Production of light scalar meson in *B* decays

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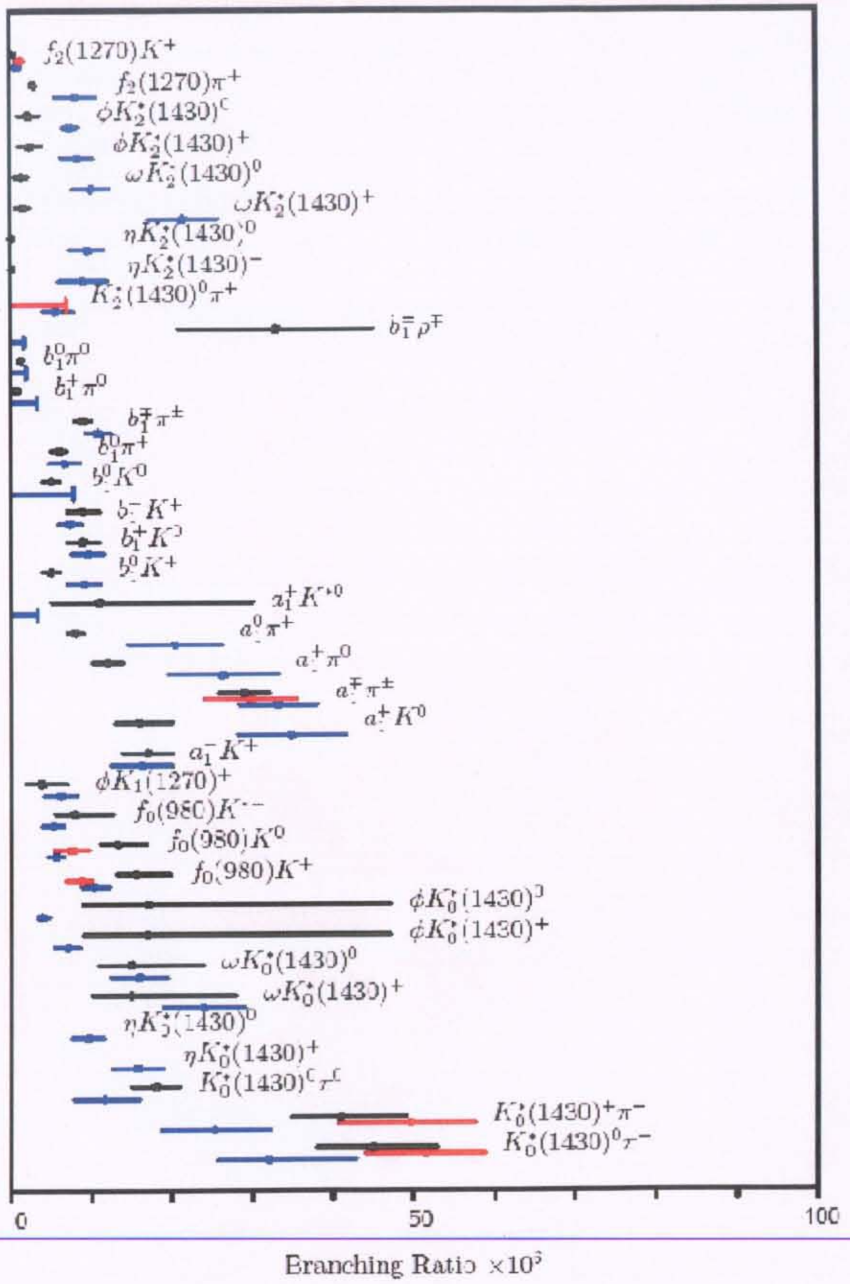
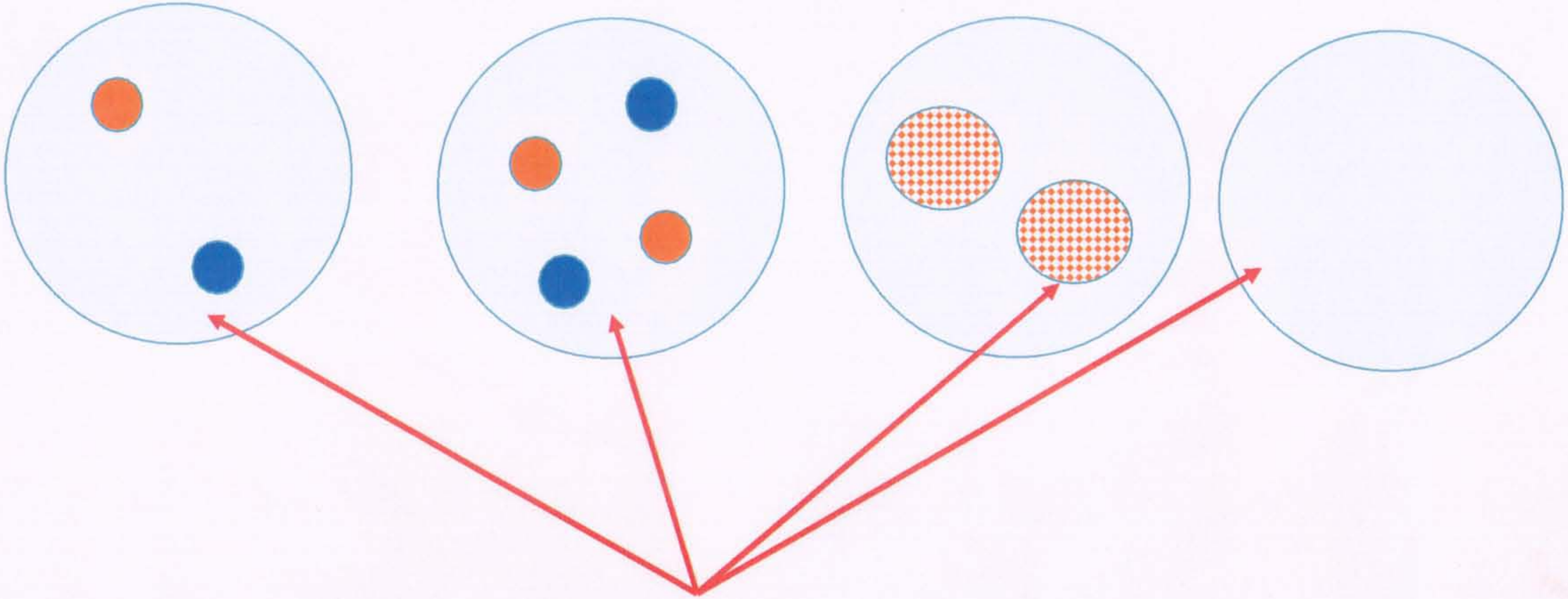
Outline

- Motivation
- Present theoretical status on the B→SX decays
- Summary and outlook



H.Y.Cheng and J.G.Smith,
arXiv: 0901.4396

Problems in scalar meson spectroscopy



(flavor singlet) scalar meson

▪Classification of the $q\bar{q}$ multiplets and exotic states

- One nonet below and one above 1 GeV

states	Scenario I	Scenario II
$f_0(980), a_0(980), \sigma, \kappa$	$q\bar{q}$ ground state	$q\bar{q}q\bar{q}$
$f_0(1500), a_0(1450), f_0(1370), K_0^*(1430)$	$q\bar{q}$ first exited state	$q\bar{q}$ ground state

- one nonet above or close to 1 GeV

  σ, κ **are not physical state**

Mixing of the flavor singlet scalar mesons

Lattice results for glueball: the mass of the scalar glueball lies in (1500-1800)MeV

The mixing scheme is still under controversy. Here are two typical schemes:

$$\begin{pmatrix} f_0(1370) \\ f_0(1500) \\ f_0(1710) \end{pmatrix} = \begin{pmatrix} -0.91 & -0.07 & 0.40 \\ -0.41 & 0.35 & -0.84 \\ 0.09 & 0.93 & 0.36 \end{pmatrix} \begin{pmatrix} |N\rangle \\ |S\rangle \\ |G\rangle \end{pmatrix}$$

C.Amsler and F.E. Close, PRD53,295(1996); PLB353, 385; PLB483,345(2000);

F.E. Close and A.Kirk, PL B483,345(2000);

F.E. Close and Q. Zhao, PLB586,332(2004); PRD71,094022 (2005);

$$\begin{pmatrix} f_0(1370) \\ f_0(1500) \\ f_0(1710) \end{pmatrix} = \begin{pmatrix} 0.78 & 0.51 & -0.36 \\ -0.54 & 0.84 & 0.03 \\ 0.32 & 0.18 & 0.93 \end{pmatrix} \begin{pmatrix} |N\rangle \\ |S\rangle \\ |G\rangle \end{pmatrix}$$

H.Y. Cheng, C.K. Chua and K.F. Liu, PRD094005 (2006)

Scalar meson decay constant and distribution amplitude

Definition of the decay constant 0

$$\langle S(p)|\bar q_2\gamma_\mu q_1|0\rangle = \boxed{f_S} p_\mu, \quad \langle S(p)|\bar q_2 q_1|0\rangle = \bar f_S m_S.$$

$$\mu_S f_S = \bar f_S, \qquad \mu_S = \frac{m_S}{m_{q_2}(\mu) - m_{q_1}(\mu)}$$

Definition of the distribution amplitude

$$\begin{aligned}\langle S(p)|\bar q_{1\beta}(z) q_{2\alpha}(0)|0\rangle &= \frac{1}{\sqrt6}\int_0^1 dx e^{ixp\cdot z}\left\{\not p\phi_S(x) + m_S\phi_S^S(x) - \frac{1}{6}m_S\sigma_{\mu\nu}p^\mu z^\nu\phi_S^\sigma(x)\right\}_{\alpha\beta} \\ &= \frac{1}{\sqrt6}\int_0^1 dx e^{ixp\cdot z}\left\{\not p\phi_S(x) + m_S\phi_S^S(x) + \frac{1}{6}m_S(\not n\not{\bar n} - 1)\phi_S^T(x)\right\}_{\alpha\beta},\end{aligned}$$

Normalization: $\int_0^1 dx\phi_S(x) = \frac{f_S}{2\sqrt6}, \quad \int_0^1 dx\phi_S^S(x) = \int_0^1 dx\phi_S^\sigma(x) = \frac{\bar f_S}{2\sqrt6},$

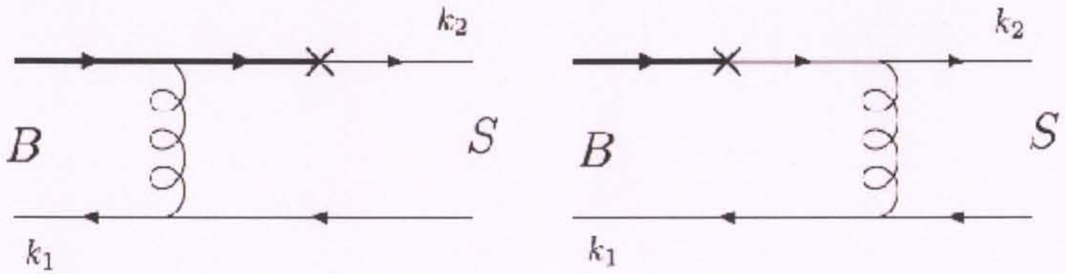
$$\phi_S(x,\mu) = \frac{\bar f_S(\mu)}{2\sqrt6}6x(1-x)\left[B_0(\mu) + \sum_{m=1}^{\infty} B_m(\mu)C_m^{3/2}(2x-1)\right]$$

$$\phi_S^s(x) = \frac{\bar f_S}{2\sqrt{2N_c}}\left[1 + \sum_{m=1}^{\infty} a_m(\mu)C_m^{1/2}(2x-1)\right]$$

- **H.Y.Cheng and K.C.Yang, PRD71, 054020;**
- **H.Y.Cheng, C.K. Chua and K.C.Yang, PRD73, 014017**
- **C.D. Lu, Y.M. Wang and H. Zou, PRD75, 056001**

Semi-leptonic decays

- The B→S transition form factor



- The model calculation

Light front quark model: H.Y.Cheng, C.K. Chua and C.W. Hwang, PRD69, 074025;

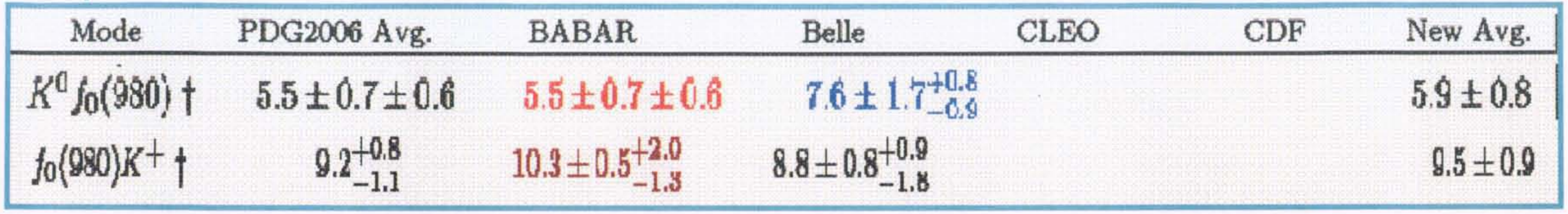
C.H. Chen, C.Q.Geng, C.C. Lih, and C.C. Liu, PRD, Phys. Rev. D **75**, 074010

Light-cone sum rules: Y.M.Wang, M.J.Aslam and C.D. Lu, PRD 78,014006
M.Z. Yang, PRD73,034027, 079901(E)

Perturbative QCD: R.H.Li, C.D.Lu, W.Wang and X.X.Wang, PRD 79,014013

The decay B→$f_0(980)$K

Experimental data



Mode	PDG2006 Avg.	BABAR	Belle	CLEO	CDF	New Avg.
$K^0 f_0(980)$ †	$5.5 \pm 0.7 \pm 0.6$	$5.5 \pm 0.7 \pm 0.6$	$7.6 \pm 1.7^{+0.8}_{-0.9}$			5.9 ± 0.8
$f_0(980)K^+$ †	$9.2^{+0.8}_{-1.1}$	$10.3 \pm 0.5^{+2.0}_{-1.3}$	$8.8 \pm 0.8^{+0.9}_{-1.8}$			9.5 ± 0.9

Theoretical studies

- **PQCD: C.H. Chen, Phys. Rev. D 67, 014012(2003); 67,094011(2003)**
- **QCDF: Cheng et al Phys. Rev. D 71,054020(2005); 73, 014017(2006)**

❖ $f_0(980)$ **is regarded as mixing of** $\bar{s}s$ **and** $\bar{n}n$ **in the calculations**

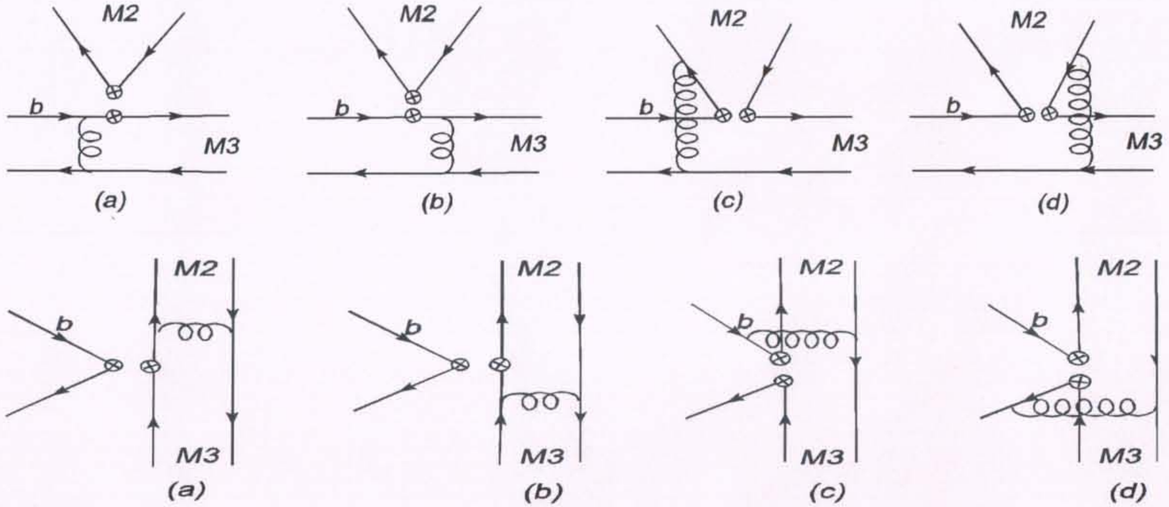
$$|f_0(980)\rangle = \cos\theta|\bar{s}s\rangle + \sin\theta|\bar{n}n\rangle$$

- **The QCDF result suffices to explain the data, while the pQCD result is much smaller: Where is the difference from? Is there really such big discrepancy between these two methods?**

PQCD

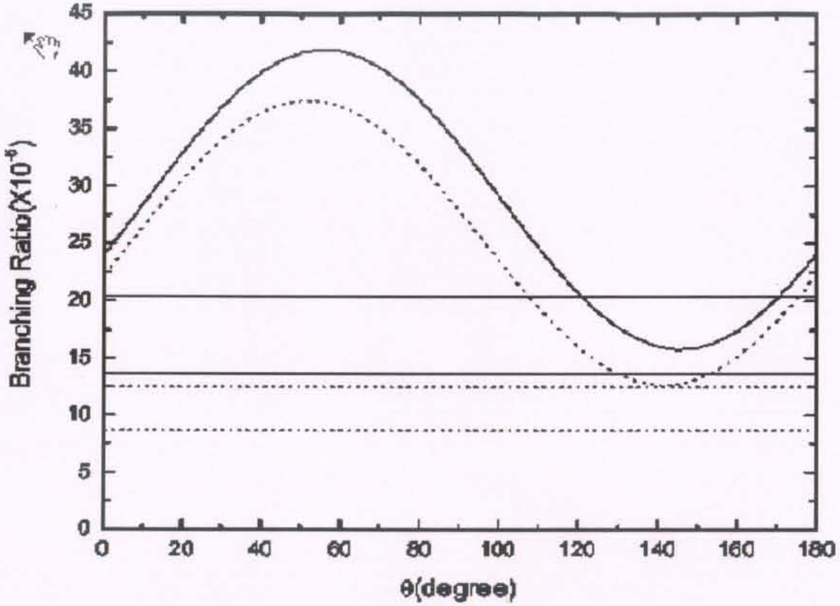
$$Amplitude \sim \int dx_1 dx_2 dx_3 b_1 db_1 b_2 db_2 b_3 db_3$$
$$\{Tr[C(t)\Phi_B(x_1,b_1)\Phi_\pi(x_2,b_2)\Phi_\pi(x_3,b_3)$$
$$H(x_i,b_i,t)S_t(x_i)e^{-S(t)}]\}$$

Hard kernel diagrams



- Only the twist-3 wave function contribute to the factorizable emission diagram, if the emitted meson is a scalar. (S-P S+P density current)
- There is enhancement rather than cancellation between the two nonfactorizable diagrams, and the twist-2 LCDA can give important contribution.

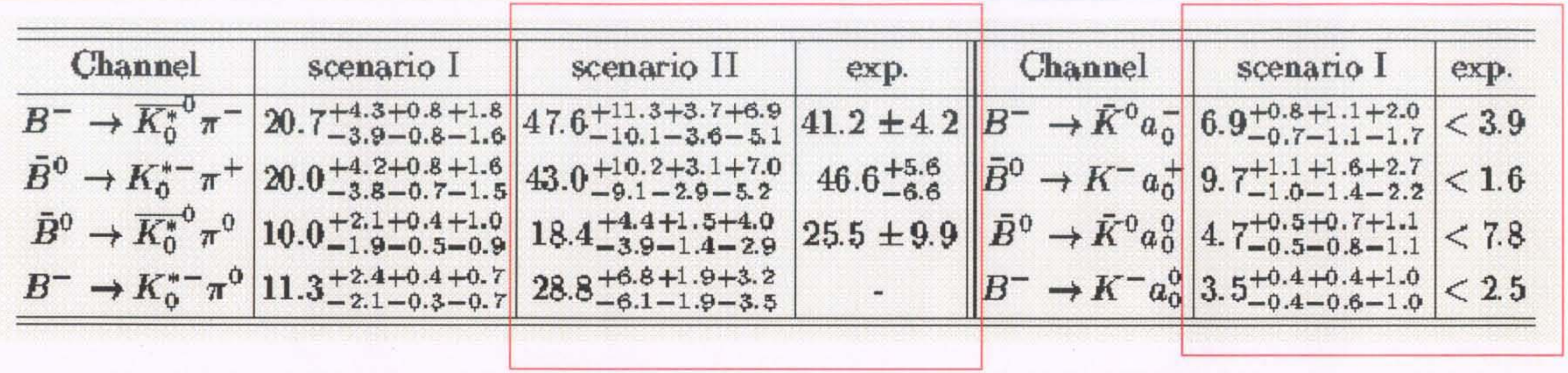
Numerical results for $B \to f_0(980)K$



W. Wang, YLS, Y. Li and C.D. Lu, PRD 74,114010(2006).

The perturbative calculation suffices to explain the data in two quark picture. This is consistent with QCDF.

$B \to K_0^*(1430)\pi$ and $B \to a_0(980)K$



Channel	scenario I	scenario II	exp.	Channel	scenario I	exp.
$B^- \to \overline{K_0^*}^0 \pi^-$	$20.7^{+4.3+0.8+1.8}_{-3.9-0.8-1.6}$	$47.6^{+11.3+3.7+6.9}_{-10.1-3.6-5.1}$	41.2 ± 4.2	$B^- \to \bar{K}^0 a_0^-$	$6.9^{+0.8+1.1+2.0}_{-0.7-1.1-1.7}$	< 3.9
$\bar{B}^0 \to K_0^{*-} \pi^+$	$20.0^{+4.2+0.8+1.6}_{-3.8-0.7-1.5}$	$43.0^{+10.2+3.1+7.0}_{-9.1-2.9-5.2}$	$46.6^{+5.6}_{-6.6}$	$\bar{B}^0 \to K^- a_0^+$	$9.7^{+1.1+1.6+2.7}_{-1.0-1.4-2.2}$	< 1.6
$\bar{B}^0 \to \overline{K_0^*}^0 \pi^0$	$10.0^{+2.1+0.4+1.0}_{-1.9-0.5-0.9}$	$18.4^{+4.4+1.5+4.0}_{-3.9-1.4-2.9}$	25.5 ± 9.9	$\bar{B}^0 \to \bar{K}^0 a_0^0$	$4.7^{+0.5+0.7+1.1}_{-0.5-0.8-1.1}$	< 7.8
$B^- \to K_0^{*-} \pi^0$	$11.3^{+2.4+0.4+0.7}_{-2.1-0.3-0.7}$	$28.8^{+6.8+1.9+3.2}_{-6.1-1.9-3.5}$	-	$B^- \to K^- a_0^0$	$3.5^{+0.4+0.4+1.0}_{-0.4-0.6-1.0}$	< 2.5

YLS, W. Wang J. Zhu and C.D. Lu, EPJC 50,877

Conclusion: Scenario II is more preferable

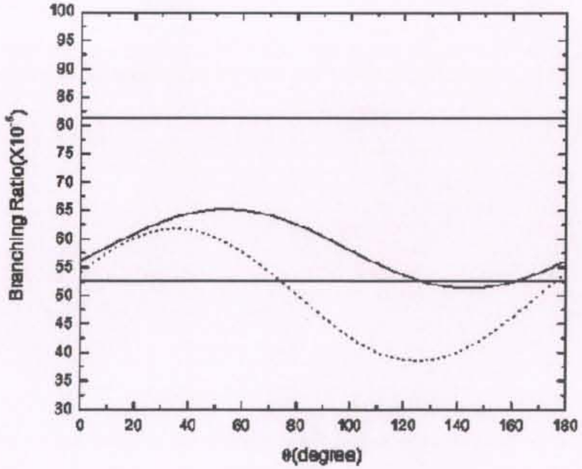
The result is consistent with the QCDF(With large annihilation topology contribution)

Other Studies: Z.-Q. Zhang, Z.-J. Xiao , **arXiv:0812.2314, 0904.3375**

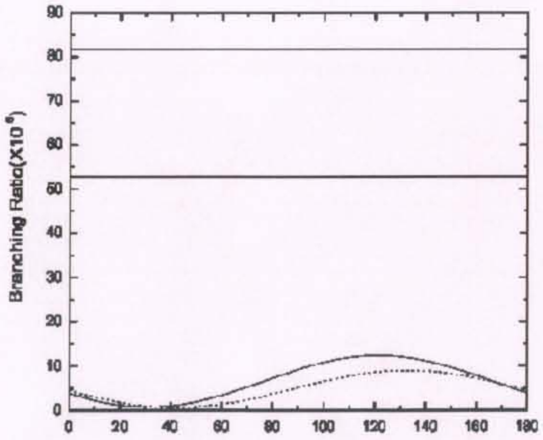
Problems: large uncertainty at both experimental and theoretical side.

Production of the flavor singlet scalar meson

- Through the Dalitz plot analysis of the three body decays B→$\pi\pi\pi$, $\pi\pi$K, πKK,KKK, some resonances like $f_X(1500)$ has been found.
- In principal, they are mixing of the qqbar state and the glueball state. In some mixing schemes, the gluonic component is negligible for $f_0(1500)$, thus we can estimate the decay rates by consider the quark components.
- The results for B→ $f_0(1500)$ K (**W. Wang, YLS, Y. Li and C.D. Lu, PRD 74,114010(2006).**)



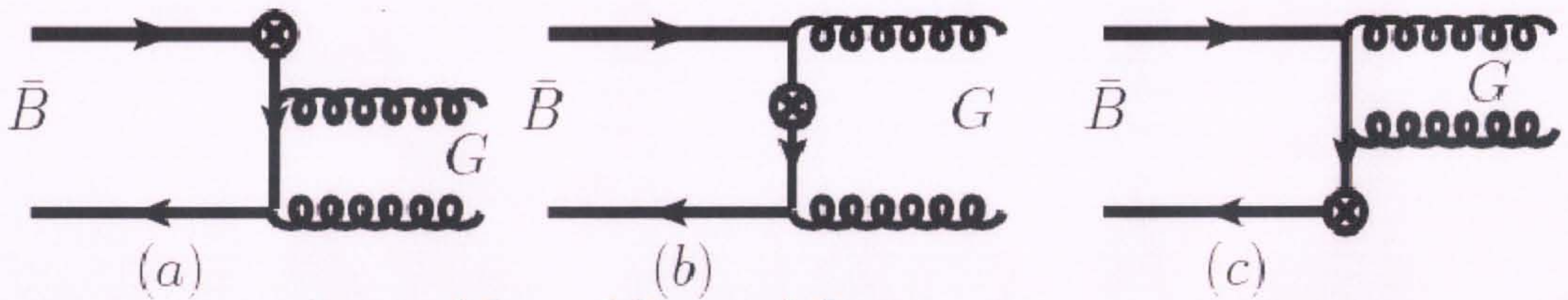
Scenario II



Scenario I

The glueball production in B decays

- The previous studies: C.H. Chen and T.C. Yuan, PLB 650(2007),379.
- The B→G form factor (W. Wang, YLS and C.D. Lu, in preparation)



- Power counting: Ma~ Mb >>Mc

$$F(B\to G) \sim F(B\to M) \sim \alpha(\sqrt{m_b\Lambda_{\rm QCD}})\left(\frac{\Lambda_{\rm QCD}}{m_b}\right)^{3/2}$$

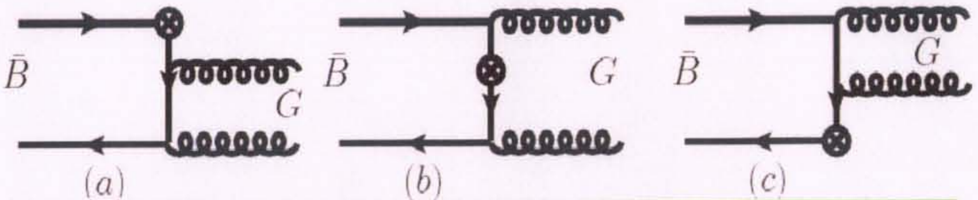
The glueball production in B decays

- Calculation

$$\langle f_0(P)|F^{a,+\mu}(z^-)F^{b,+\nu}(0)|0\rangle = \int_0^1 dx\, e^{ixz^- P^+} P^{+2} \frac{f_s \delta^{ab}}{2(N_c^2-1)} [g_\perp^{\mu\nu}\phi(x)]$$

$$\phi(x) = 30x^2(1-x^2)\left[1+\sum_n a_n C_n^{5/2}(2x-1)\right]$$

- The result for form factors and branching ratios



(a) (b) (c)

	a	b	c	total	asymptotic
$F_1 = F_0$	0.084	0.024	0.003	0.111	0.087
F_T	0.071	−0.022	0.001	0.050	0.034

$$\mathcal{BR}(B \to G l \bar{\nu}) = (1.73[1.03]) \times 10^{-5},$$
$$\mathcal{BR}(B \to G \tau \bar{\nu}_\tau) = (13.6[8.4]) \times 10^{-6},$$

The B to glueball transition is smaller than that for the quark component, but it is not negligible

Summary and outlook

- We briefly introduced the current research status of the scalar meson production in B decays, and get some hints of the scalar meson structures.

- The theoretical calculations still have large hadron uncertainty, thus we need more careful studies of the non-perturbation inputs.

- We hope the forthcoming LHCb and the future superB factory can provide more accurate data to test the predictions


Thank you