign}\ :(DCSD) \qquad B = Amp(B^0 \to D^{*+}\pi^-) = |V_{ub}^* V_{cd}|\ e^{i\delta_b}\ |\tilde{B}|$$

where

$$\tilde{A} = f_\pi\ FDT + MDT + f_B\ FAT + MAT$$

$$\tilde{B} = f_D\ F\pi T + M\pi T + f_B\ FAT + MAT$$

Numerical Results:

$$\tilde{A} = N \cdot (1.19 \times 10^{-1}, -8.29 \times 10^{-3}), \qquad \delta_a = -4.0^o;$$
$$\tilde{B} = N \cdot (-4.54 \times 10^{-2}, -1.02 \times 10^{-2}), \qquad \delta_b = (\pi + 12.6)^o;$$

Hence we get

$$\delta = \delta_b - \delta_a = \pi + (16.6^{+12.6}_{-9.0})^o; \qquad r = \left|\frac{\overline{B}}{A}\right| = 0.0212 \quad \text{with } \mathrm{R_b} = 0.38 \text{ and } \phi_3 = 80^{\mathrm{o}}$$

Figures:

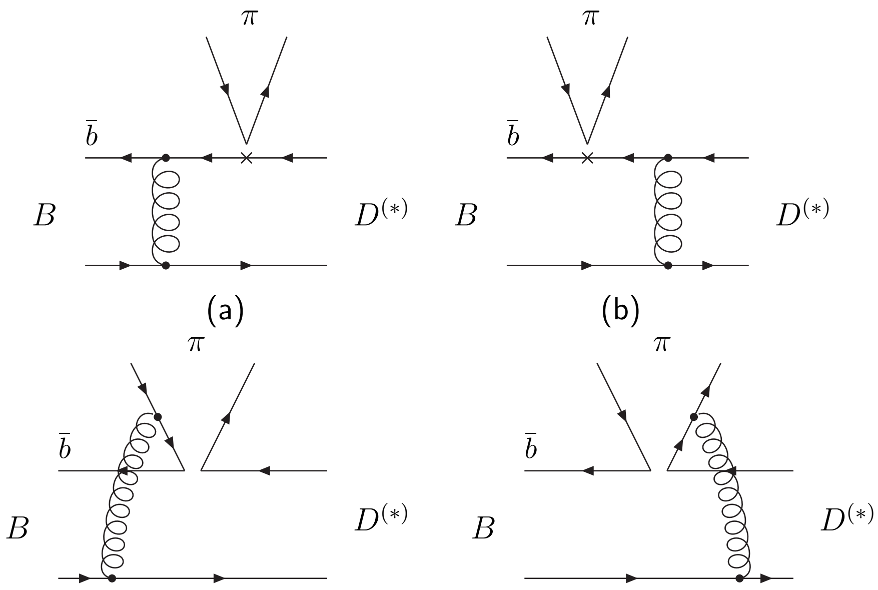


Figure 6: Color-allowed emission diagrams contributing to the $B \to D^{(*)}\pi$ decays.

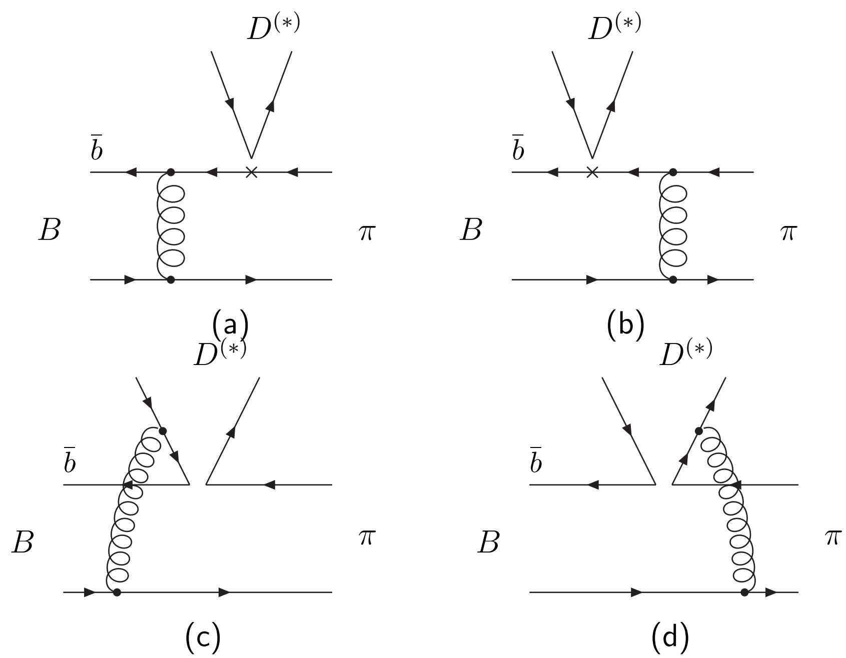


Figure 7: Color-suppressed emission diagrams contributing to the $B \to D^{(*)}\pi$ decays.

Part-III

Radiative $B \to V\gamma$ in PQCD

Experimental Mesurements in $B \to V\gamma$ decays

Decay Modes	CLEO	BaBar	Belle
Br$(B \to K^{*0}\gamma)$ (10^{-5})	$4.55 \pm 0.70 \pm 0.34$	$4.23 \pm 0.40 \pm 0.22$	$4.09 \pm 0.21 \pm 0.19$
Br$(B \to K^{*\pm}\gamma)(10^{-5})$	$3.76 \pm 0.86 \pm 0.28$	$3.83 \pm 0.62 \pm 0.22$	$4.40 \pm 0.33 \pm 0.24$
Br$(B \to \rho^0\gamma)$ (10^{-6})	< 17	< 1.2	< 2.6
Br$(B \to \rho^+\gamma)$ (10^{-6})	< 13	< 2.1	< 2.7
Br$(B \to \omega\gamma)$ (10^{-6})		< 1.0	< 4.4
$\mathcal{A}_{CP}(B \to K^{*0}\gamma)$ $(\%)$	$8 \pm 13 \pm 3$	$-3.5 \pm 9.4 \pm 2.2$	$-6.1 \pm 5.9 \pm 1.8$
$\mathcal{A}_{CP}(B \to K^{*+}\gamma)$ $(\%)$			$+5.3 \pm 8.3 \pm 1.6$

Table 5: Experimental measurements of the averaged branching ratios and CP-violating asymmetries of the exclusive $B \to V\gamma$ decays for $V = K^*, \rho$ and ω.

- World Averaged Data-:
- Br$(B \to K^{*0}\gamma)$=$(4.17 \pm 0.23) \times 10^{-5}$,
- Br$(B \to K^{*\pm}\gamma)$=$(4.18 \pm 0.32) \times 10^{-5}$.

Effective Hamiltonian for exclusive $B \to V\gamma$ decay

Up to dimension 6 Ops. with $m_s = 0$,

$$\mathcal{H}_{eff} = \frac{G_F}{\sqrt{2}} \sum_{p=u,c} \lambda_p^s \left[C_1 Q_1^p + C_2 Q_2^p + \sum_{j=3}^{8} C_j Q_j \right] \tag{28}$$

where $\lambda_p^q = V_{pq}^* V_{pb}$ for $q = (d, s)$ is the Cabibbo-Kobayashi-Maskawa (CKM) factor. And the current-current, QCD penguin, electromagnetic and chromomagnetic dipole operators in the standard basis are given:

$$\begin{aligned}
Q_1^p &= (\bar{s}p)_{V-A}(\bar{p}b)_{V-A}\,, \qquad Q_2^p = (\bar{s_\alpha}p_\beta)_{V-A}(\bar{p_\beta}b_\alpha)_{V-A}\,,\\
Q_3 &= (\bar{s}b)_{V-A}\sum(\bar{q}q)_{V-A}\,, \qquad Q_4 = (\bar{s_\alpha}b_\beta)_{V-A}\sum(\bar{q_\beta}q_\alpha)_{V-A}\,,\\
Q_5 &= (\bar{s}b)_{V-A}\sum(\bar{q}q)_{V+A}\,, \qquad Q_6 = (\bar{s_\alpha}b_\beta)_{V-A}\sum(\bar{q_\beta}q_\alpha)_{V+A}\,,\\
Q_7 &= \frac{e}{8\pi^2} m_b \bar{s_\alpha}\sigma^{\mu\nu}(1+\gamma_5)b_\alpha F_{\mu\nu}\,,\\
Q_8 &= \frac{g}{8\pi^2} m_b \bar{s_\alpha}\sigma^{\mu\nu}(1+\gamma_5)T^a_{\alpha\beta}b_\beta G^a_{\mu\nu}\,,
\end{aligned} \tag{29}$$

where T_a $(a = 1, \ldots, 8)$ stands for $SU(3)_c$ generators, α and β are color indices, e and g_s are the electromagnetic and strong coupling constants, Q_1 and Q_2 are current-current operators, $Q_3 - Q_6$ are the QCD penguin operators, Q_7 and Q_8 are the electromagnetic and chromomagnetic penguin operators. The effective Hamiltonian for $b \to d\gamma$ is obtained from Eqs.(28) - (29) by the replacement $s \to d$.

Magnetic Penguin Op. and Chromomagnetic penguin Op. contributions

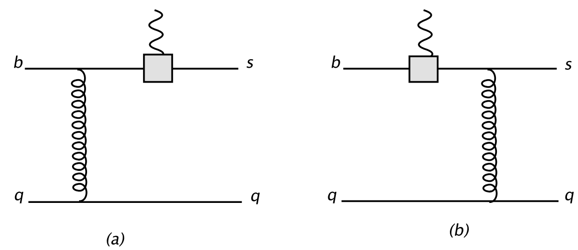


Figure 8: Feynman diagrams of Magnetic penguin operator O_7 contributions in the decay $B \to K^*\gamma$. The spring(wiggle) line here and in subsequent figures represents a gluon(photon).

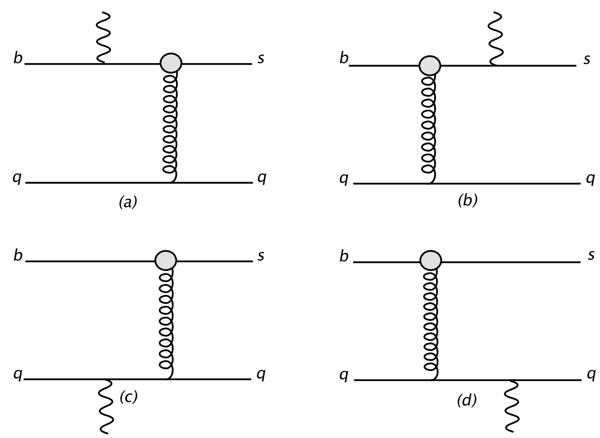


Figure 9: Feynman diagrams of chromomagetic penguin operator O_8 contributions in the decay $B \to K^*\gamma$. Photon is emitted from the flavour-changing quark line in (a) and (b); photon radiation off the spectator quark line in (c) and (d).

O_2-penguin contributions

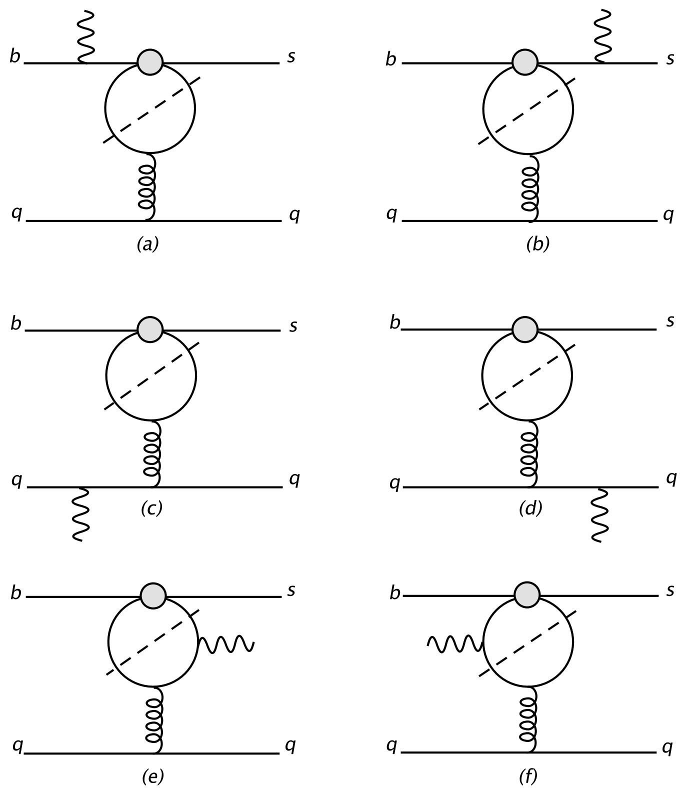


Figure 10: Feynman diagrams of O_2-penguin contributions in the decay $B \to K^*\gamma$. Photon is emitted from the flavour-changing quark line in (a) and (b); photon radiation off the spectator quark line in (c) and (d); (e) and (f) for the case when both the photon and the virtual gluon are emitted from the internal quark loop line.

Annihilation and longdistance contributions

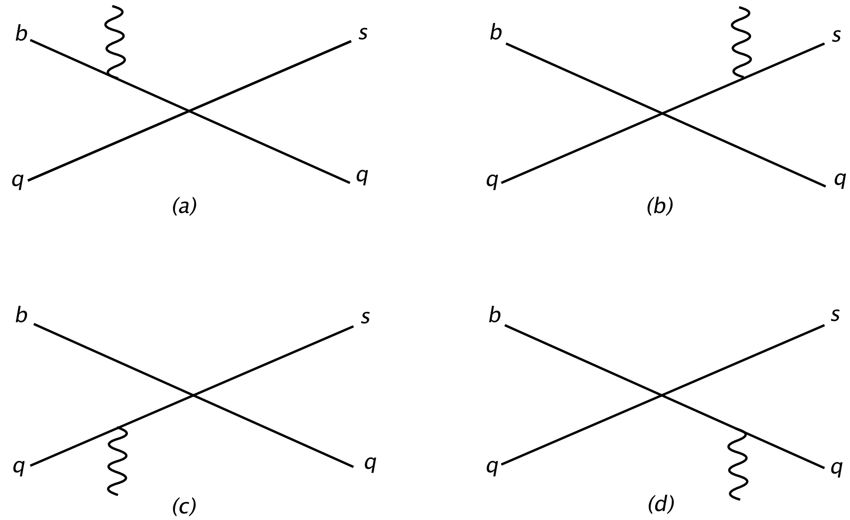


Figure 11: Feynman diagrams of annihilation contributions in the decay $B \to K^* \gamma$.

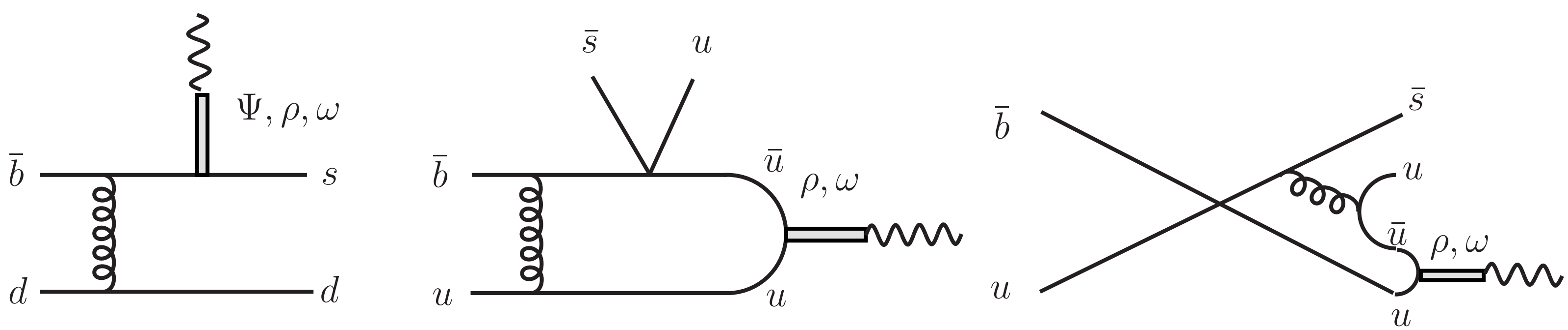


Figure 12: Long-distance contributions in the decay $B \to K^* \gamma$.

Numerical Results:

Amplitudes of $B^0 \to K^{*0}\gamma$:

Diagrams	Ops	CKM	M^S	M^P
Mag.-Peng	$O_{7\gamma}$	$V_{tb}V_{ts}^*(A\lambda^2)$	-577.21	577.21
Chromo-Mag.-Peng	O_{8g}	$V_{tb}V_{ts}^*(A\lambda^2)$	$-8.02 - 0.03\ i$	$8.10 + 0.11\ i$
QCD-penguin	O_{3-6}	$V_{tb}V_{ts}^*(A\lambda^2)$	$-16.66 - 7.23\ i$	$16.78 + 7.05\ i$
Charm-Peng.	O_2	$V_{cb}V_{cs}^*(-A\lambda^2)$	(84.70 ± 18.00) $-(13.84 \pm 12.28)\ i$	(8.11 ± 20.10) $+(14.54 \pm 13.69)\ i$
Long-Dist. (Ψ)	O_2	$V_{cb}V_{cs}^*(-A\lambda^2)$	-34.30	34.30
Uquark-Peng.	O_2	$V_{ub}V_{us}^*(-A\lambda^4)$	$9.95 + 3.59\ i$	$-8.22 - 1.73\ i$
Annihilation	O_2	$V_{ub}V_{us}^*(-A\lambda^4)$	0.0	0.0
Long-Dist. (ρ,ω)	O_2	$V_{ub}V_{us}^*(-A\lambda^4)$	$-10.92 - 1.79\ i$	$10.92 + 1.79\ i$

Amplitudes of $B^+ \to K^{*+}\gamma$:

Charm-Peng.	O_2	$V_{cb}V_{cs}^*(-A\lambda^2)$	(-154.53 ± 36.10) $+(30.19 \pm 24.28)\ i$	(-0.71 ± 40.20) $-(26.74 \pm 27.38)\ i$
Annihilation	O_2	$V_{ub}V_{us}^*(-A\lambda^4)$	$78.08 - 19.09\ i$	$-99.69 - 1.68\ i$
Long-Dist. (ρ,ω)	O_2	$V_{ub}V_{us}^*(-A\lambda^4)$	$100.99 + 15.93\ i$	$19.59 - 8.38\ i$

Br. of $B \to K^*/\rho\gamma$

- Input Parameters:
  - $G_F = 1.16639 \times 10^{-5}\text{GeV}^{-2}$,
  - the decay constants: $f_B = 190\text{MeV}$ and $f_{K^*} = 226\text{MeV}$,
  - the masses $m_b = 4.2\text{GeV}$, $m_c = 1.2\text{GeV}$, $M_B = 5.28\text{GeV}$ and $M_{K^*} = 0.892\text{GeV}$,
  - the meson lifetime $\tau_{B^0} = 1.542\text{ps}$ and $\tau_{B^+} = 1.764\text{ps}$.
  - the CKM parameter $\bar{\rho} = \rho(1-\lambda^2/2) = 0.22 \pm 0.101$ and $\bar{\eta} = \eta(1-\lambda^2/2) = 0.35 \pm 0.05$,
  - B meson wave function parameter: $\omega_B = 0.40 \pm 0.04$.

The branching ratios for $B \to K^*\gamma$:

$$Br(B^0 \to K^{*0}\gamma) = (3.5^{+1.1}_{-0.8}) \times 10^{-5} \quad (30)$$

$$Br(B^\pm \to K^{*\pm}\gamma) = (3.4^{+1.2}_{-0.9}) \times 10^{-5} \quad (31)$$

The branching ratios for $B \to \rho\gamma$:

- $Br(\rho\gamma) = S_\rho \left|\frac{V_{td}}{V_{ts}}\right|^2 \left(\frac{1-m_\rho^2/m_B^2}{1-m_{K^*}^2/m_B^2}\right)^3 \times Br(B \to K^*\gamma)$
- $S_\rho = 1$ for $\rho^\pm$-meson and $S_\rho = 1/2$ for ρ^0-meson
- Br$(B^0 \to \rho^0\gamma) = (0.9^{+0.3}_{-0.2}) \times 10^{-6}$,
- Br$(B^\pm \to \rho^\pm\gamma) = (1.8^{+0.4}_{-0.5}) \times 10^{-6}$,

Comparision with other results:

- A. Ali and A.Y. Parkhomenko: NLO-Large Energy Effective Theory
  Br$(B^0 \to K^{*0}\gamma) = (7.2 \pm 2.77) \times 10^{-5}$,
  Br$(B^\pm \to \rho^\pm\gamma) = (0.90 \pm 0.33) \times 10^{-6}$,
  Br$(B^0 \to \rho^0\gamma) = (0.49 \pm 0.18) \times 10^{-6}$.

- A. Ali and V.M. Braun: QCD Sum rule
  Br$(B^\pm \to \rho^\pm\gamma) = (1.9 \pm 1.6) \times 10^{-6}$,
  Br$(B^0 \to \rho^0\gamma) = (0.85 \pm 0.65) \times 10^{-6}$,

- S.W.Bosch and G. Buchalla: QCD-Factorization
  Br$(B^0 \to K^{*0}\gamma) = (7.27^{+2.58}_{-2.37}) \times 10^{-5}$,
  Br$(B^\pm \to K^{*\pm}\gamma) = (7.31^{+2.57}_{-2.37}) \times 10^{-5}$,
  Br$(B^0 \to \rho^0\gamma) = (0.91^{+0.42}_{-0.40}) \times 10^{-6}$,
  Br$(B^\pm \to \rho^\pm\gamma) = (2.0^{+0.8}_{-0.7}) \times 10^{-6}$.

- J.G. Chay and C. Kim: Soft-collinear Effective Theory

CP Asymmetry and Isospin Symmetry Breaking

- CP-Asymmetry :

$$A_{cp} = \frac{\Gamma(B \to K^*\gamma) - \Gamma(\bar{B} \to \bar{K}^*\gamma)}{\Gamma(B \to K^*\gamma) + \Gamma(\bar{B} \to \bar{K}^*\gamma)} \quad (32)$$

- $Acp(B^0 \to K^{0*}\gamma) = (0.39^{+0.06}_{-0.07})\%$ $\qquad Acp(B^+ \to K^{+*}\gamma) = (0.62 \pm 0.13)\%$

- Isospin Symmetry Breaking :

The small difference in the branching fraction between $K^{0*}\gamma$ and $K^{+*}\gamma$ can be detected as the isospin symmetry breaking which tells us the sign of the combination of the Wilson coefficients, c_6/c_7. We obtain

$$\Delta_{0-} = \frac{\eta_\tau Br(B \to \bar{K}^{0*}\gamma) - Br(B \to K^{*-}\gamma)}{\eta_\tau Br(B \to \bar{K}^{0*}\gamma) + Br(B \to K^{*-}\gamma)} = (5.7^{+1.1}_{-1.3})\% \quad (33)$$

where $\eta_\tau = \tau_{B^+}/\tau_{B^0}$. The first error term comes from the uncertainty of shape parameter of the B-meson wave function $(0.36 < \omega_B < 0.44)$ and the second term is origined from the uncertainty of η_τ. By using the world averaged value of measurement and $\tau_{B^+}/\tau_{B^0} = 1.083 \pm 0.017$, we find numerically that $\Delta_{0-}(K^*\gamma)^{exp} = (3.9 \pm 4.8)\%$.

In PQCD we can not expect large isospin symmetry breaking in $B \to K^*\gamma$ system.

Why PQCD has small Brs. than other Approaches

The main short-distance (SD) contribution to the $B \to K^*\gamma$ decay rate involves the matrix element

$$< K^*\gamma|O_7|B >= \frac{em_b}{8\pi^2}(-2i)\epsilon_\gamma^\mu < K^*|\bar{s}\sigma_{\mu\nu}q^\nu(1-\gamma_5)b|B(p) >, \quad (34)$$

which is parameterized in terms of two invariant form fectors as

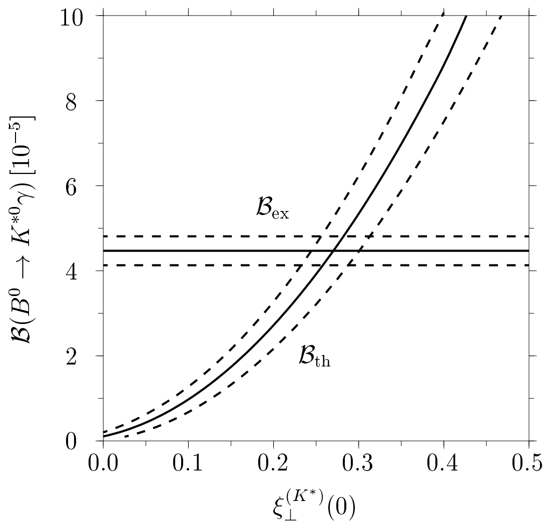
$$\begin{aligned} < K^*(P_3,\epsilon_3)|\bar{s}\sigma_{\mu\nu}q^\nu(1-\gamma_5)b|B(P) > \;&=\; [\epsilon_{3,\mu}(q\cdot P) - P_\mu(q\cdot\epsilon_3)]\cdot 2T_2(q^2) \\ &\quad + i\epsilon_{\mu\nu\alpha\beta}\epsilon_3^\nu P^\alpha q^\beta \cdot 2T_1(q^2). \end{aligned} \quad (35)$$

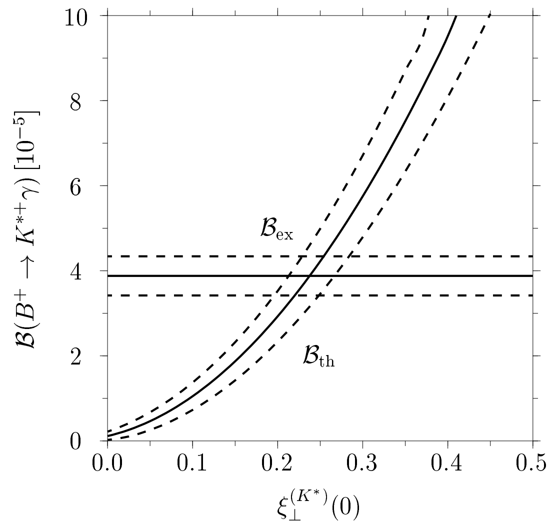
Here P and $P_3 = P - q$ are the B-meson and K^* meson momentum, respectively and ϵ_3 is the polarization vector of the K^* meson.

- For the real photon emission process the two form factors coincide, $T_1(0) = T_2(0) = T(0)$.
- This form factor can be calculable in the k_T factorization method including the sudakov suppression factor and the threshold resummation effects.
- In PQCD $T(0) = 0.25 \pm 0.04$ for $B \to K^*\gamma$
- far away from $T(0) = 0.38 \pm 0.06$ by using the light-cone QCD sum rule [Ball and Braun;PRD58,1998]
- in agreement with Lattice QCD result $T(0) = 0.25 \pm 0.06$[Becirevic;hep-ph/0211340] and 0.24 in the covariant light-front approach[Cheng and Chua; hep-ph/0401141]. .

Phenomenological fits

By A. Ali and A. Parkhomenko





$$\bar{\xi}_\perp^{(K^*)}(0) = 0.25 \pm 0.04, \qquad \left[\bar{T}_1^{(K^*)}(0, \bar{m}_b) = 0.27 \pm 0.04\right]. \tag{36}$$

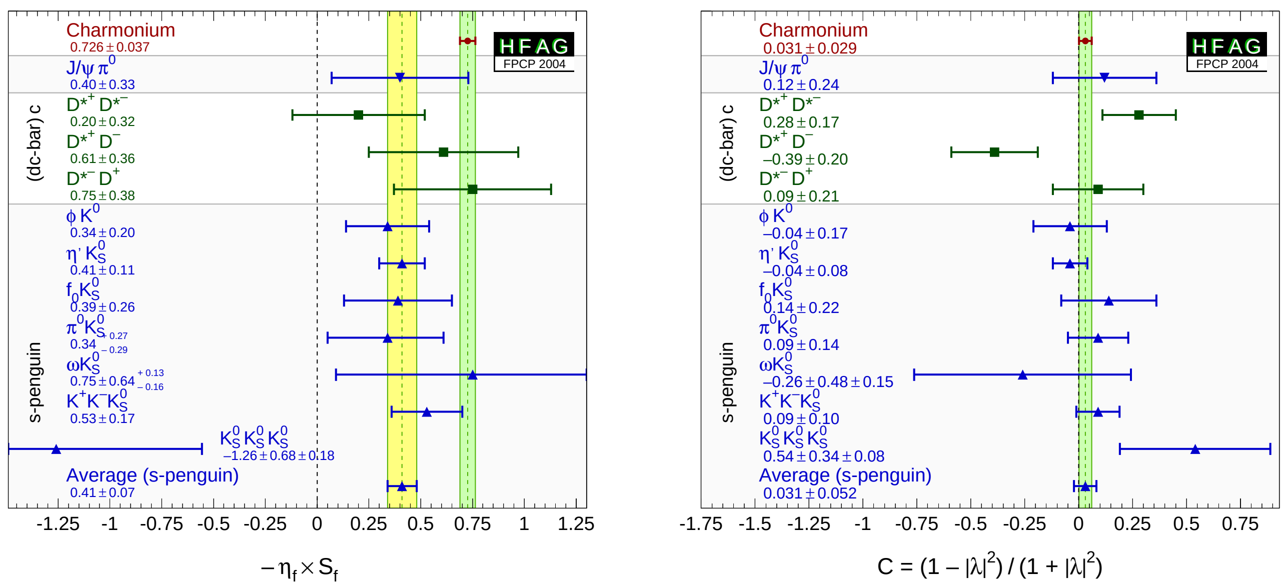
Part-IV

New Physics Search in Non-leptonic B-decays

Vertex Corrections and New Physics Search in $B \to \phi K_s$ decays

Experimental data:

$$S_{J/\psi Ks} = 0.726 \pm 0.037, \qquad S_{\phi Ks} = 0.34 \pm 0.20, \qquad S_{\eta' Ks} = 0.41 \pm 0.11. \qquad (37)$$



New physics Effects in $B^0 \to \phi K_s$:
The off-diagonal elements affect Flavor/CP-violation.

- SUSY contribution is negligible in $B^0 \to J/\psi K_s$.
  In SM, color-suppressed $B^o \to J/\psi K_s$ occurs at the tree level, however SUSY effects are involved at the one-loop level.
- $B^0 \to \phi K_s$ is via loop effects in SM and SUSY. SUSY contribution can be sizable !!!

Vertex Corrections in $B \to M_1 M_2$

(1) α_s-corrections inside four quark operators: Short distance contributions

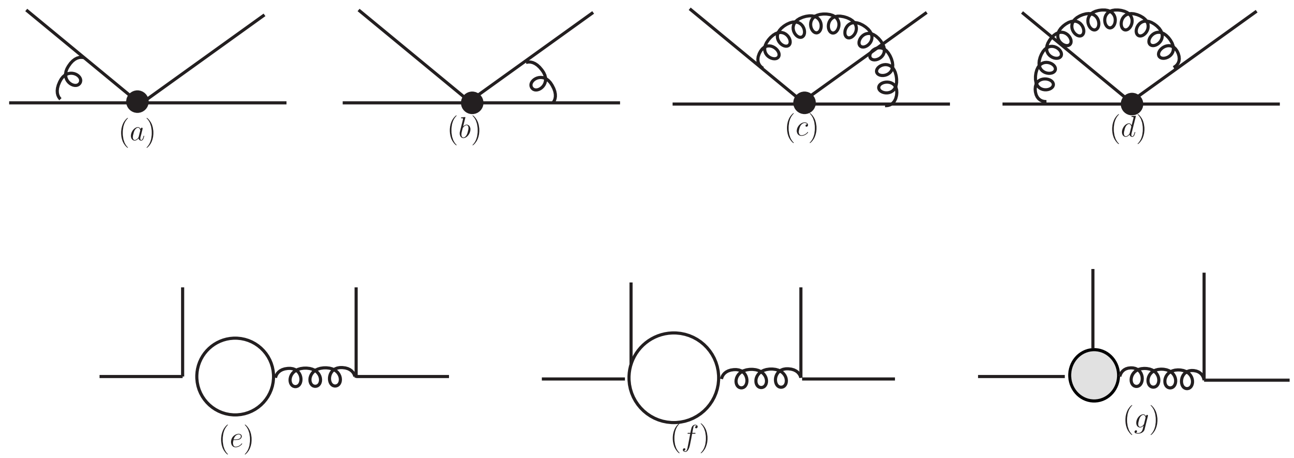


Figure 13: *Order α_s corrections inside four quark operators. These diagrams are commonly called vertex corrections and penguin corrections for fig.(a-d) and fig.(e-g) respectively*

(2) QCD-coefficients a_i(with NDR-scheme for γ_5):

(a) Tree coefficients:

$$a_1 = c_1 + \frac{c_2}{N_c} + \frac{\alpha_s}{4\pi}\frac{C_F}{N_c}c_2\left[-18 + 12\ln\frac{m_b}{\mu} + f_I\right];$$

$$a_2 = c_2 + \frac{c_1}{N_c} + \frac{\alpha_s}{4\pi}\frac{C_F}{N_c}c_1\left[-18 + 12\ln\frac{m_b}{\mu} + f_I\right];$$

(b) QCD-Penguin coefficients:

$$a_3 = c_3 + \frac{c_4}{N_c} + \frac{\alpha_s}{4\pi}\frac{C_F}{N_c} c_4 \left[-18 + 12\ln\frac{m_b}{\mu} + f_I \right];$$

$$a_4 = c_4 + \frac{c_3}{N_c} + \frac{\alpha_s}{4\pi}\frac{C_F}{N_c} \left\{ c_3 \left[-18 + 12\ln\frac{m_b}{\mu} + f_I \right] + (c_3 - \frac{c_9}{2})(G[s_s] + G[s_b]) \right.$$
$$\left. -c_1\left(\frac{\lambda_u}{\lambda_t}G[s_u] + \frac{\lambda_c}{\lambda_t}G[s_c]\right) + \sum_{q=u,d,s,c,b}(c_4 + c_6 + \frac{3}{2}e_q(c_8 + c_{10}))G[s_q] \right\}$$
$$+\frac{\alpha_s}{4\pi}\frac{C_F}{N_c}c_g^{eff}G_g;$$

$$a_5 = c_5 + \frac{c_6}{N_c} - \frac{\alpha_s}{4\pi}\frac{C_F}{N_c} c_6 \left[-6 + 12\ln\frac{m_b}{\mu} + \tilde{f}_I \right];$$

$$a_6 = c_6 + \frac{c_5}{N_c} + \frac{\alpha_s}{4\pi}\frac{C_F}{N_c} \left\{ -6\ c_3 + (c_3 - \frac{c_9}{2})(Gp[s_s] + Gp[s_b]) \right.$$
$$\left. -c_1\left(\frac{\lambda_u}{\lambda_t}Gp[s_u] + \frac{\lambda_c}{\lambda_t}Gp[s_c]\right) + \sum_{q=u,d,s,c,b}(c_4 + c_6 + \frac{3}{2}e_q(c_8 + c_{10}))Gp[s_q] \right\}$$
$$-2\ \frac{\alpha_s}{4\pi}\frac{C_F}{N_c}c_g^{eff};$$

Gluino Mediated SUSY FCNC

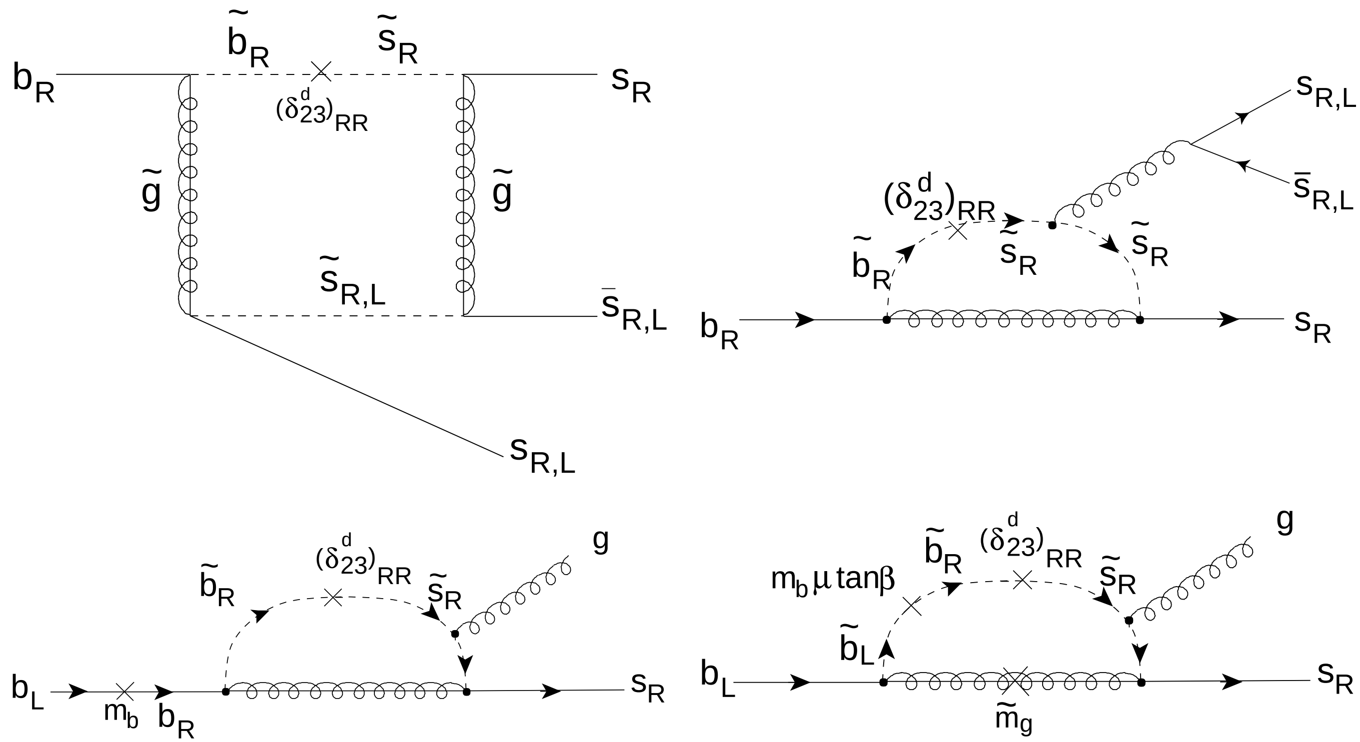


Figure 14: Box and penguin contributions to the $b \to ss$ transition. The bottom row shows contributions to the chromo-dipole operator. We show the mass insertions for pedagogical purposes but perform calculations in the mass eigenbasis.

The effective Hamiltonian for $B \to \phi K$ in the SM;

$$H_{\rm eff} = \frac{G_F}{\sqrt{2}} \sum_{p=u,c} \lambda_p^{(s)} \left[C_1 O_1^p + C_2 O_2^p + \sum_{i=3}^{10} C_i(\mu) O_i(\mu) + C_{7\gamma} O_{7\gamma} + C_{8g} O_{8g} \right] + {\rm H.c.}, \quad (38)$$

where $\lambda_p = V_{ps}^* V_{pb}$ with $p = u, c$ are the appropriate CKM factors, and $\lambda_u + \lambda_c + \lambda_t = 0$ due to the unitarity of the CKM matrix.

The relevant Wilson coefficients due to the gluino box/penguin loop diagrams (at the scale $\mu \sim m_W$) involving the LL and LR insertions;

$$\begin{aligned}
C_3^{\rm SUSY} &= -\frac{\alpha_s^2}{2\sqrt{2} G_F m^2 \lambda_t} \left(-\frac{1}{9} B_1(x) - \frac{5}{9} B_2(x) - \frac{1}{18} P_1(x) - \frac{1}{2} P_2(x) \right) \left(\delta_{LL}^d \right)_{23} \\
C_4^{\rm SUSY} &= -\frac{\alpha_s^2}{2\sqrt{2} G_F m^2 \lambda_t} \left(-\frac{7}{3} B_1(x) + \frac{1}{3} B_2(x) + \frac{1}{6} P_1(x) + \frac{3}{2} P_2(x) \right) \left(\delta_{LL}^d \right)_{23} \\
C_5^{\rm SUSY} &= -\frac{\alpha_s^2}{2\sqrt{2} G_F m^2 \lambda_t} \left(\frac{10}{9} B_1(x) + \frac{1}{18} B_2(x) - \frac{1}{18} P_1(x) - \frac{1}{2} P_2(x) \right) \left(\delta_{LL}^d \right)_{23} \\
C_6^{\rm SUSY} &= -\frac{\alpha_s^2}{2\sqrt{2} G_F m^2 \lambda_t} \left(-\frac{2}{3} B_1(x) + \frac{7}{6} B_2(x) + \frac{1}{6} P_1(x) + \frac{3}{2} P_2(x) \right) \left(\delta_{LL}^d \right)_{23} \\
C_{7\gamma}^{\rm SUSY} &= -\frac{8\pi Q_b \alpha_s}{3\sqrt{2} G_F \tilde{m}^2 \lambda_t} \left[(\delta_{LL}^d)_{23} M_4(x) - (\delta_{LR}^d)_{23} \left(\frac{m_{\tilde{g}}}{m_b} \right) 4 B_1(x) \right], \\
C_{8g}^{\rm SUSY} &= -\frac{2\pi \alpha_s}{\sqrt{2} G_F \tilde{m}^2 \lambda_t} \left[(\delta_{LL}^d)_{23} \left(\frac{3}{2} M_3(x) - \frac{1}{6} M_4(x) \right) \right.
\end{aligned}$$

$$+(\delta^d_{LR})_{23}\left(\frac{m_{\tilde{g}}}{m_b}\right)\ \frac{1}{6}\ \left(4B_1(x)-9x^{-1}B_2(x)\right)\Big], \quad (39)$$

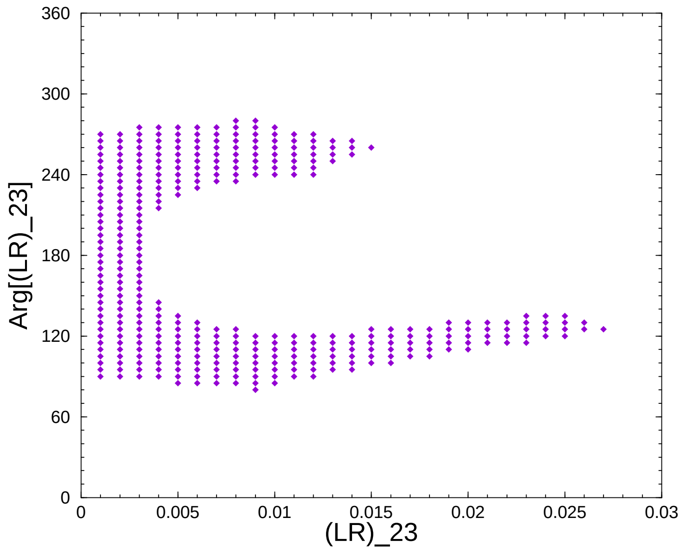
where $x \equiv (m_{\tilde{g}}/\tilde{m})^2$, and P_i, B_i and M_i are loop functions.

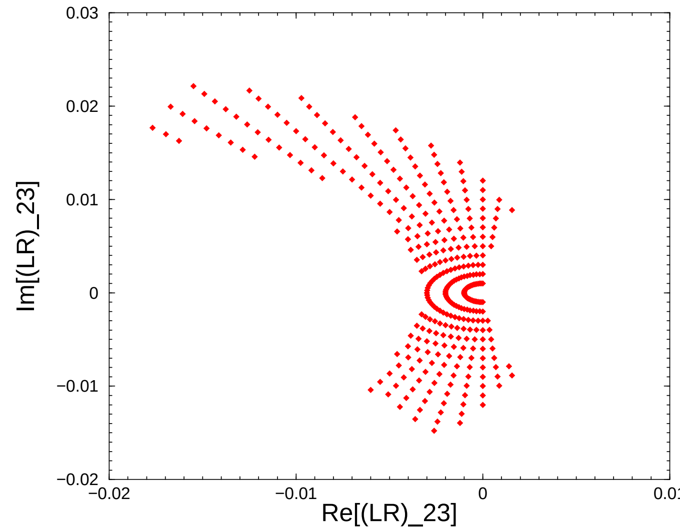
- LR-insertion case:
  - C_{8g} contribution can be important both for Branching ratio and A_{cp}.
  - Most strong constraint comes from $Br(B \to X_s\gamma)$.
- LL-insertion case:
  - Both QCD-penguin Ops.(O_{3-6}) and C_{8g} are generated by $(\delta^d_{LL})_{23}$.
  - Constraint comes from $Br(B \to X_s\gamma)$ is not so significant.
  - Most strong constraint comes from ΔM_s [$(B_s - \bar{B}_s)$ Mixing].
  - Br.$(B^0 \to \phi K_s) < 5.2 \cdot 10^{-6}$ when $14.4\ ps^{-1} < \Delta M_s < 100.\ ps^{-1}$.

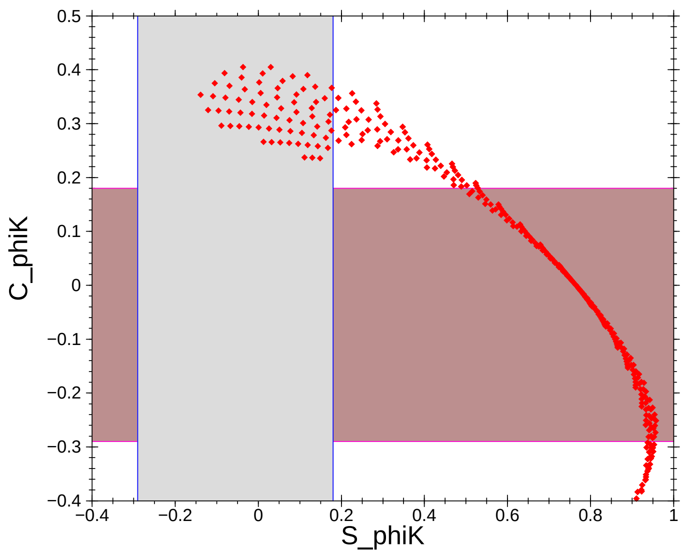
Constraints on $b \to s$ transitions: G. Kane et al, PRL 2003

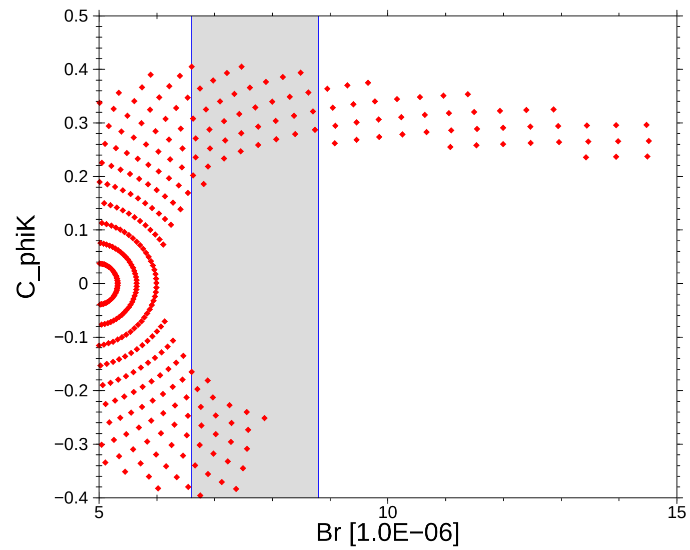
- Br$(B^0 \to X_s\gamma) = (3.29 \pm 0.34)10^{-4}$
  $\Rightarrow \quad 2.0 \times 10^{-4} < Br(b \to s\gamma) < 4.5 \times 10^{-4}$.
- $A_{cp}(B \to X_s\gamma) = -(0.02 \pm 0.04) \quad \Rightarrow \quad -27\% < A_{cp}(b \to s\gamma) < +10\%$.
- $Br(B^0 \to X_s l^+ l^-) = (6.1 \pm 1.4 \pm 1.3) \cdot 10^{-6}$
- $\Delta M_s > 14.4\ ps^{-1}$

New Physics-(LR)









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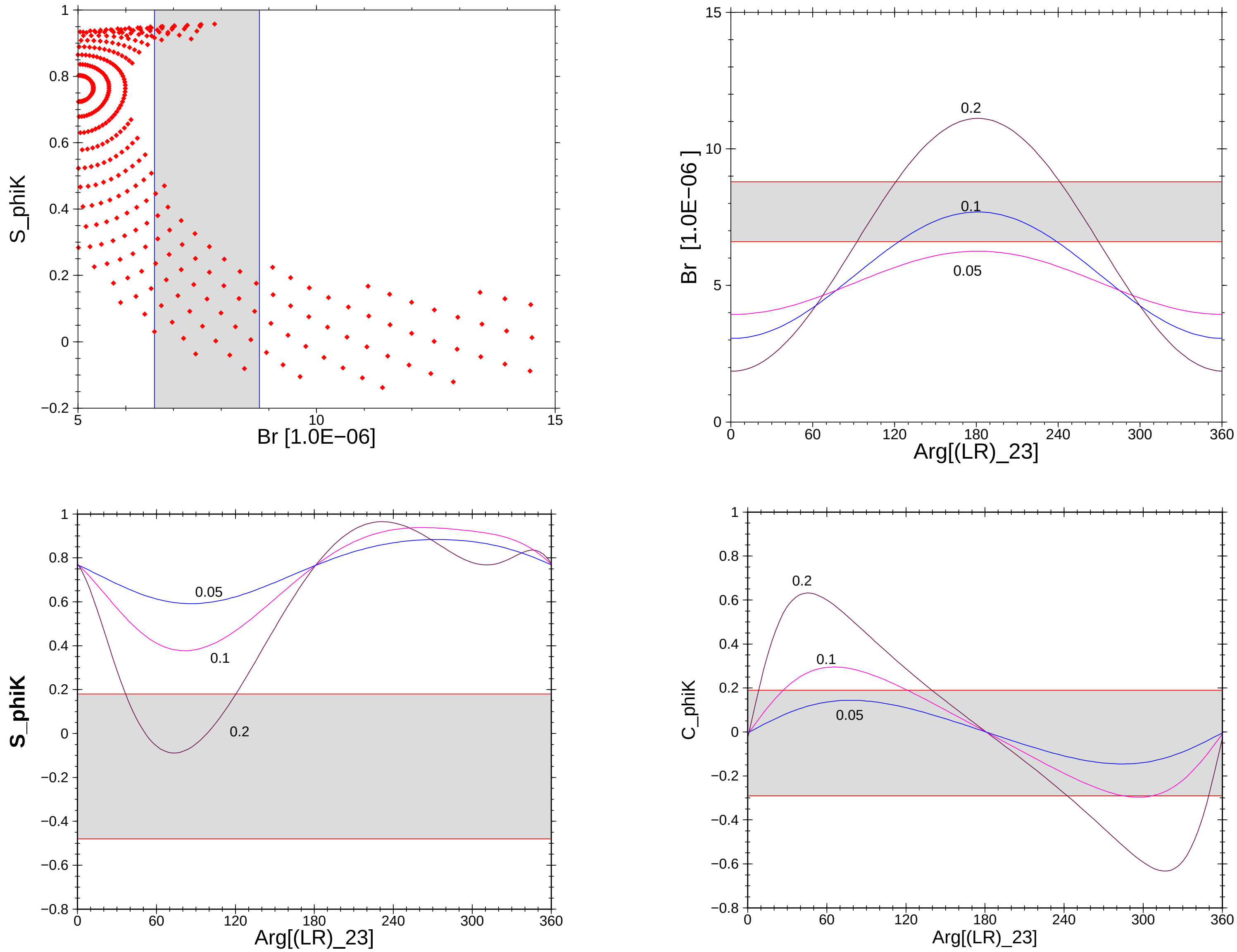
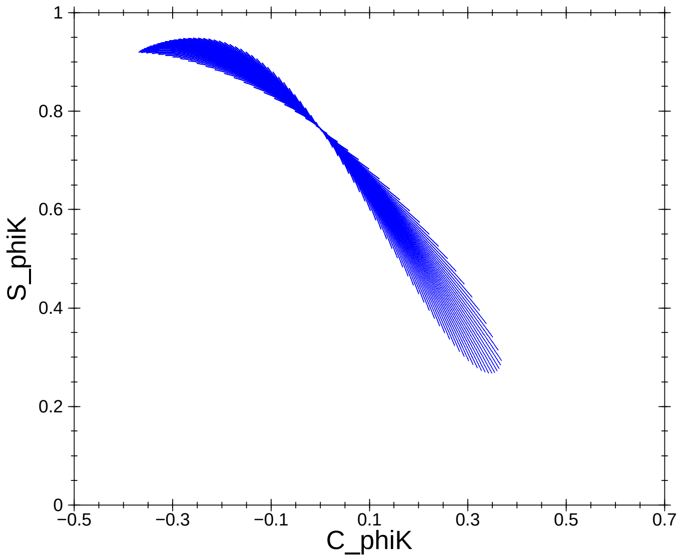
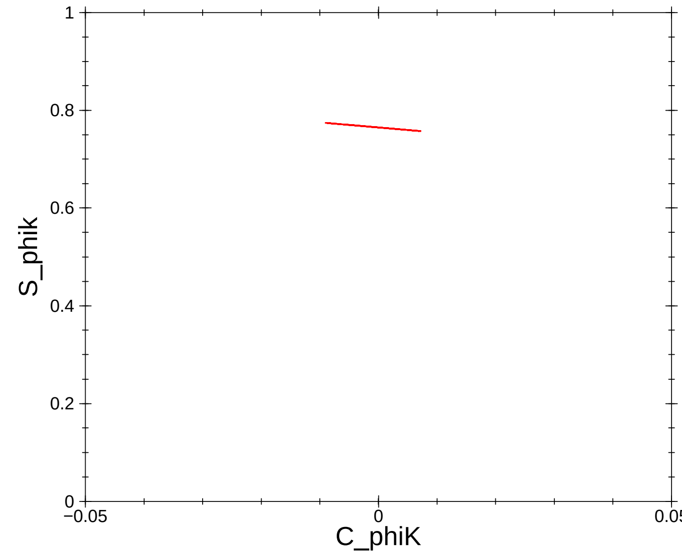
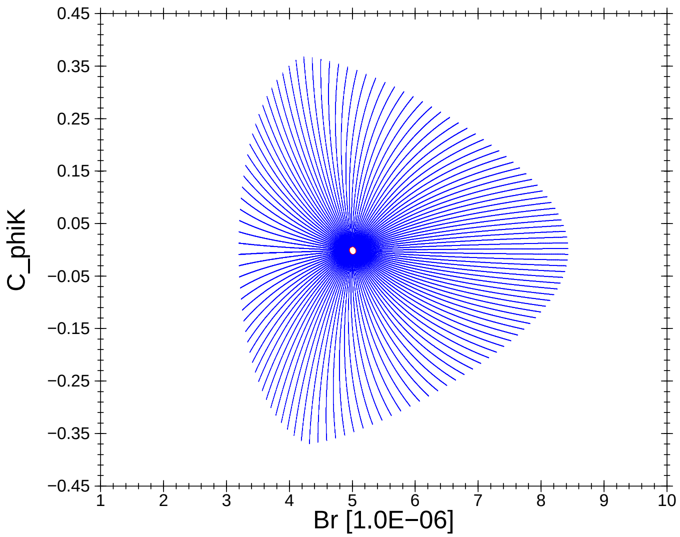
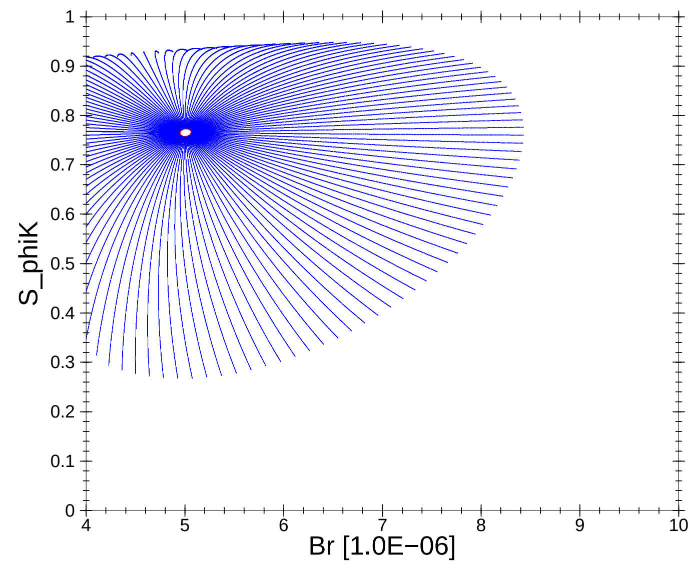


New Physics-(LL)

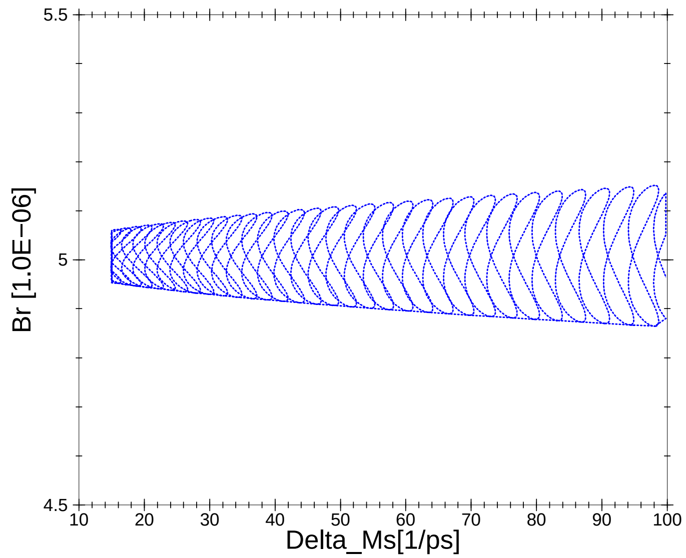


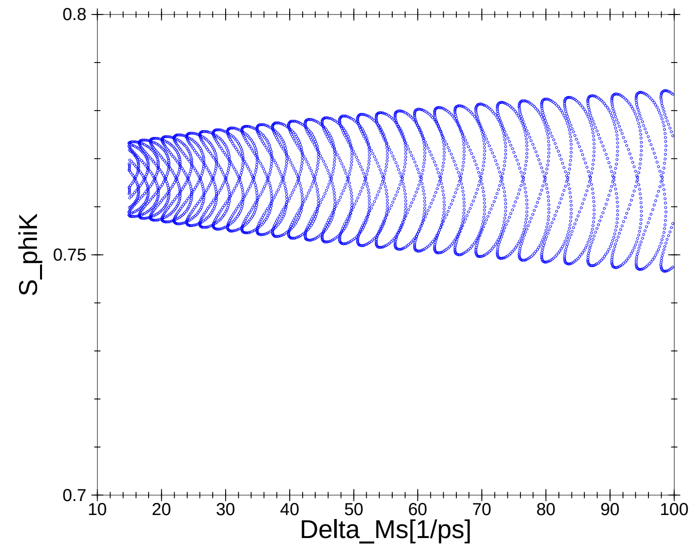






New Physics-(LL)

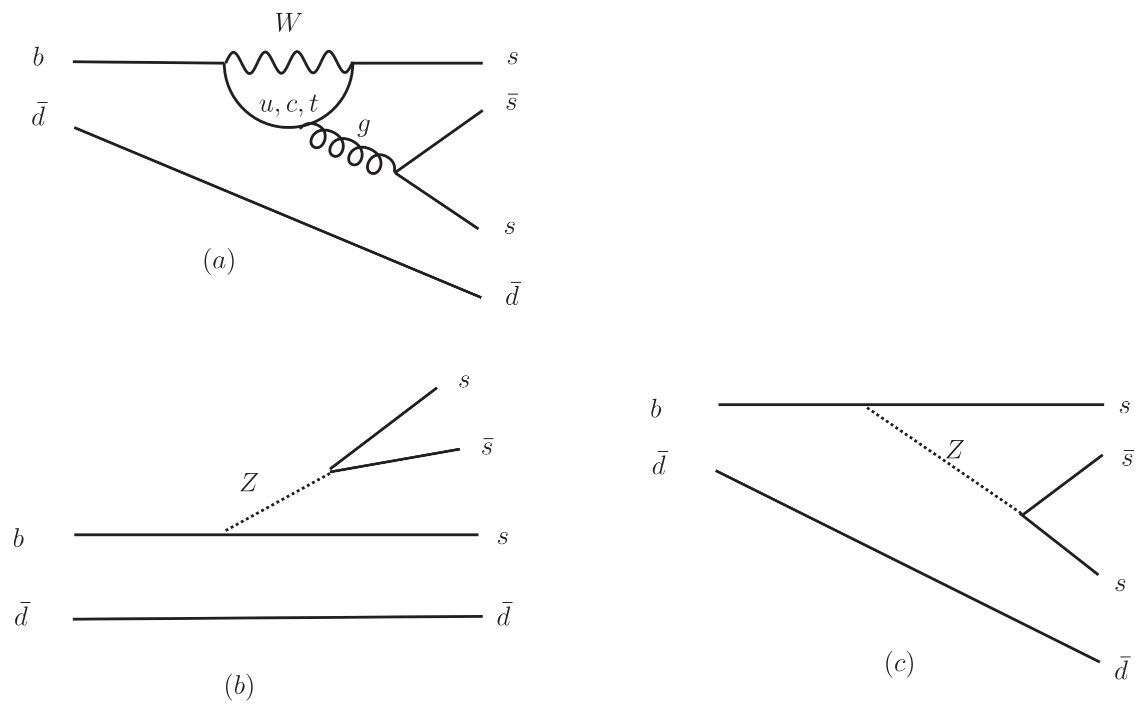




Comments:

- At present, SUSY models with $(\delta^d_{LR,RL})_{23} \simeq O(10^{-2})$ and $300 - 500$ GeV squark/gluinos can reproduce experimental data including deviations from SM in $S_{\phi K_s}, C_{\phi K_s}$.
- If NP is present in $B \to \phi K s$ and violates CP Conservation, DCPV aries natually since strong phases are large even pertubatively in QCD-Factorization and PQCD approach. $\Rightarrow$ Direct CP violation can be a key to distinguish many SUSY models based on the different QCD method.

Down-type Vector-Quark Model



The neutral current lagrangian is given

$$\mathcal{L}_Z = \frac{g}{2\,cos\theta_W}\left[\bar{u}_{Li}\gamma^\mu u_{Li} - \bar{d}_{L\alpha}U_{\alpha\beta}\gamma^\mu d_{L\beta} - 2\,sin^2\theta_W\ J^\mu_{em}\right] Z_\mu; \qquad (40)$$

$$U_{\alpha\beta} = \sum_{i=u,c,t} V^\dagger_{\alpha\,i} V_{i\ \beta} = \delta_{\alpha\beta} - V^*_{4\alpha}V_{4\beta} \qquad (41)$$

DVQ-2

The effective Hamiltonian for $b \to s s \bar{s}$ decay:

$$\mathcal{H}_Z^{New} = -\frac{G_F}{\sqrt{2}} V_{tb} V_{ts}^* \left[\tilde{c}_3(O_3 + O_5) + \tilde{c}_4(O_4 + O_6)\right] \quad (42)$$

$$\tilde{c}_3 = \tilde{c}_5 = -\left(\frac{4U_{bs}}{V_{ts}^* V_{tb}}\right)(C_V + C_A) \quad (43)$$

$$\tilde{c}_4 = \tilde{c}_6 = -\left(\frac{4U_{bs}}{V_{ts}^* V_{tb}}\right)(C_V - C_A) \quad (44)$$

where

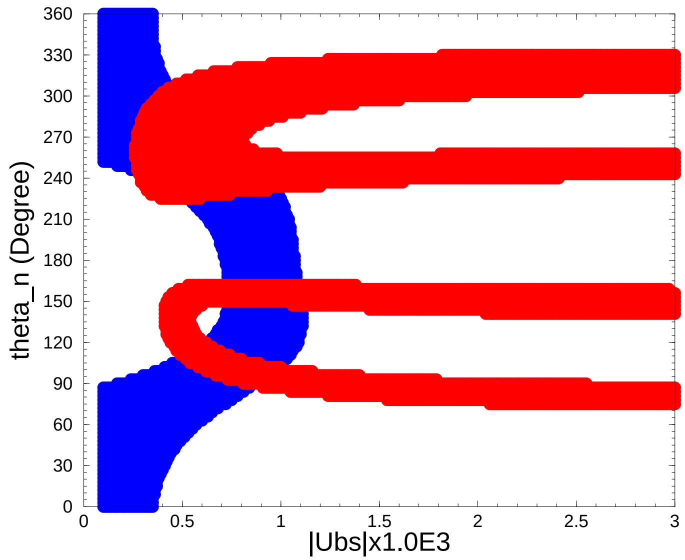
$$C_V = -\frac{1}{2} + \frac{2}{3} sin^2\theta_W, \qquad C_A = -\frac{1}{2} \quad (45)$$

$$U_{bs} = V_{us}^* V_{ub} + V_{cs}^* V_{cb} + V_{ts}^* V_{tb} = |U_{bs}| e^{i\theta_n} \quad (46)$$

Constraint Conditions:

- $Br(B \to X_s \gamma) = (3.28 \pm 0.33) \cdot 10^{-4} \Rightarrow \quad -0.0020 < U_{bs} < 0.0027;$
- $Br(B \to X_s \gamma) = (3.60 \pm 0.33) \cdot 10^{-4} \Rightarrow \quad -0.0032 < U_{bs} < 0.0010;$
- $Br(B \to X_s l^+ l^-) = (0.54 \pm 0.08) \cdot 10^{-8} \Rightarrow \quad |U_{bd}|, |U_{bs}| < 1.9 \cdot 10^{-3}$

DVQ-3(Results)



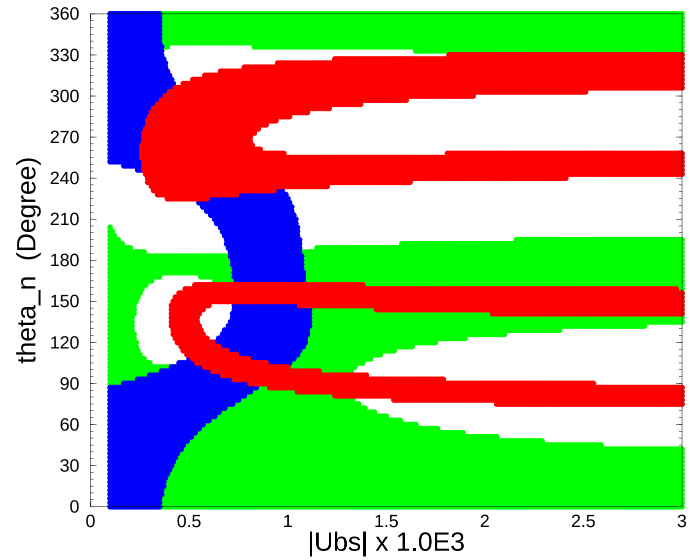


Figure 15: Blue region is allowded by Branching ratio, red region by $S_{\phi K_s}$ and Green region by $C_{\phi K_s}$.

Summary and Discussions

- In PQCD, we expect about 30% uncertainties from the nonperturbative physics.
- We only consider the leading order diagrams of α_s and $1/M_B$ power expansion. Hence we don't include vertex correction. Even including the vertex corr., DCPV doesn't change much.
- The input parameters are ω_B[B-meson shape parameter]; $m_0 = m_P^2/(m_u + m_{s,d})$[chiral enhancement factor]. Also LCDAs of light-meson are input, which was derived in the light-cone sum rule.
- All amplitudes are numerical output from these inputs. We don't do data fitting.
- In our previous numerics, we included all moment of gegenbauer polynomial terms upto twist-3 amplitudes of light mesons.
- Our prediction of DCPV in $B^0 \to K^+\pi^-$ is in agreement with experimental data, however not with the $K^+\pi^0$ data, which may be a signal of new physics.
- We can explain well the large branching ratios of $B \to PP, VP, VV$ modes, but cannot reach to the branching ratios of the color-suppressed decays: $B \to \pi^0\pi^0$, since C is relatively small. (lower hard scale, small spectator contribution in Charmless decays)
- We need more efforts (NLO-contributions) to solve these important limitations, to understand internal dynamics inside hadrons and to confirm the signal of new physics.

Conclusion

- We investigate the PQCD method (k_T-factorization approach) in Non-leptonic 2-body decays.
- We predicted large direct CP-violation effects in $B \to \pi^+\pi^-, K^+\pi^-$, which is in agreement with experimental measurements.
- We add the vertex correction in PQCD calculation.
- It is still difficult to explain Anomalies of non-leptonic B-decays in $B \to \pi^0\pi^0, K^0\pi^0$ and ϕK_S within the Standard Model.
- There are large possibilities of New Physics contributions to reproduce experimental results.
- We need more precise measurements to look for New physics effects.