$B_{(s)} \to V\gamma$ and $B_{(s)} \to A\gamma$ decays in PQCD approach

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Based on: W. Wang [1], R.H. Li [2;1] and C.D. Lu [1], arXiv: 0711.0432.

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Menu

- Brief introduction
- Calculation
  - Form factors
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Introduction

Dominated by FCNC

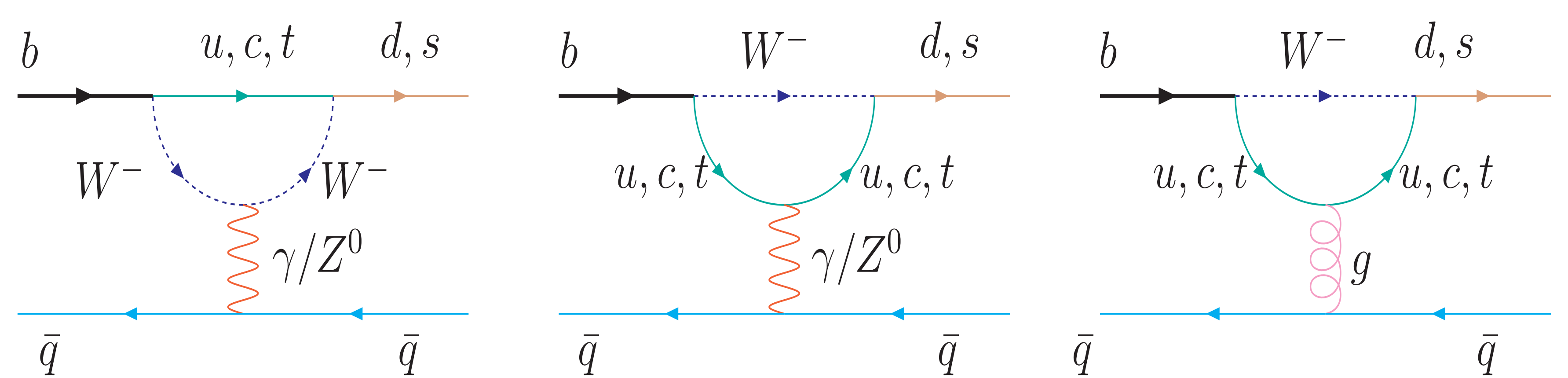
$b \to d\gamma$

$b \to s\gamma$

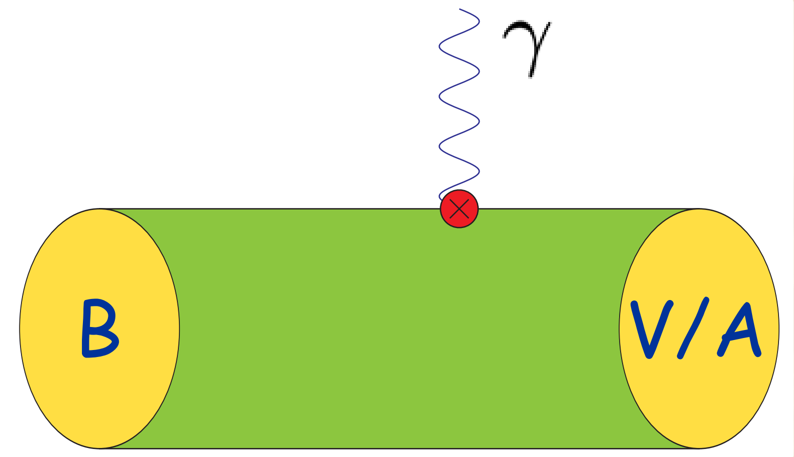
Loop effects in SM

Ideal probe for new physics

FCNC in SM



The dominate contribution is proportional to the transition form factor.

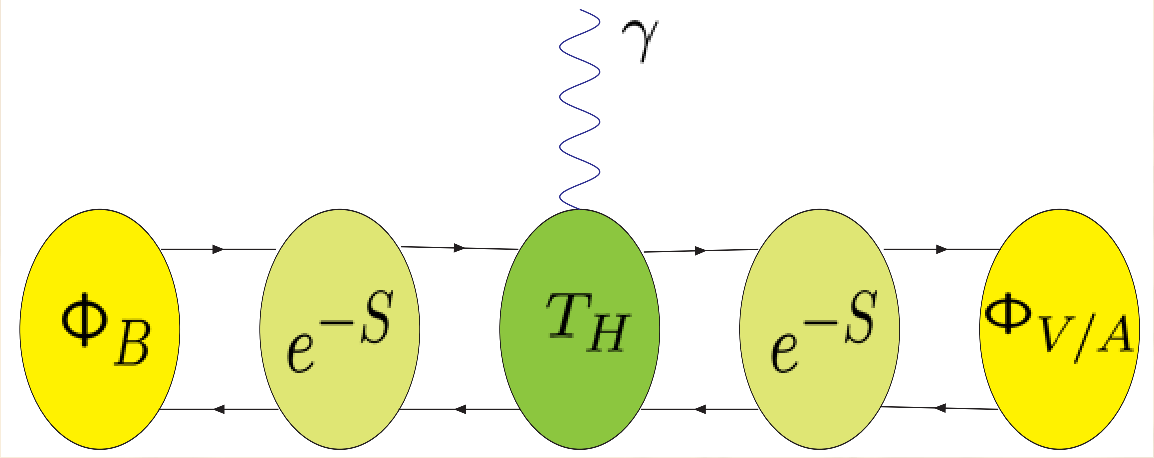


Main difficulty in theory for this type of decays

Deal with $\langle V\gamma|O_i|\bar{B}\rangle$

- LQCD
- LFQM
- LCSR
- QCDF
- SCET
- PQCD
- ……

$B \to V/A\,\gamma$ in PQCD



$$\mathcal{M} = \int_0^1 dx_1 dx_2 \int d^2\vec{b}_1 d^2\vec{b}_2 (2\pi)^2 \phi_B(x_1, \vec{b}_1, p_1, t)$$
$$\times T_H(x_1, x_2, Q, \vec{b}_1, \vec{b}_2, t)\phi_V(x_2, \vec{b}_2, p_2, t) S_t(x_2) \exp[-S_B(t) - S_2(t)]$$

For axial vector mesons:

$$\langle A(P_2,\epsilon^*)|\bar{q}\gamma^\mu\gamma_5 b|\bar{B}(P_1)\rangle = -\frac{2iA(q^2)}{m_B-m_A}\epsilon^{\mu\nu\rho\sigma}\epsilon^*_\nu P_{1\rho}P_{2\sigma},$$

$$\langle A(P_2,\epsilon^*)|\bar{q}\gamma^\mu b|\bar{B}(P_1)\rangle = -2m_A V_0(q^2)\frac{\epsilon^*\cdot q}{q^2}q^\mu - (m_B-m_A)V_1(q^2)\left[\epsilon^*_\mu - \frac{\epsilon^*\cdot q}{q^2}q^\mu\right]$$
$$+V_2(q^2)\frac{\epsilon^*\cdot q}{m_B-m_A}\left[(P_1+P_2)^\mu - \frac{m_B^2-m_A^2}{q^2}q^\mu\right],$$

$$\langle A(P_2,\epsilon^*)|\bar{q}\sigma^{\mu\nu}\gamma_5 q_\nu b|\bar{B}(P_1)\rangle = -2T_1(q^2)\epsilon^{\mu\nu\rho\sigma}\epsilon^*_\nu P_{1\rho}P_{2\sigma},$$

$$\langle A(P_2,\epsilon^*)|\bar{q}\sigma^{\mu\nu}q_\nu b|\bar{B}(P_1)\rangle = -iT_2(q^2)\left[(m_B^2-m_A^2)\epsilon^{*\mu} - (\epsilon^*\cdot q)(P_1+P_2)^\mu\right]$$
$$-iT_3(q^2)(\epsilon^*\cdot q)\left[q^\mu - \frac{q^2}{m_B^2-m_A^2}(P_1+P_2)^\mu\right]$$

At q2 = 0, there is $2m_A V_0 = (m_B - m_A)V_1 - (m_B + m_A)V_2$.

Form Factors

For vector mesons:

$$\langle V(P_2,\epsilon^*)|\bar{q}\gamma^\mu b|\bar{B}(P_1)\rangle = -\frac{2V(q^2)}{m_B+m_V}\epsilon^{\mu\nu\rho\sigma}\epsilon^*_\nu P_{1\rho}P_{2\sigma},$$

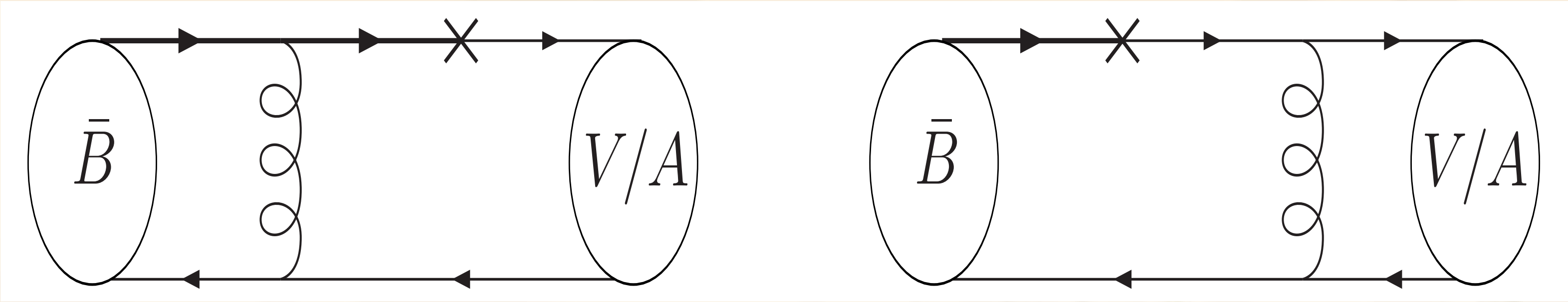
$$\langle V(P_2,\epsilon^*)|\bar{q}\gamma^\mu\gamma_5 b|\bar{B}(P_1)\rangle = 2im_V A_0(q^2)\frac{\epsilon^*\cdot q}{q^2}q^\mu + i(m_B+m_V)A_1(q^2)\left[\epsilon^*_\mu - \frac{\epsilon^*\cdot q}{q^2}q^\mu\right]$$
$$-iA_2(q^2)\frac{\epsilon^*\cdot q}{m_B+m_V}\left[(P_1+P_2)^\mu - \frac{m_B^2-m_V^2}{q^2}q^\mu\right],$$

$$\langle V(P_2,\epsilon^*)|\bar{q}\sigma^{\mu\nu}q_\nu b|\bar{B}(P_1)\rangle = -2iT_1(q^2)\epsilon^{\mu\nu\rho\sigma}\epsilon^*_\nu P_{1\rho}P_{2\sigma},$$

$$\langle V(P_2,\epsilon^*)|\bar{q}\sigma^{\mu\nu}\gamma_5 q_\nu b|\bar{B}(P_1)\rangle = T_2(q^2)\left[(m_B^2-m_V^2)\epsilon^{*\mu} - (\epsilon^*\cdot q)(P_1+P_2)^\mu\right]$$
$$+T_3(q^2)(\epsilon^*\cdot q)\left[q^\mu - \frac{q^2}{m_B^2-m_V^2}(P_1+P_2)^\mu\right]$$

At q2 = 0, there is $2m_V A_0(0) = (m_B+m_V)A_1(0) - (m_B-m_V)A_2(0)$.

Contributions to form factor in PQCD



Mixing of the axial vector mesons

$$|K_1(1270)\rangle = |K_{1A}\rangle \sin\theta_K + |K_{1B}\rangle \cos\theta_K$$

$$|K_1(1400)\rangle = |K_{1A}\rangle \cos\theta_K - |K_{1B}\rangle \sin\theta_K$$

$$|f_1(1285)\rangle = |f_1\rangle \cos\theta_{^3P_1} + |f_8\rangle \sin\theta_{^3P_1}$$

$$|f_1(1420)\rangle = -|f_1\rangle \sin\theta_{^3P_1} + |f_8\rangle \cos\theta_{^3P_1}$$

$$|h_1(1170))\rangle = |h_1\rangle \cos\theta_{^1P_1} + |h_8\rangle \sin\theta_{^1P_1}$$

$$|h_1(1380)\rangle = -|h_1\rangle \sin\theta_{^1P_1} + |h_8\rangle \cos\theta_{^1P_1}$$

Kwei-Chou Yang, Nucl. Phys. B 776, 187 (2007)

form factors of B ⟶ V

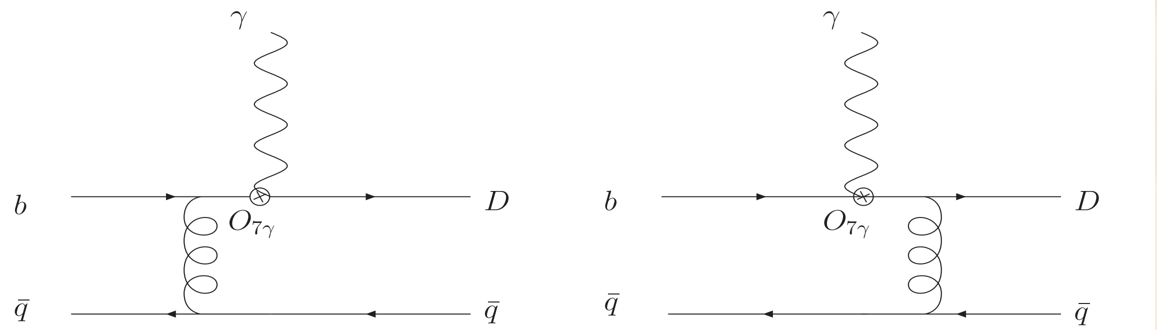
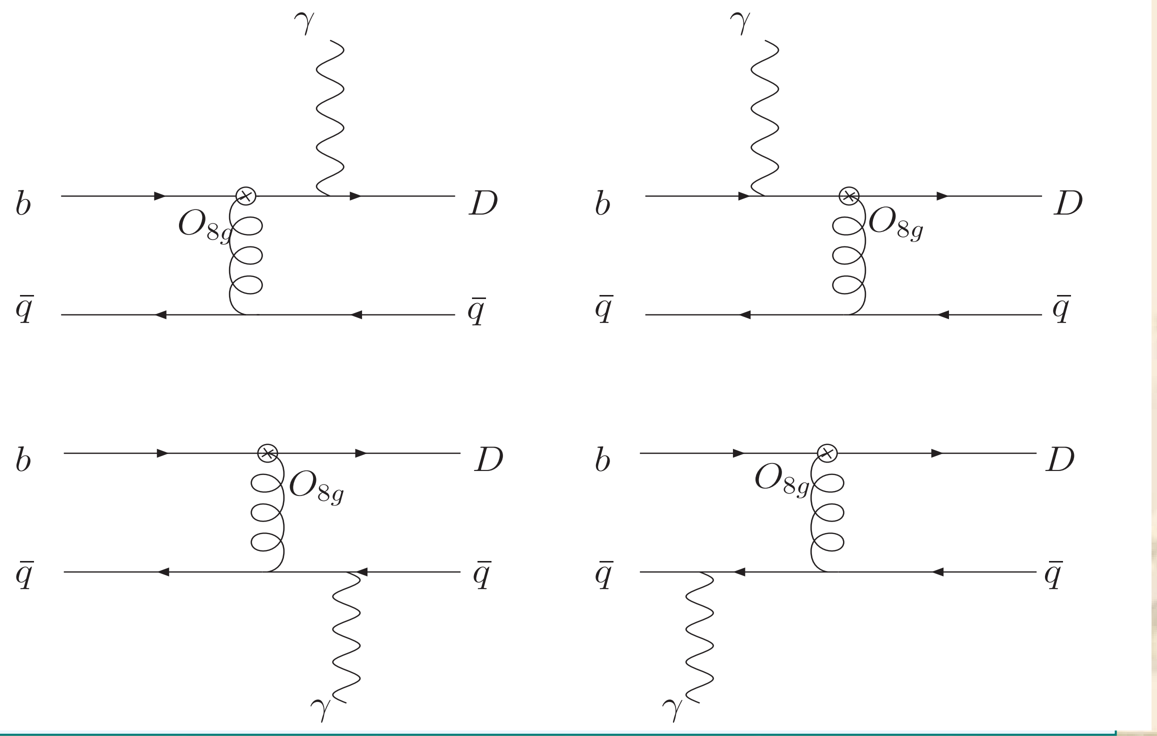
		$B \to \rho$	$B \to K^*$	$B \to \omega$	$B_s \to K^*$	$B_s \to \phi$
LFQM	V	0.27	0.31			
	A_0	0.28	0.31			
	A_1	0.22	0.26			
	A_2	0.20	0.24			
LCSR	V	0.323	0.411	0.293	0.311	0.434
	A_0	0.303	0.374	0.281	0.360	0.474
	A_1	0.242	0.292	0.219	0.233	0.311
	A_2	0.221	0.259	0.198	0.181	0.234
	T_2	0.267	0.333	0.242	0.260	0.349
LQCD	V	0.35				
	A_0	0.30				
	A_1	0.27				
	A_2	0.26				
	T_1		0.24			
SCET LCQM	V	0.298	0.339	0.275	0.323	0.329
	A_0	0.260	0.283	0.240	0.279	0.279
	A_1	0.227	0.248	0.209	0.228	0.232
	A_2	0.215	0.233	0.198	0.204	0.210
	$T_1 = T_2$	0.260	0.290	0.239	0.271	0.276
	T_3	0.184	0.194	0.168	0.165	0.170
This work	V	$0.21^{+0.05+0.00}_{-0.04-0.00}$	$0.25^{+0.05+0.00}_{-0.05-0.00}$	$0.20^{+0.04+0.00}_{-0.04-0.00}$	$0.21^{+0.04+0.00}_{-0.03-0.01}$	$0.25^{+0.05+0.00}_{-0.04-0.01}$
	A_0	$0.25^{+0.05+0.00}_{-0.05-0.01}$	$0.30^{+0.06+0.00}_{-0.05-0.01}$	$0.24^{+0.05+0.00}_{-0.04-0.01}$	$0.26^{+0.05+0.00}_{-0.04-0.01}$	$0.30^{+0.05+0.00}_{-0.05-0.01}$
	A_1	$0.17^{+0.04+0.00}_{-0.03-0.00}$	$0.19^{+0.04+0.00}_{-0.03-0.00}$	$0.15^{+0.03+0.00}_{-0.03-0.00}$	$0.16^{+0.03+0.00}_{-0.02-0.01}$	$0.18^{+0.03+0.00}_{-0.03-0.01}$
	A_2	$0.13^{+0.03+0.00}_{-0.02-0.00}$	$0.14^{+0.03+0.00}_{-0.03-0.00}$	$0.13^{+0.03+0.00}_{-0.02-0.00}$	$0.12^{+0.02+0.00}_{-0.02-0.01}$	$0.13^{+0.02+0.00}_{-0.02-0.01}$
	$T_1 = T_2$	$0.20^{+0.04+0.00}_{-0.04-0.00}$	$0.23^{+0.05+0.00}_{-0.04-0.00}$	$0.18^{+0.04+0.00}_{-0.03-0.00}$	$0.19^{+0.04+0.00}_{-0.03-0.01}$	$0.22^{+0.04+0.00}_{-0.04-0.01}$
	T_3	$0.13^{+0.03+0.00}_{-0.02-0.00}$	$0.13^{+0.03+0.00}_{-0.02-0.00}$	$0.12^{+0.03+0.00}_{-0.02-0.00}$	$0.11^{+0.02+0.00}_{-0.02-0.01}$	$0.12^{+0.02+0.00}_{-0.02-0.01}$

form factors of B→A

This work	$B\to a_1$	$B\to b_1$	$B\to K_{1A}$	$B\to K_{1B}$	$B_s\to K_{1A}$	$B_s\to K_{1B}$
A	$0.26^{+0.06+0.03}_{-0.05-0.03}$	$0.19^{+0.04+0.03}_{-0.03-0.02}$	$0.27^{+0.06+0.05}_{-0.05-0.05}$	$0.20^{+0.04+0.04}_{-0.04-0.04}$	$0.25^{+0.05+0.05}_{-0.04-0.05}$	$0.18^{+0.03+0.04}_{-0.03-0.04}$
V_0	$0.34^{+0.07+0.08}_{-0.06-0.08}$	$0.45^{+0.09+0.04}_{-0.08-0.04}$	$0.35^{+0.07+0.13}_{-0.06-0.13}$	$0.52^{+0.10+0.06}_{-0.09-0.07}$	$0.36^{+0.07+0.11}_{-0.06-0.12}$	$0.42^{+0.08+0.06}_{-0.07-0.06}$
V_1	$0.43^{+0.09+0.05}_{-0.08-0.05}$	$0.33^{+0.07+0.04}_{-0.06-0.04}$	$0.48^{+0.10+0.09}_{-0.09-0.09}$	$0.36^{+0.07+0.08}_{-0.06-0.08}$	$0.43^{+0.08+0.08}_{-0.07-0.08}$	$0.39^{+0.06+0.07}_{-0.05-0.07}$
V_2	$0.14^{+0.03+0.00}_{-0.03-0.00}$	$0.03^{+0.01+0.01}_{-0.00-0.01}$	$0.15^{+0.03+0.02}_{-0.03-0.02}$	$0.00^{+0.00+0.03}_{-0.00-0.03}$	$0.12^{+0.02+0.01}_{-0.02-0.01}$	$0.03^{+0.01+0.02}_{-0.01-0.02}$
$T_1(T_2)$	$0.34^{+0.07+0.05}_{-0.06-0.05}$	$0.27^{+0.06+0.03}_{-0.05-0.03}$	$0.37^{+0.08+0.08}_{-0.07-0.08}$	$0.29^{+0.06+0.06}_{-0.05-0.06}$	$0.34^{+0.06+0.07}_{-0.05-0.07}$	$0.26^{+0.05+0.05}_{-0.04-0.05}$
T_3	$0.19^{+0.04+0.01}_{-0.03-0.01}$	$0.06^{+0.01+0.02}_{-0.01-0.02}$	$0.20^{+0.04+0.02}_{-0.04-0.02}$	$0.03^{+0.01+0.00}_{-0.00-0.00}$	$0.17^{+0.03+0.02}_{-0.03-0.02}$	$0.06^{+0.01+0.03}_{-0.01-0.03}$

LFQM	$B\to a_1$	$B\to b_1$	$B\to K_{1A}$	$B\to K_{1B}$
A	0.25	0.10	0.26	0.11
V_0	0.13	0.39	0.14	0.41
V_1	0.37	0.18	0.39	0.19
V_2	0.18	−0.03	0.17	−0.05
$T_1(T_2)$	−−	−−	0.11	0.13
T_3	−−	−−	0.19	−0.07

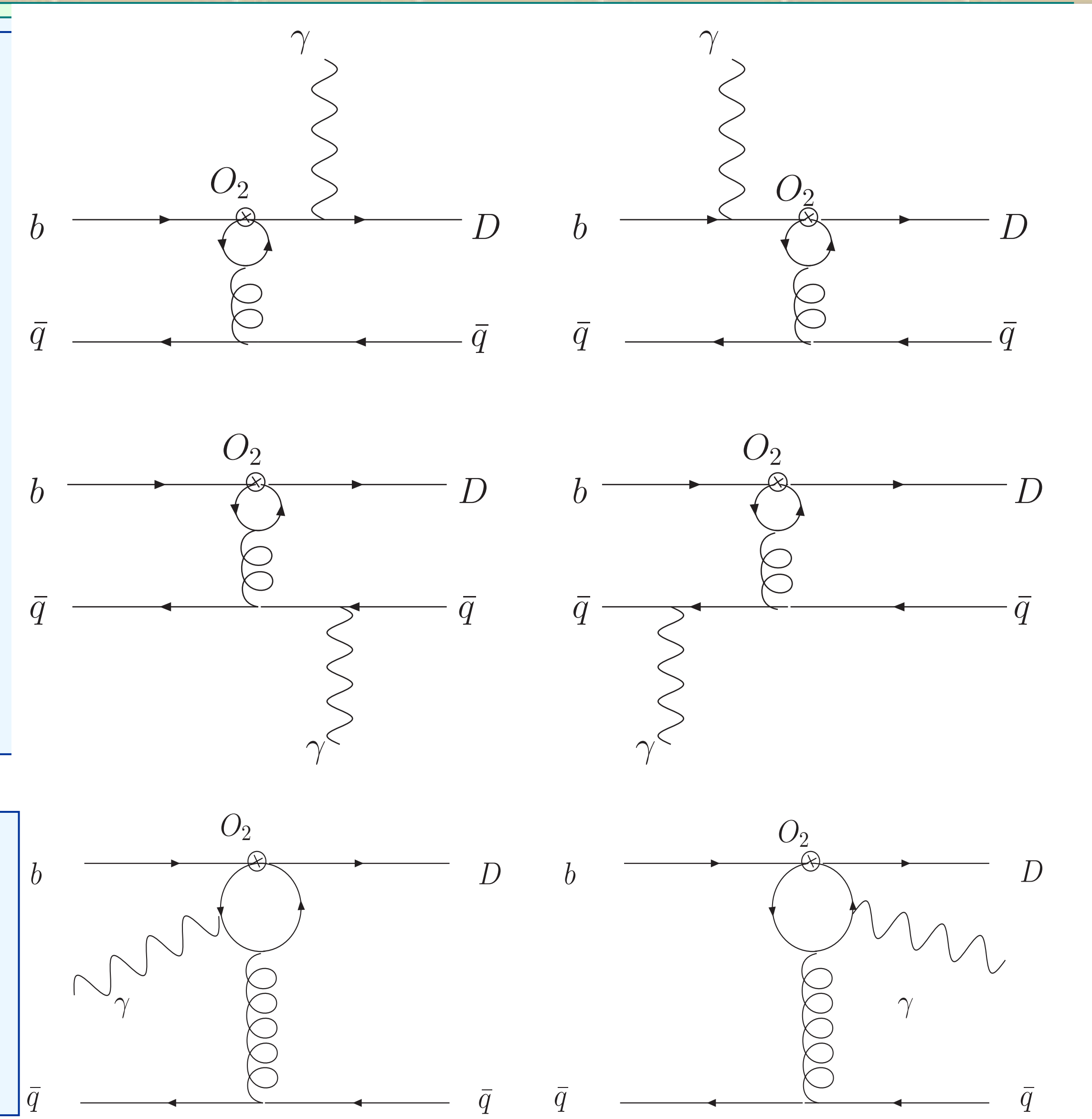
Amplitudes

$O_{7\gamma}$	
O_{8g}	

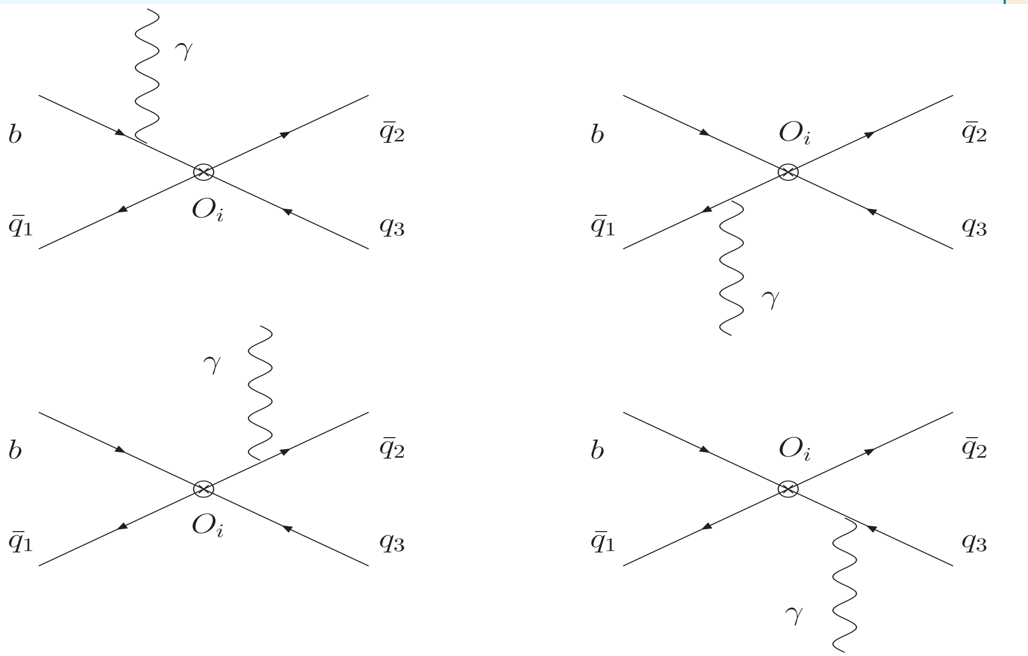
Loop contributions

Quark line photon emission

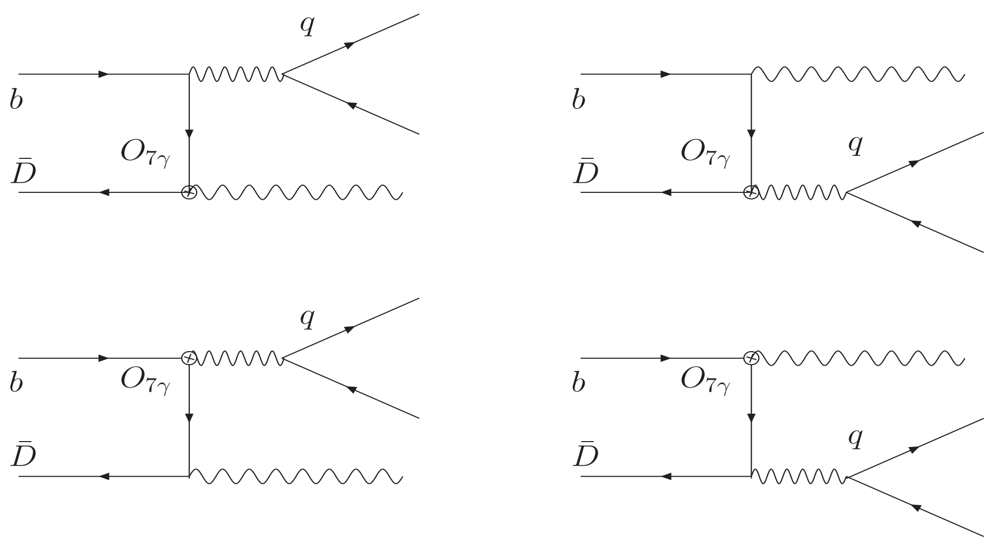
Loop line photon emission



Annihilation contributions



Two photon diagrams



Branch ratios

Branch ratios of $\bar{B} \to V\gamma$ Unit: 10^{-6}

Modes	QCDF	SCET	This work	Exp.
$B^- \to K^{*-}\gamma$	$53.3 \pm 13.5 \pm 5.8$	$46 \pm 12 \pm 4 \pm 2 \pm 1$	$35.8^{+17.6+5.4+1.1}_{-12.8-4.0-1.1}$	40.3 ± 2.6 [HFAG]
$\bar{B}^0 \to \bar{K}^{*0}\gamma$	$54.2 \pm 13.2 \pm 6.7$	$43 \pm 11 \pm 4 \pm 2 \pm 1$	$38.1^{+17.3+5.5+1.1}_{-12.7-3.8-1.1}$	40.1 ± 2.0 [HFAG]
$\bar{B}^0_s \to \phi\gamma$	$39.4 \pm 10.7 \pm 5.3$	$43 \pm 11 \pm 3 \pm 3 \pm 1$	$35.8^{+13.7+4.9+1.1}_{-10.3-3.5-1.1}$	57^{+18+12}_{-15-11} [Belle]

Modes	QCDF	This work	Exp.	
$B^- \to \rho^-\gamma$	$1.16 \pm 0.22 \pm 0.13$	$1.15^{+0.57+0.18+0.17}_{-0.39-0.11-0.09}$	$1.10^{+0.37}_{-0.33} \pm 0.09$ [BaBar]	$0.55^{+0.42+0.09}_{-0.36-0.08}$ [Belle]
$\bar{B}^0 \to \rho^0\gamma$	$0.55 \pm 0.11 \pm 0.07$	$0.57^{+0.26+0.09+0.08}_{-0.19-0.06-0.04}$	$0.79^{+0.22}_{-0.20} \pm 0.06$ [BaBar]	$1.25^{+0.37+0.07}_{-0.33-0.06}$ [Belle]
$\bar{B}^0 \to \omega\gamma$	$0.44 \pm 0.09 \pm 0.05$	$0.51^{+0.23+0.08+0.08}_{-0.17-0.05-0.03}$	$0.40^{+0.24}_{-0.20} \pm 0.05$ [BaBar]	$0.56^{+0.34+0.05}_{-0.27-0.10}$ [Belle]
$\bar{B}^0_s \to K^{*0}\gamma$	$1.26 \pm 0.25 \pm 0.18$	$1.11^{+0.42+0.15+0.16}_{-0.32-0.12-0.07}$	—	
$\bar{B}^0 \to \phi\gamma$	—	$(7.5^{+2.8+2.1+1.1}_{-2.1-0.9-0.5}) \times 10^{-6}$	< 0.85 [HFAG]	
$\bar{B}^0_s \to \rho^0\gamma$	—	$(1.7^{+0.4+0.1+0.0}_{-0.4-0.1-0.1}) \times 10^{-3}$	—	
$\bar{B}^0_s \to \omega\gamma$	—	$(1.8^{+0.4+0.1+0.1}_{-0.4-0.2-0.1}) \times 10^{-4}$	—	

Cai-Dian Lu, M. Matsumori, A.I. Sanda, Mao-Zhi Yang ,Phys.Rev. D72 (2005) 094005

Branch ratios of $\bar{B} \to A\gamma$

Unit: 10^{-6}

$B^- \to a_1^-(1260)\gamma$	$3.0^{+1.6+0.4+0.4+0.8}_{-1.1-0.3-0.2-0.7}$
$\bar{B}^0 \to a_1^0(1260)\gamma$	$1.5^{+0.7+0.2+0.2+0.4}_{-0.5-0.2-0.1-0.4}$
$\bar{B}_s \to a_1^0(1260)\gamma$	$(2.1^{+0.6+0.3+0.1+0.0}_{-0.5-0.1-0.1-0.0}) \times 10^{-4}$
$B^- \to b_1^-(1235)\gamma$	$2.0^{+1.0+0.4+0.3+0.6}_{-0.7-0.3-0.1-0.5}$
$\bar{B}^0 \to b_1^0(1235)\gamma$	$1.1^{+0.5+0.2+0.2+0.3}_{-0.3-0.1-0.1-0.2}$
$\bar{B}_s \to b_1^0(1235)\gamma$	$(5.4^{+1.0+6.4+0.3+2.1}_{-0.9-2.5-0.2-1.8}) \times 10^{-5}$

Unit: 10^{-6}

Modes	$\theta_K = 45°$	$\theta_K = -45°$
$B^- \to K_1^-(1270)\gamma$	$134^{+68+21+4+41}_{-49-18-4-38}$	$1.4^{+1.2+0.3+0.0+5.0}_{-0.7-0.6-0.0-2.0}$
$\bar{B}^0 \to \bar{K}_1^0(1270)\gamma$	$141^{+64+19+4+45}_{-48-18-4-41}$	$1.4^{+0.9+0.3+0.0+5.4}_{-0.6-0.5-0.0-1.9}$
$B^- \to K_1^-(1400)\gamma$	$1.4^{+1.2+0.3+0.0+5.0}_{-0.7-0.6-0.0-2.0}$	$134^{+68+21+4+41}_{-49-18-4-38}$
$\bar{B}^0 \to \bar{K}_1^0(1400)\gamma$	$1.4^{+0.9+0.3+0.0+5.4}_{-0.6-0.5-0.0-1.9}$	$141^{+64+19+4+45}_{-48-18-4-41}$
$\bar{B}_s \to K_1^0(1270)\gamma$	$0.19^{+0.07+0.02+0.02+0.34}_{-0.06-0.03-0.01-0.22}$	$0.38^{+0.24+0.09+0.07+0.44}_{-0.15-0.07-0.03-0.32}$
$\bar{B}_s \to K_1^0(1400)\gamma$	$0.38^{+0.24+0.09+0.07+0.44}_{-0.15-0.07-0.03-0.32}$	$0.19^{+0.07+0.02+0.02+0.34}_{-0.06-0.03-0.01-0.22}$

Modes	$\theta_{^3P_1} = 38°$	$\theta_{^3P_1} = 50°$
$\bar{B}^0 \to f_1(1285)\gamma$	$1.7^{+0.8+0.2+0.2+0.5}_{-0.6-0.2-0.1-0.4}$	$1.6^{+0.7+0.2+0.2+0.4}_{-0.5-0.2-0.1-0.4}$
$\bar{B}^0 \to f_1(1420)\gamma$	$(4.9^{+2.3+0.6+0.7+3.9}_{-1.7-1.1-0.3-2.7}) \times 10^{-3}$	$0.11^{+0.05+0.01+0.02+0.04}_{-0.04-0.02-0.01-0.04}$
$\bar{B}_s^0 \to f_1(1285)\gamma$	$0.11^{+0.05+0.01+0.00+0.03}_{-0.04-0.01-0.00-0.03}$	$3.8^{+1.6+0.4+0.1+0.7}_{-1.2-0.4-0.1-0.7}$
$\bar{B}_s^0 \to f_1(1420)\gamma$	$61.9^{+24.5+5.5+1.8+17.4}_{-18.9-6.0-1.8-15.5}$	$58.2^{+22.9+5.1+1.6+16.7}_{-17.7-5.6-1.7-14.8}$

Modes	$\theta_{^1P_1} = 10°$	$\theta_{^1P_1} = 45°$
$\bar{B}^0 \to h_1(1170)\gamma$	$0.99^{+0.43+0.16+0.14+0.24}_{-0.33-0.13-0.06-0.21}$	$1.24^{+0.55+0.20+0.18+0.31}_{-0.41-0.16-0.08-0.27}$
$\bar{B}^0 \to h_1(1380)\gamma$	$0.28^{+0.12+0.05+0.04+0.07}_{-0.09-0.04-0.02-0.06}$	$(2.0^{+0.8+0.3+0.3+0.3}_{-0.7-0.3-0.1-0.3}) \times 10^{-2}$
$\bar{B}_s^0 \to h_1(1170)\gamma$	$7.9^{+2.9+1.0+0.2+1.8}_{-2.2-0.7-0.2-1.6}$	$2.3^{+0.9+0.3+0.1+0.7}_{-0.7-0.3-0.1-0.6}$
$\bar{B}_s^0 \to h_1(1380)\gamma$	$44.4^{+16.8+5.6+1.3+11.0}_{-12.8-4.1-1.3-9.7}$	$50.0^{+18.8+6.3+1.5+12.2}_{-14.3-4.5-1.5-10.7}$

CP Violation

Direct CPV

$$A_{\rm CP}^{dir} \equiv \frac{\mathcal{BR}(\bar{B} \to \bar{V}\gamma) - \mathcal{BR}(B \to V\gamma)}{\mathcal{BR}(\bar{B} \to \bar{V}\gamma) + \mathcal{BR}(B \to V\gamma)}$$

Mixing -induced CPV

$$\Gamma(B^0(t) \to f) \;=\; e^{-\Gamma t}\,\overline{\Gamma}(B \to f)\Big[\cosh\left(\frac{\Delta\Gamma t}{2}\right) + H_f \sinh\left(\frac{\Delta\Gamma t}{2}\right) - A_{\rm CP}^{dir}\cos(\Delta m t) - S_f \sin(\Delta m t)\Big]$$

$\bar{B} \to V\gamma$ Unit: %

$B^- \to \rho^- \gamma$	$12.8^{+0.8+2.9+0.8}_{-0.3-1.8-0.8}$
$\bar{B}^0 \to \rho^0 \gamma$	$12.4^{+0.2+1.8+0.5}_{-0.4-2.4-0.9}$
$\bar{B}^0 \to \omega \gamma$	$12.1^{+0.0+1.8+0.5}_{-0.2-2.4-0.8}$
$\bar{B}^0_s \to K^{*0} \gamma$	$12.7^{+0.1+1.6+0.5}_{-0.5-2.3-0.9}$
$B^- \to K^{*-} \gamma$	$-0.4 \pm 0.0 \pm 0.1 \pm 0.0$
$\bar{B}^0 \to \bar{K}^{*0} \gamma$	$-0.3^{+0.0+0.0+0.0}_{-0.0-0.0-0.0}$
$\bar{B}^0_s \to \rho^0 \gamma$	$-0.1^{+0.0+0.3+0.0}_{-0.0-0.1-0.0}$
$\bar{B}^0_s \to \omega \gamma$	$-0.3^{+0.0+0.9+0.0}_{-0.0-0.5-0.0}$
$\bar{B}^0_s \to \phi \gamma$	$-0.3^{+0.0+0.0+0.0}_{-0.0-0.0-0.0}$

⇒ $b \to d\gamma$

⇒ $b \to s\gamma$

$\bar{B} \to A\gamma$ Unit: %

$B^- \to a_1^-(1260)\gamma$	$11.2^{+2.3+3.0+0.9+2.7}_{-0.5-2.4-0.8-1.3}$
$\bar{B}^0 \to a_1^0(1260)\gamma$	$3.8^{+0.3+0.3+0.2+0.4}_{-0.5-0.5-0.3-0.7}$
$B^- \to b_1^-(1235)\gamma$	$16.0^{+1.3+4.2+0.7+1.7}_{-0.5-2.7-1.1-0.7}$
$\bar{B}^0 \to b_1^0(1235)\gamma$	$11.0^{+0.2+1.9+0.5+0.3}_{-0.3-2.5-0.7-0.2}$
$\bar{B}_s \to a_1^0(1260)\gamma$	$0.8^{+0.1+0.8+0.1+0.0}_{-0.1-1.5-0.0-0.0}$
$\bar{B}_s \to b_1^0(1235)\gamma$	$-0.5^{+0.0+2.7+0.0+0.0}_{-0.0-1.5-0.0-0.0}$

⇒ $b \to d\gamma$

⇒ $b \to s\gamma$

Modes	$\theta_K = 45^\circ$	$\theta_K = -45^\circ$
$B^- \to K_1^-(1270)\gamma$	$-0.6^{+0.0+0.2+0.0+0.1}_{-0.0-0.1-0.0-0.1}$	$-3.8^{+0.7+1.1+1.8+4.0}_{-1.3-0.3-0.3-13.0}$
$\bar{B}^0 \to \bar{K}_1^0(1270)\gamma$	$-0.2 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0$	$0.1^{+0.0+0.1+0.0+2.2}_{-0.1-0.3-0.0-0.4}$
$B^- \to K_1^-(1400)\gamma$	$-3.8^{+0.7+1.1+1.8+4.0}_{-1.3-0.3-0.3-13.0}$	$-0.6^{+0.0+0.2+0.0+0.1}_{-0.0-0.1-0.0-0.1}$
$\bar{B}^0 \to \bar{K}_1^0(1400)\gamma$	$0.1^{+0.0+0.1+0.0+2.2}_{-0.1-0.3-0.0-0.4}$	$-0.2 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0$
$\bar{B}_s \to K_1^0(1270)\gamma$	$-8.4^{+0.0+0.5+0.4+5.1}_{-2.9-3.4-0.4-11.2}$	$-3.1^{+3.9+4.0+0.8+8.6}_{-0.1-3.1-0.6-14.1}$
$\bar{B}_s \to K_1^0(1400)\gamma$	$-3.1^{+3.9+4.0+0.8+8.6}_{-0.1-3.1-0.6-14.1}$	$-8.4^{+0.0+0.5+0.4+5.1}_{-2.9-3.4-0.4-11.2}$

Modes	$\theta_{^3P_1} = 38^\circ$	$\theta_{^3P_1} = 50^\circ$
$\bar{B}^0 \to f_1(1285)\gamma$	$3.4^{+0.6+0.8+0.2+0.7}_{-0.1-0.5-0.2-0.1}$	$3.4^{+0.7+0.8+0.2+0.8}_{-0.1-0.4-0.2-0.1}$
$\bar{B}^0 \to f_1(1420)\gamma$	$7.1^{+0.0+0.7+0.3+0.0}_{-3.1-7.7-0.5-2.3}$	$4.1^{+0.1+0.5+0.2+0.1}_{-0.3-1.9-0.3-0.4}$
$\bar{B}_s^0 \to f_1(1285)\gamma$	$-0.1^{+0.3+0.1+0.0+0.1}_{-0.0-0.1-0.0-0.2}$	$-0.2^{+0.1+0.0+0.0+0.0}_{-0.0-0.1-0.0-0.0}$
$\bar{B}_s^0 \to f_1(1420)\gamma$	$-0.2 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0$	$-0.2 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0$

Modes	$\theta_{^1P_1} = 10^\circ$	$\theta_{^1P_1} = 45^\circ$
$\bar{B}^0 \to h_1(1170)\gamma$	$10.2^{+0.0+1.4+0.4+0.0}_{-0.9-2.5-0.7-0.4}$	$10.1^{+0.1+1.7+0.4+0.2}_{-0.5-2.3-0.7-0.3}$
$\bar{B}^0 \to h_1(1380)\gamma$	$9.8^{+0.8+2.4+0.4+1.1}_{-0.0-2.0-0.7-0.0}$	$11.3^{+0.0+0.0+0.5+0.0}_{-5.1-4.2-0.7-3.5}$
$\bar{B}_s^0 \to h_1(1170)\gamma$	$-0.2 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0$	$-0.1^{+0.0+0.0+0.0+0.0}_{-0.0-0.1-0.0-0.0}$
$\bar{B}_s^0 \to h_1(1380)\gamma$	$-0.2 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0$	$-0.2 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0$

Iso-spin and U-spin asymmetry

$A(\rho,\omega) = \frac{\overline{\Gamma}(B^0\to\omega\gamma)}{\overline{\Gamma}(B^0\to\rho^0\gamma)} - 1$	$-0.11^{+0.01+0.01+0.00}_{-0.00-0.00-0.00}$
$A(\rho,\omega) = \frac{\overline{\Gamma}(B^0\to\omega\gamma)}{\overline{\Gamma}(B^0\to\rho^0\gamma)} - 1$	$0.06^{+0.03+0.01+0.04}_{-0.03-0.01-0.02}$
$A_I(K^*) = \frac{\overline{\Gamma}(\bar{B}^0\to\bar{K}^{*0}\gamma)-\overline{\Gamma}(B^\pm\to K^{*\pm}\gamma)}{\overline{\Gamma}(\bar{B}^0\to\bar{K}^{*0}\gamma)+\overline{\Gamma}(B^\pm\to K^{*\pm}\gamma)}$	$0.06^{+0.02+0.01+0.00}_{-0.01-0.00-0.00}$
$\Delta \equiv A_{CP}(B^- \to K^{*-}\gamma) - A_{CP}(B^- \to \rho^-\gamma) \times \frac{\mathcal{BR}(B^- \to \rho^-\gamma)}{\mathcal{BR}(B^- \to K^{*-}\gamma)}$	$(-8.4^{+0.4+1.3+0.3}_{-0.8-2.3-0.6}) \times 10^{-3}$

Summary

- We calculated the radiative decays of B mesons in PQCD approach.
- Most our results are consistent with the experiments within the uncertainties.
- The results of the axial vector mesons are sensitive to the mixing angles.
- Some of our results are confronted with the forth-coming experiments.
- The iso-spin symmetry and U-spin symmetry breaking effects are small.

Thank you!