Hadronic $B_{(s)}$ Decays

Cai-Dian Lü (吕才典)
IHEP, Beijing

Outline:

- **Measurements and Theoretical problems**
  - **rare decays**
  - **direct CP asymmetry**
  - **polarizations**
- **Possible Theoretical solution to problems and improvements**
- **Summary**

$B \to M_2 M_3$ non-perturbative QCD

decay amplitude rely on factorization

$$A = \langle f | H_{eff} | B \rangle = \frac{G_F}{\sqrt{2}} \sum_i V_{CKM}^i C_i(\mu) \langle M_2 M_3 | O_i(\mu) | B \rangle$$

- ✓ **Naïve factorization**
- ✓ **Generalized Factorization**
- ✓ **QCD factorization (QCDF)**
- ✓ **Soft-collinear effective theory (SCET)**
- ✓ **Perturbative QCD approach (PQCD)**

Non-leptonic B decays after B factories

- Experimental precision requires more reliable and higher precision theoretical calculations
- **Phi (p_2) x $J(p_1,p_2)$ x phi (p_1)**
- $J(p_1,p_2) = 1 + \alpha_s + \alpha_s^2 + \ldots$
- **phi** $(p_1) = 1 + p_1/m_b + (p_1/m_b)^2 + \ldots$

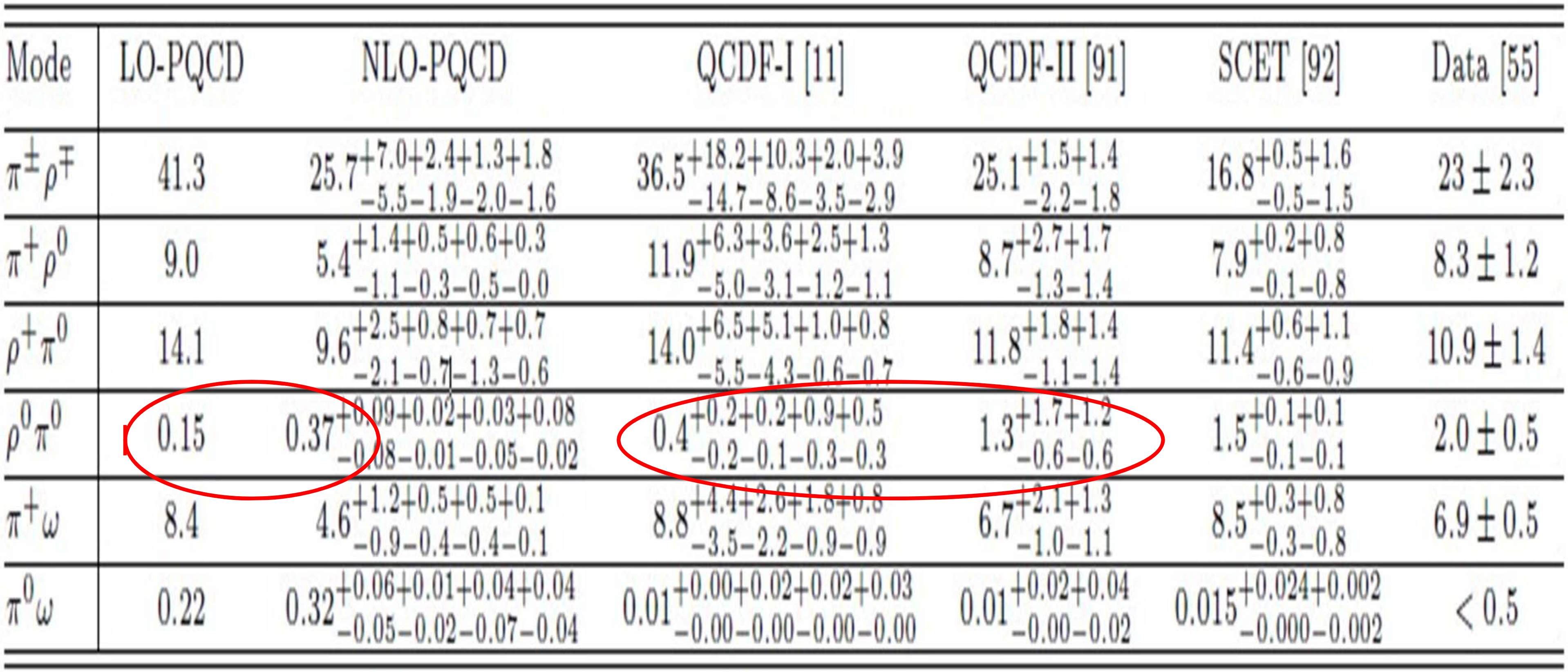
QCDF and SCET has already gone to NLO or NNLO at α_s expansion

- **Heavy-to-light currents at NNLO in SCET, G. Bell M. Beneke T. Huber X-Q Li NPB843 (2011) 143**
- **NNLO vertex corrections to non-leptonic B decays: Tree amplitudes, M. Beneke, T. Huber, XQ Li NPB832 (2010) 109 ...**
- **However, the knowledge of power corrections is limited and numerically more important**

Perturbative QCD (PQCD) in B decays is going to next-to-leading order now

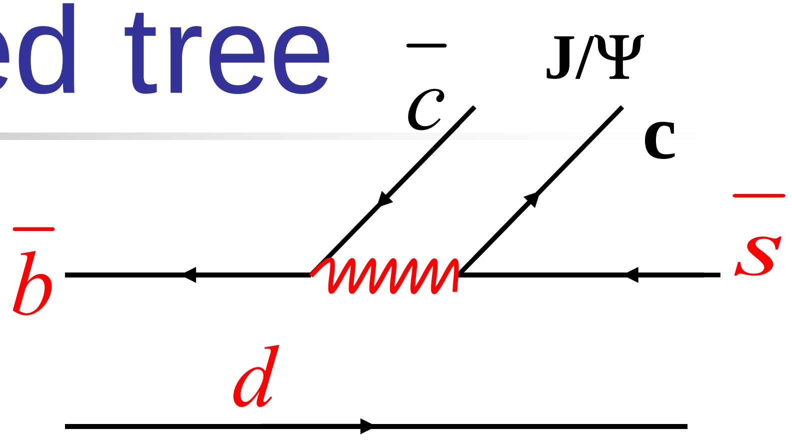
- **NLO correction to pion form factor in k_T factorization, H.-n. Li, Y.L. Shen, Y.M. Wang, H. Zou, PRD83 (2011) 054029**
- **NLO time-like pion form factors in k_T factorization, HC Hu, Hn Li, arXiv:1204.6708**
- **NLO corrections to $B \rightarrow \pi$ form factors in k_T factorization, H.n. Li, Y.L. Shen, Y.M. Wang, PRD85 (2012) 074004**

Revisiting the B→πρ, πω Decays in the perturbative QCD Approach Beyond the Leading Order, Zhou R, Gao XD, CDL, EPJC72 (2012) 1923 (10^{-6})



Mode	LO-PQCD	NLO-PQCD	QCDF-I [11]	QCDF-II [91]	SCET [92]	Data [55]
$\pi^\pm\rho^\mp$	41.3	$25.7^{+7.0+2.4+1.3+1.8}_{-5.5-1.9-2.0-1.6}$	$36.5^{+18.2+10.3+2.0+3.9}_{-14.7-8.6-3.5-2.9}$	$25.1^{+1.5+1.4}_{-2.2-1.8}$	$16.8^{+0.5+1.6}_{-0.5-1.5}$	23 ± 2.3
$\pi^+\rho^0$	9.0	$5.4^{+1.4+0.5+0.6+0.3}_{-1.1-0.3-0.5-0.0}$	$11.9^{+6.3+3.6+2.5+1.3}_{-5.0-3.1-1.2-1.1}$	$8.7^{+2.7+1.7}_{-1.3-1.4}$	$7.9^{+0.2+0.8}_{-0.1-0.8}$	8.3 ± 1.2
$\rho^+\pi^0$	14.1	$9.6^{+2.5+0.8+0.7+0.7}_{-2.1-0.7-1.3-0.6}$	$14.0^{+6.5+5.1+1.0+0.8}_{-5.5-4.3-0.6-0.7}$	$11.8^{+1.8+1.4}_{-1.1-1.4}$	$11.4^{+0.6+1.1}_{-0.6-0.9}$	10.9 ± 1.4
$\rho^0\pi^0$	0.15	$0.37^{+0.09+0.02+0.03+0.08}_{-0.08-0.01-0.05-0.02}$	$0.4^{+0.2+0.2+0.9+0.5}_{-0.2-0.1-0.3-0.3}$	$1.3^{+1.7+1.2}_{-0.6-0.6}$	$1.5^{+0.1+0.1}_{-0.1-0.1}$	2.0 ± 0.5
$\pi^+\omega$	8.4	$4.6^{+1.2+0.5+0.5+0.1}_{-0.9-0.4-0.4-0.1}$	$8.8^{+4.4+2.6+1.8+0.8}_{-3.5-2.2-0.9-0.9}$	$6.7^{+2.1+1.3}_{-1.0-1.1}$	$8.5^{+0.3+0.8}_{-0.3-0.8}$	6.9 ± 0.5
$\pi^0\omega$	0.22	$0.32^{+0.06+0.01+0.04+0.04}_{-0.05-0.02-0.07-0.04}$	$0.01^{+0.00+0.02+0.02+0.03}_{-0.00-0.00-0.00-0.00}$	$0.01^{+0.02+0.04}_{-0.00-0.02}$	$0.015^{+0.024+0.002}_{-0.000-0.002}$	< 0.5

Problem 1:
Color suppressed tree



- **It is small, since the Wilson coefficients of Effective operators are small**
- **It may be enhanced by soft contributions, but hard to explain the difference between $B^0 \to \pi^0\pi^0$ and $\rho^0\rho^0$**

$B^0 \to \pi^0\pi^0$, $\pi^0\rho^0$ and $\rho^0\rho^0$ (10^{-6})

	QCDF	PQCD	SCET	Exp.
$\pi^0\pi^0$	0.3 ± 0.5 1.1 ± 1.1	0.29 ± 0.50	0.84 ±0.46	1.62 ± 0.31
$\pi^0\rho^0$	0.4 ± 1.0 1.3 ± 1.8	0.37 ± 0.12	1.5 ± 0.1	2.0 ± 0.5
$\rho^0\rho^0$	0.9 ± 1.6	0.92 ± 1.10	-	0.73 ± 0.28

Amplitude parametrization of B→ K π decays

- $$\begin{aligned} A(B^+ \to K^0\pi^+) &= P' \,, \\ A(B_d^0 \to K^+\pi^-) &= -P'\left(1+\frac{T'}{P'}e^{i\phi_3}\right) \,, \\ \sqrt{2}A(B^+ \to K^+\pi^0) &= -P'\left[1+\frac{P'_{ew}}{P'}+\left(\frac{T'}{P'}+\frac{C'}{P'}\right)e^{i\phi_3}\right] \,, \\ \sqrt{2}A(B_d^0 \to K^0\pi^0) &= P'\left(1-\frac{P'_{ew}}{P'}-\frac{C'}{P'}e^{i\phi_3}\right) \,, \end{aligned}$$

$$\frac{T'}{P'} \sim \lambda \,, \qquad \frac{P'_{ew}}{P'} \sim \lambda \,, \qquad \frac{C'}{P'} \sim \lambda^2$$

↑

$(C_2/C_4)(V_{us}V_{ub}/V_{ts}V_{tb})$» $(1/\lambda^2)(\lambda^5/\lambda^2)$» λ

B→ Kπ puzzle

- $K^+\pi^-$ and $K^+\pi^0$ differ by sub-leading amplitudes P_{ew} and color suppressed tree (C). Their CP asymmetry are expected to be similar.
- Their data differ by 5σ! A puzzle!

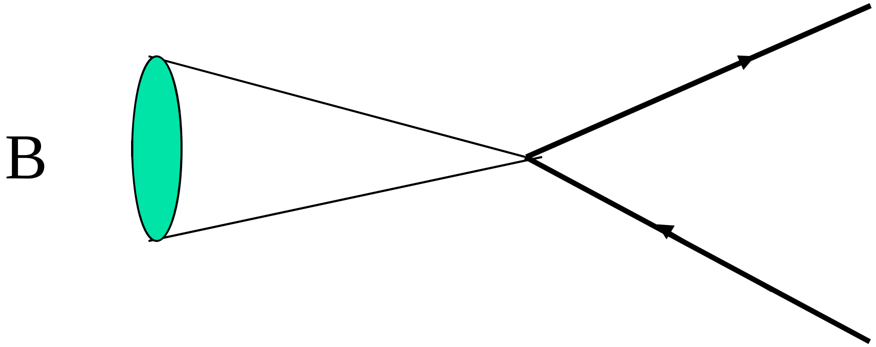
$$A_{CP}(K^+pi^-) = (-9.8 \pm 1.3)\%$$

$$A_{CP}(K^+pi^0) = (5.1 \pm 2.5)\%$$

Importance of power corrections

The power suppressed terms, sometimes chiral enhanced

Questions No. 2: **Annihilation type diagrams suppressed ~ $1/m_B$** **10%**



- **Helicity suppressed:** **pseudo-scalar decays to two massless quarks**

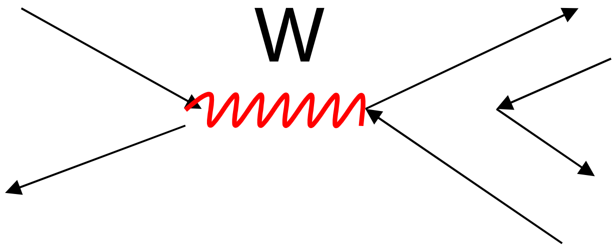
“Annihilation”

- W annihilation
- W exchange
- Time-like penguin
- Space-like penguin

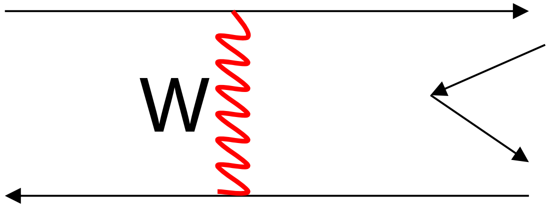
Can not be universal for all decays, since not only one type

----sensitive to many parameters

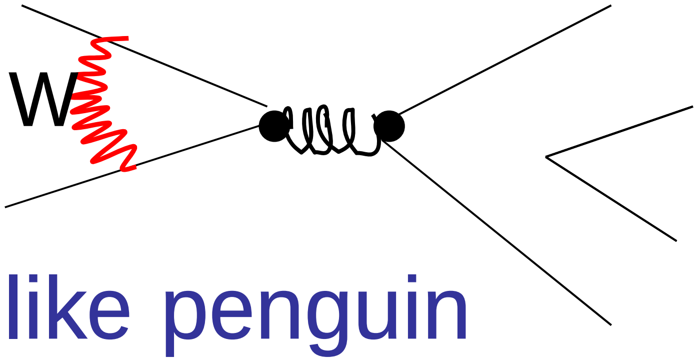
Annihilation-Type diagrams



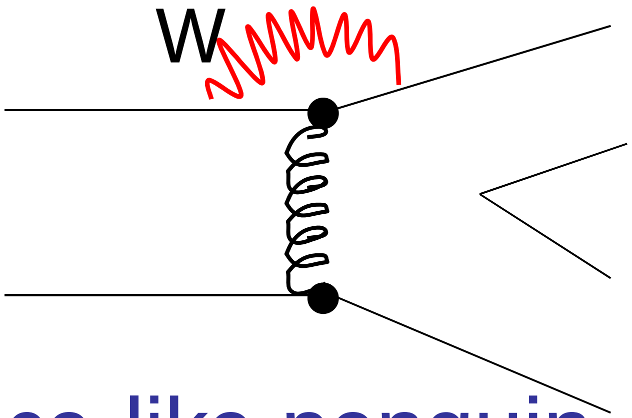
W annihilation(A)



W exchange(E)

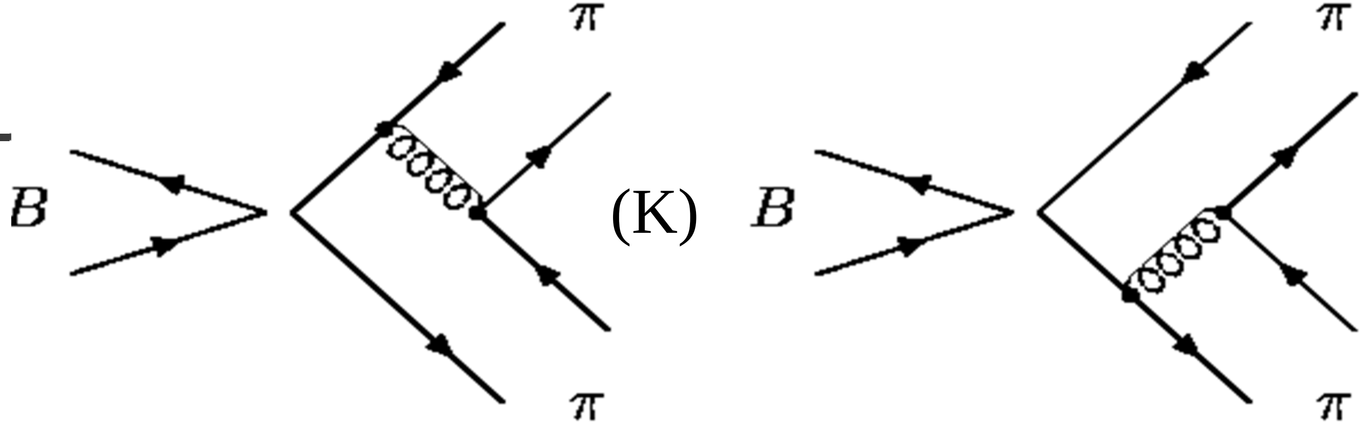


Time-like penguin

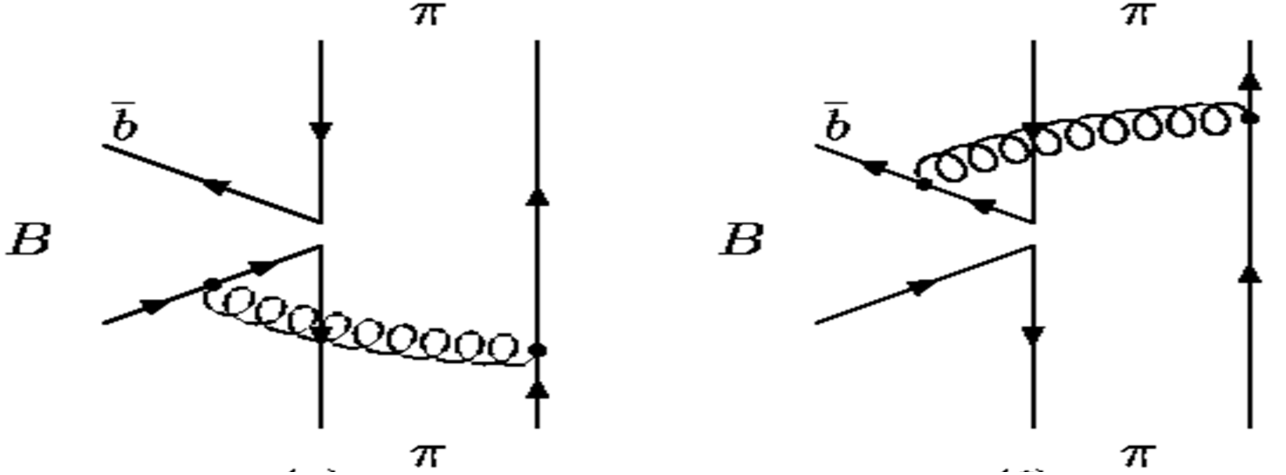


Space-like penguin

PQCD Approach



Two diagrams cancel each other for tree operators, leaving only the other two

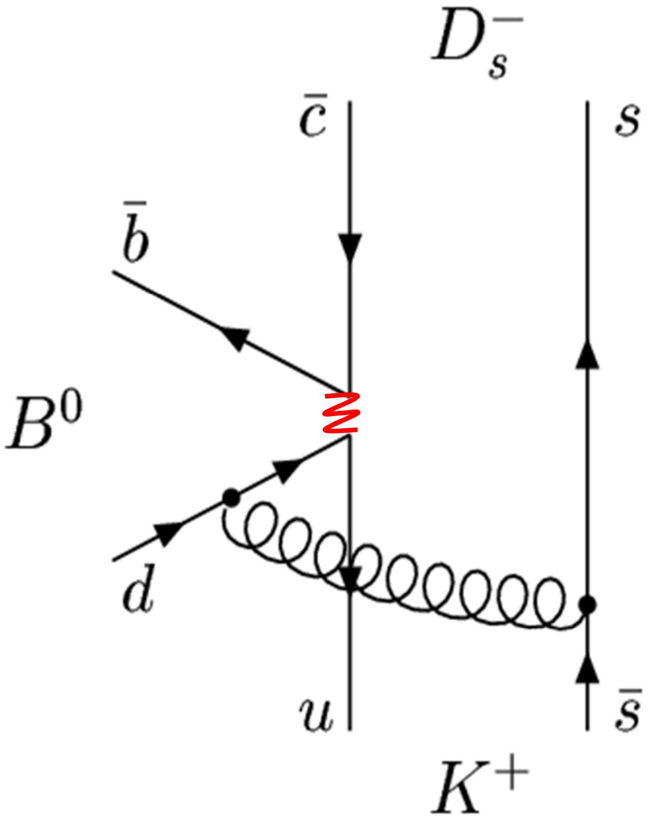


Gluon propagator $\frac{i}{(k_1-k_2)^2}=\frac{i}{-2xym_B^2}$

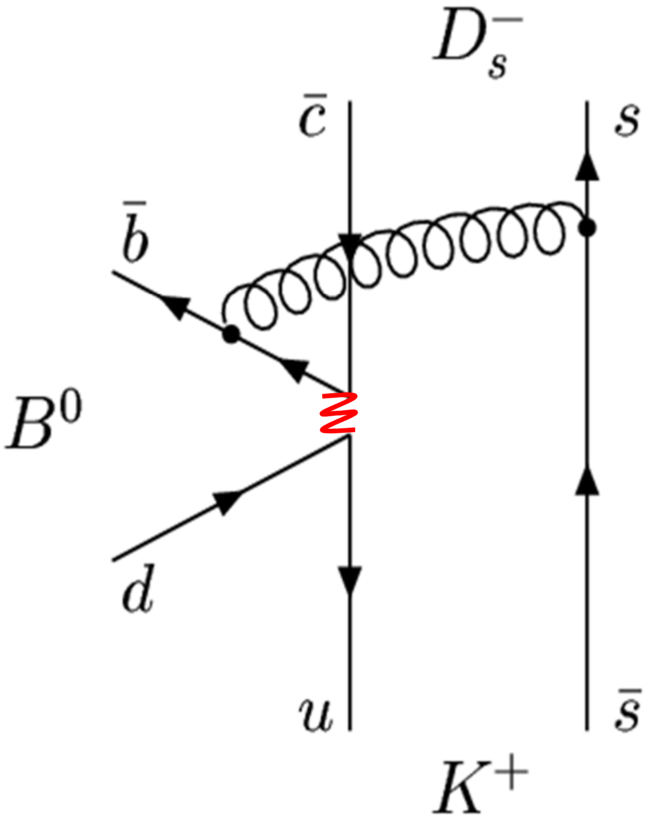
- In collinear factorization(QCDF and SCET), there is endpoint singularity in the annihilation type diagrams, not calculable, usually a free parameter
- However the transverse momentum at the endpoint is not negligible. In pQCD approach, we pick up back the transverse momentum of valence quarks to kill the divergence, Thus calculable

$$\frac{i}{(k_1-k_2)^2}=\frac{i}{-2xym_B^2-(k_1^T-k_2^T)^2}$$

W Exchange Process



(c)



(d)

First annihilation type B decay

Results:

$$Br(B^0 \to D_S^- K^+) = (4.6^{+0.8}_{-0.6}) \times 10^{-5}$$

$$Br(B^0 \to D_S^{*-} K^+) = (2.7 \pm 0.6) \times 10^{-5}$$

Reported by Ukai in BCP4 (2001) before Exps:

Lü, Ukai, hep-ph/0210206, EPJC28 (2003) 305

$$Br(B^0 \to D_S^- K^+) = (4.6^{+1.2}_{-0.6} \pm 1.3) \times 10^{-5}, Belle$$

$$Br(B^0 \to D_S^- K^+) = (3.2 \pm 1.0 \pm 1.0) \times 10^{-5}, BaBar$$

Penguin over tree

- $B^0 \to K^+\pi^-$ **and** $B^0 \to \pi^+ \pi^-$ **are dominated by penguin (P) and tree (T) operators, respectively**
- **In leading power,**
- $|P/T| \sim |f_K/f_\pi| \times |V_{ts}/V_{ub}| \times |a4/a1|$

$$=158/132 \times 41.61/3.96 \times 0.045/1.05 = 0.5$$

Exp: $B(B^0 \to K^+\pi^-)/B(B^0 \to \pi^+\pi^-) = 18.2/4.6 = 4$

Power Corrections

- (V-A)(V+A) operator O_6 can be chirally enhanced when doing Fierz transformation in QCDF and pQCD.
- a_6 only slightly larger than a_4, QCDF needs very large chiral factor $m_0 = m_K^2/m_s$, ⇨small m_s.
- pQCD has additional chiral enhanced annihilation penguin contribution O_6, does not need small m_s
- SCET/BPRS without a_6, needs very large charming penguin

Fierz transformation

$$\langle P_1 P_2 | O_6 | B \rangle = -2 \sum_q \left(\langle P_1 | \bar{s} R q | 0 \rangle \langle P_2 | \bar{q} L b | B \rangle \right.$$

$$\langle K | \bar{s} \gamma^\mu \gamma^5 u | 0 \rangle = i f_K p^\mu$$

$$\langle P_1 P_2 | O_6 | B \rangle = R[P_1, P_2] \langle P_1 P_2 | O_4 | B \rangle$$

$$R[P_1, P_2] \equiv \frac{2 M_{P_1}^2}{(m_q + m_s)(m_b - m_q)}$$

The dominant contribution

The biggest contribution for B→ π K in various approaches:

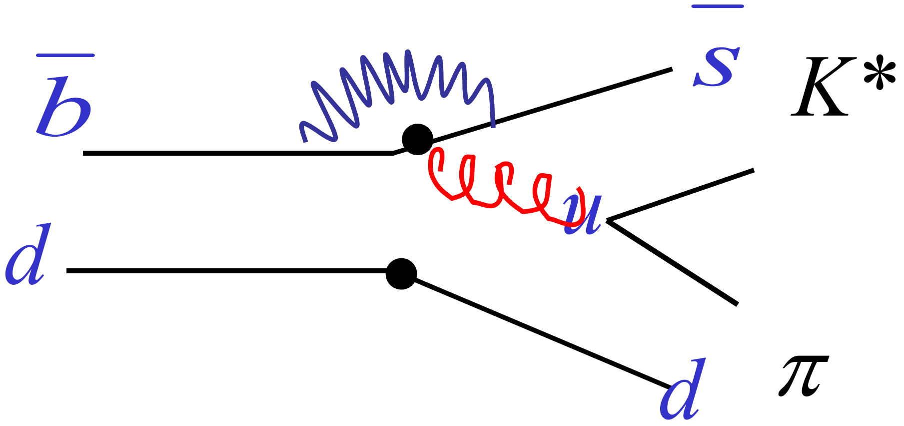
- Chiral enhanced penguin -- QCDF
- Chiral enhanced + annihilation penguin -- pQCD
- Charming penguin -- SCET

B→ VP decays

- Difficult for QCDF to get large enough BRs
- No chiral enhanced penguin for *B*→ π *K**

$$\langle K^* | \bar{s}\gamma^\mu u | 0 \rangle = m_{K^*} f_{K^*} \varepsilon^\mu$$

$$\langle K^* | \bar{s}(1-\gamma^5) u | 0 \rangle = 0$$

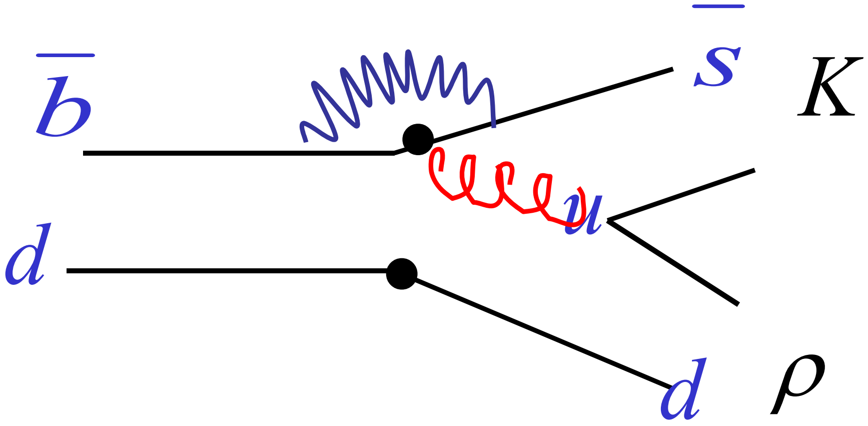


Even worse for *B*→ ρ *K*

- Ordinary penguin canceled by chiral enhanced penguin (minus sign) for *B*→ ρ *K*

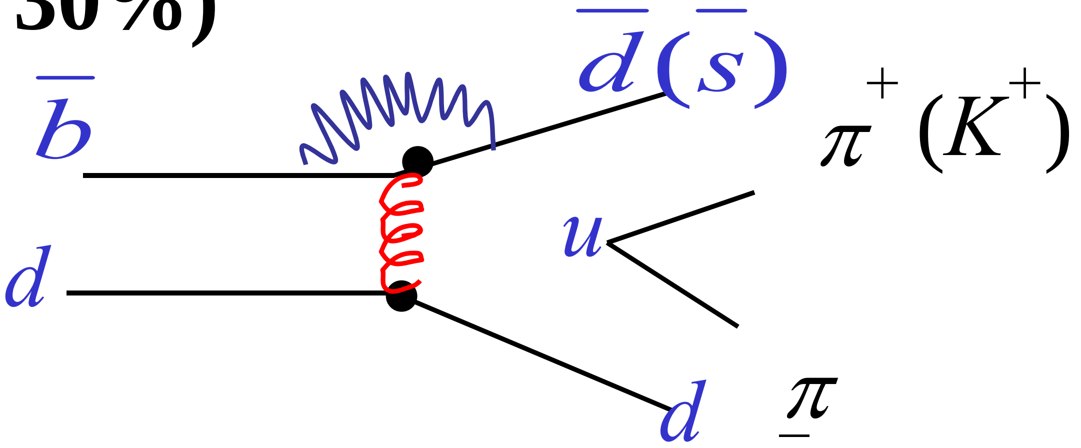
$$\langle K\rho \,|\, o_6 \,|\, B\rangle = R\langle K\rho \,|\, o_4 \,|\, B\rangle$$

$$R = \frac{-2m_K^2}{(m_b + m_u)(m_s + m_u)}$$



No suppression for O_6

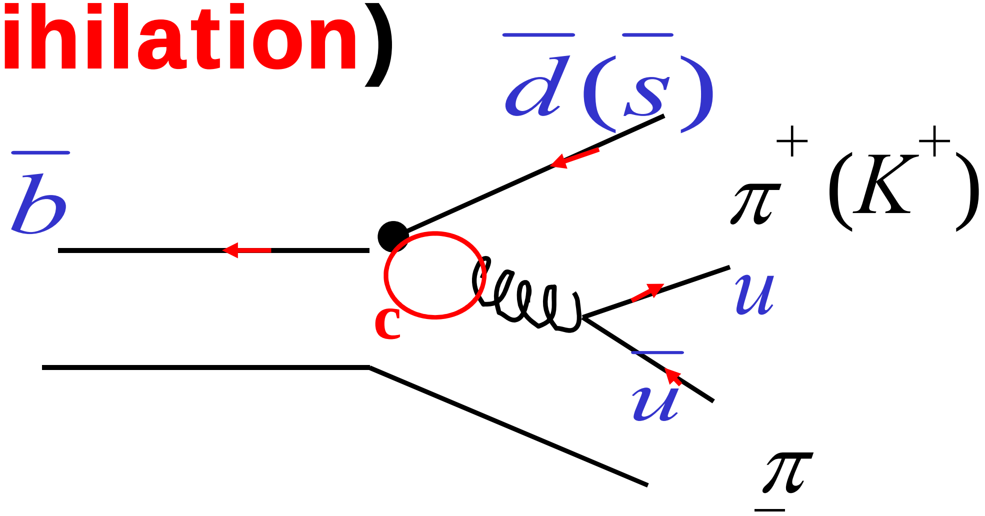
- Space-like penguin (annihilation)
- Become (s-p)(s+p) operator after Fiertz transformation **Chirally enhanced**
- No suppression, contribution "big" (20-30%)



Calculable in pQCD approach

Charming penguins in SCET

- **Play the similar role as annihilation penguin, but not calculable**
- **Charming penguin appear always together with space like penguin (annihilation)**



CP Violation in $B \rightarrow \pi\,\pi\,(K)$ (real prediction before exp.)

CP(%)	FA	BBNS	PQCD *(2001)*	Exp *(2004)*
$\pi^+ K^-$	$+9 \pm 3$	$+5 \pm 9$	-17 ± 5	-11.5 ± 1.8
$\pi^+ K^0$	1.7 ± 0.1	1 ± 1	-1.0 ± 0.5	-2 ± 4
$\pi^0 K^+$	$+8 \pm 2$	7 ± 9	-13 ± 4	$+4 \pm 4$
$\pi^+ \pi^-$	-5 ± 3	-6 ± 12	$+30 \pm 10$	$+37 \pm 10$

CP Violation in $B \to \pi\,\pi\,(K)$

Including large annihilation fixed from exp.

CP(%)	FA	Cheng HY	PQCD *(2001)*	Exp *(2004)*
π^+K^-	+9±3	-7.4 ± 5.0	−17±5	−11.5±1.8
π^+K^0	1.7± 0.1	0.28±0.10	−1.0±0.5	−2 ±4
π^0K^+	+8 ± 2	4.9 ± 5.9	−13 ±4	+4 ± 4
$\pi^+\pi^-$	−5±3	17 ± 1.3	+30±10	+37±10

Polarization of B→VV decays

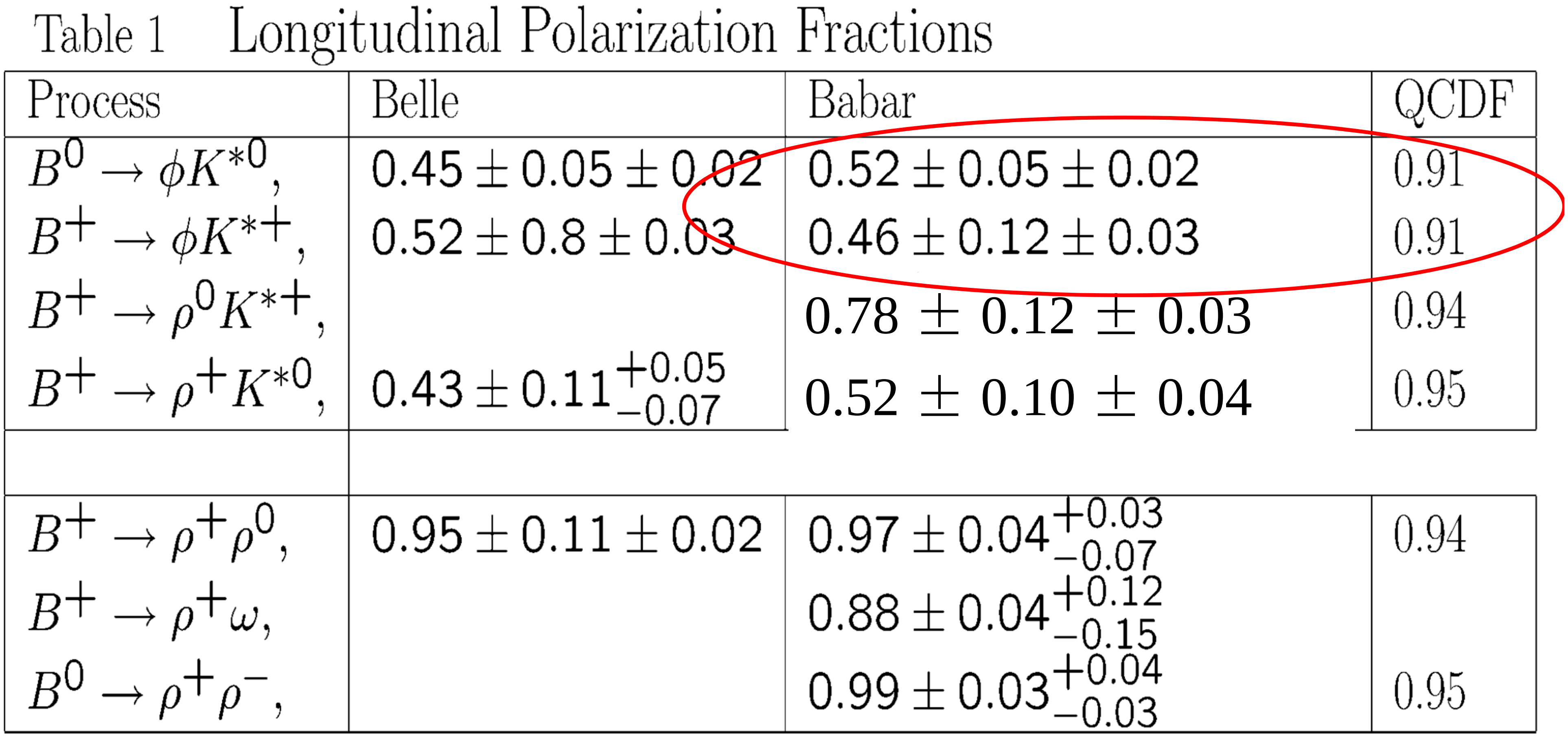
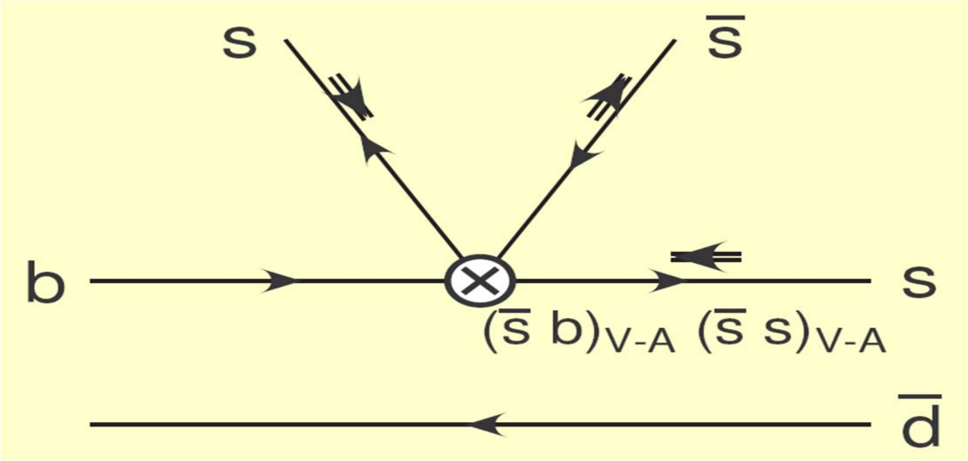


Table 1 Longitudinal Polarization Fractions

Process	Belle	Babar	QCDF
$B^0 \to \phi K^{*0}$,	$0.45 \pm 0.05 \pm 0.02$	$0.52 \pm 0.05 \pm 0.02$	0.91
$B^+ \to \phi K^{*+}$,	$0.52 \pm 0.8 \pm 0.03$	$0.46 \pm 0.12 \pm 0.03$	0.91
$B^+ \to \rho^0 K^{*+}$,		$0.78 \pm 0.12 \pm 0.03$	0.94
$B^+ \to \rho^+ K^{*0}$,	$0.43 \pm 0.11^{+0.05}_{-0.07}$	$0.52 \pm 0.10 \pm 0.04$	0.95
$B^+ \to \rho^+ \rho^0$,	$0.95 \pm 0.11 \pm 0.02$	$0.97 \pm 0.04^{+0.03}_{-0.07}$	0.94
$B^+ \to \rho^+ \omega$,		$0.88 \pm 0.04^{+0.12}_{-0.15}$	
$B^0 \to \rho^+ \rho^-$,		$0.99 \pm 0.03^{+0.04}_{-0.03}$	0.95

Helicity flip suppression of the transverse polarization amplitude



$$H_0 >> H_- >> H_+$$

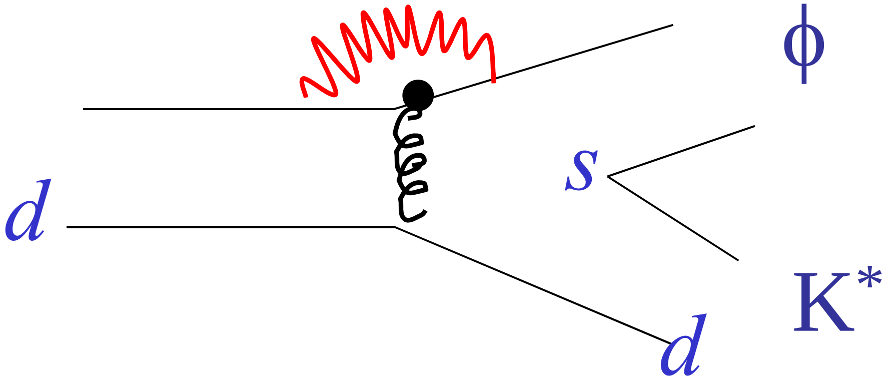
$$\mathbf{H_\pm = M_N \pm M_T}$$

Naïve counting rule

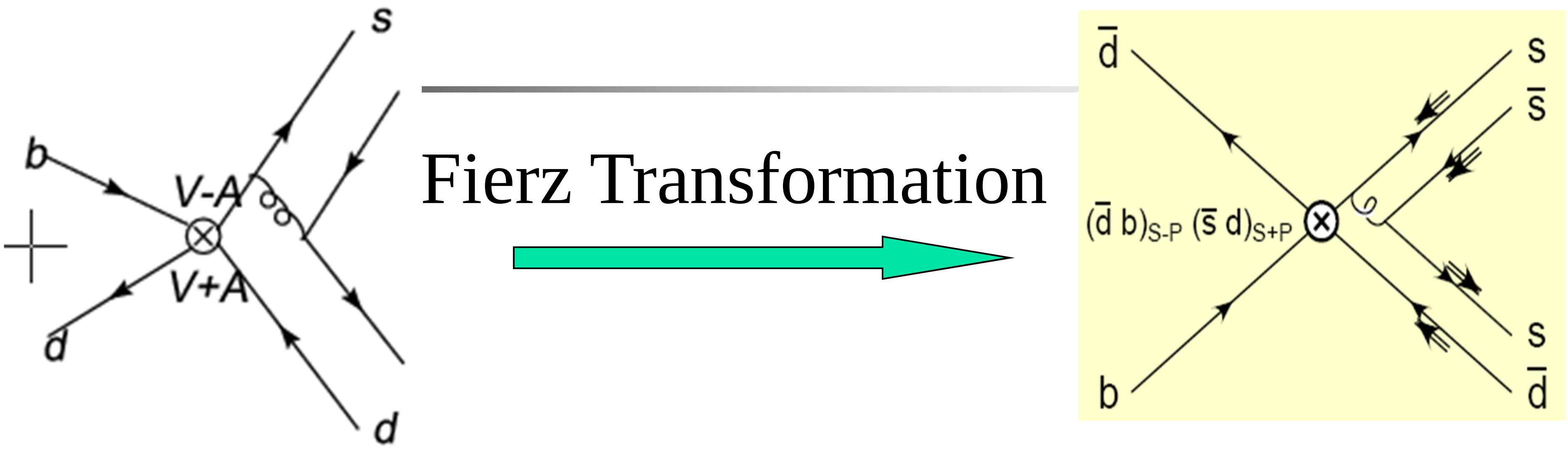
$$R_L = \Gamma_L/\Gamma_{total} = \mathcal{O}(1), R_N \sim R_T = \mathcal{O}(m_V^2/m_B^2)$$

Large transverse component in $B \rightarrow \phi K^*$ decays

- Annihilation can also enhance transverse contribution



The annihilation diagram



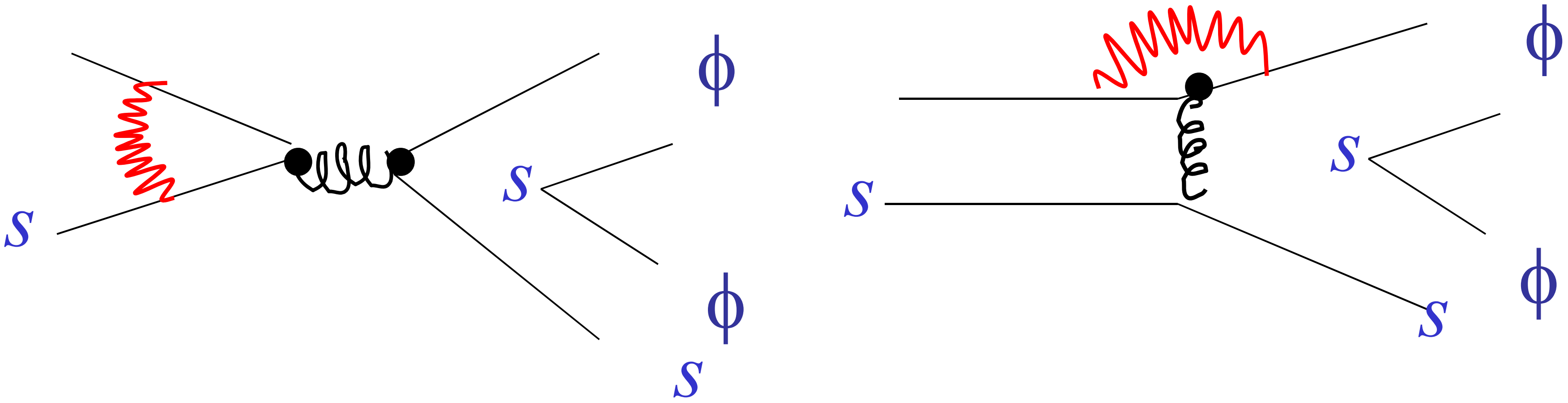
Fierz Transformation

The (S+P)(S-P) current can break the counting rule,

The annihilation diagram contributes equally to the three polarization amplitudes

Time-like and space-like penguin in $B_s \to \phi\, \phi$ decays

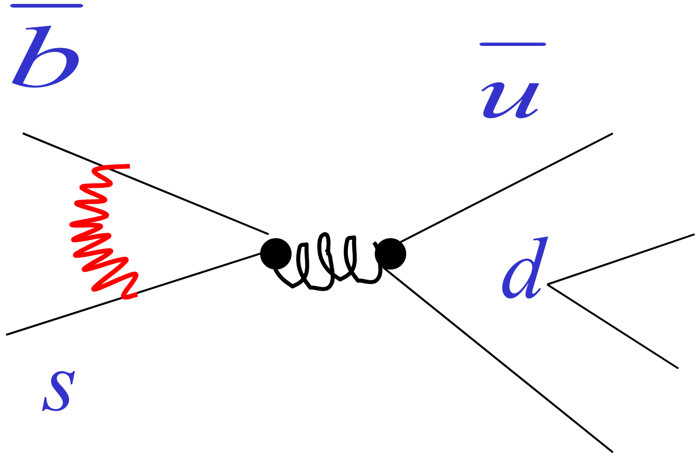
- **Recenly measured by LHCb arXiv:1204.2813**
- **f_L = 0.365 ± 0.022 ± 0.012**



CDF Results

arXiv:1111.0485

First evidence: $B^0_s \to \pi^+\pi^-$

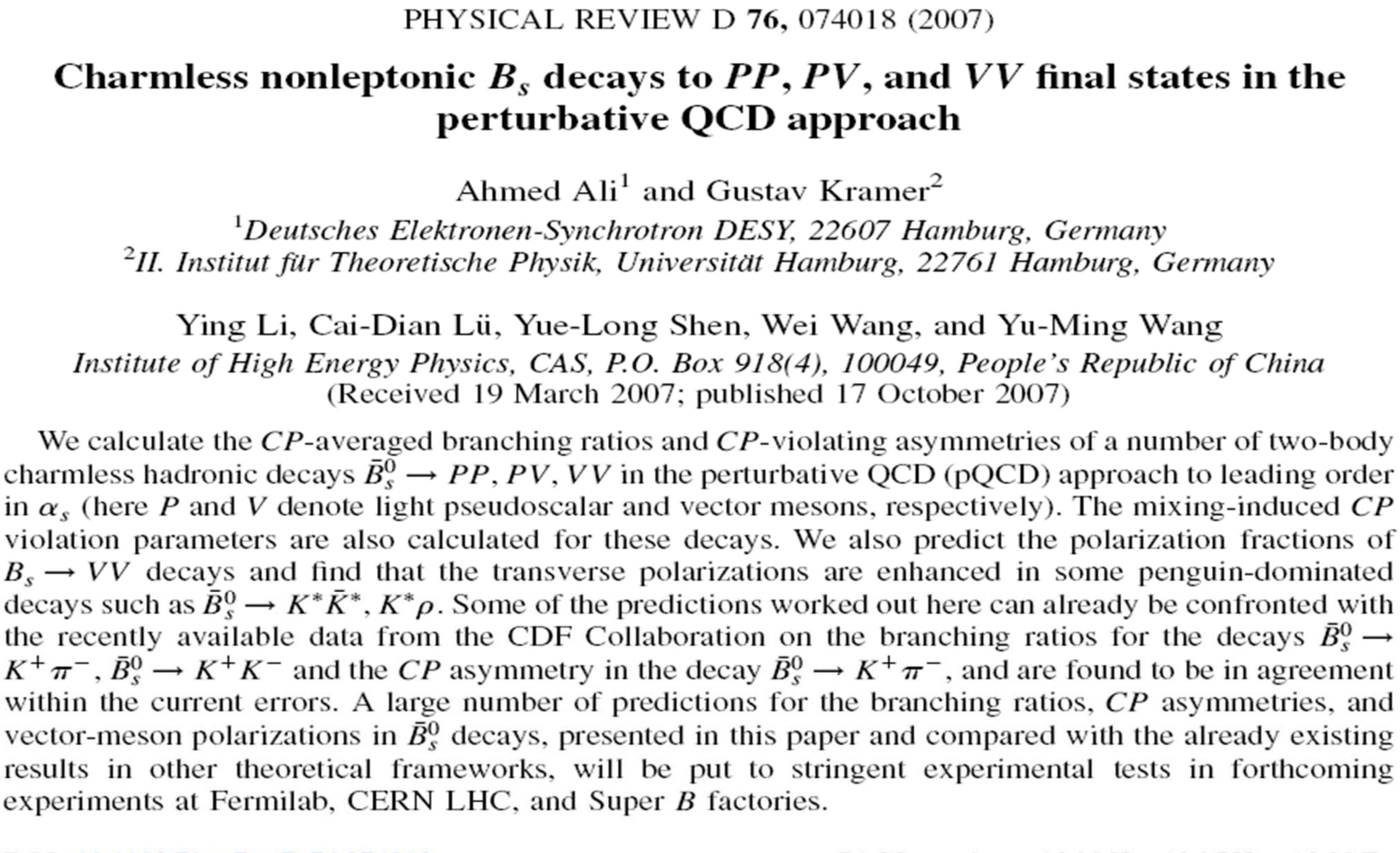


Pure annihilation

$$\mathcal{B}(B_s^0 \to \pi^+\pi^-) = (0.57 \pm 0.15\ (stat.) \pm 0.10\ (syst.)) \times 10^{-6}.$$

The pQCD prediction given at 2007

Br(Bs^0 → π+ π-) = 5.7 x 10^{-7}



PHYSICAL REVIEW D **76,** 074018 (2007)

Charmless nonleptonic B_s decays to PP, PV, and VV final states in the perturbative QCD approach

Ahmed Ali[1] and Gustav Kramer[2]

[1]*Deutsches Elektronen-Synchrotron DESY, 22607 Hamburg, Germany*
[2]*II. Institut für Theoretische Physik, Universität Hamburg, 22761 Hamburg, Germany*

Ying Li, Cai-Dian Lü, Yue-Long Shen, Wei Wang, and Yu-Ming Wang
Institute of High Energy Physics, CAS, P.O. Box 918(4), 100049, People's Republic of China

(Received 19 March 2007; published 17 October 2007)

We calculate the CP-averaged branching ratios and CP-violating asymmetries of a number of two-body charmless hadronic decays $\bar{B}_s^0 \to PP, PV, VV$ in the perturbative QCD (pQCD) approach to leading order in α_s (here P and V denote light pseudoscalar and vector mesons, respectively). The mixing-induced CP violation parameters are also calculated for these decays. We also predict the polarization fractions of $B_s \to VV$ decays and find that the transverse polarizations are enhanced in some penguin-dominated decays such as $\bar{B}_s^0 \to K^* \bar{K}^*, K^* \rho$. Some of the predictions worked out here can already be confronted with the recently available data from the CDF Collaboration on the branching ratios for the decays $\bar{B}_s^0 \to K^+ \pi^-$, $\bar{B}_s^0 \to K^+ K^-$ and the CP asymmetry in the decay $\bar{B}_s^0 \to K^+ \pi^-$, and are found to be in agreement within the current errors. A large number of predictions for the branching ratios, CP asymmetries, and vector-meson polarizations in $\bar{B}_s^0$ decays, presented in this paper and compared with the already existing results in other theoretical frameworks, will be put to stringent experimental tests in forthcoming experiments at Fermilab, CERN LHC, and Super B factories.

DOI: 10.1103/PhysRevD.76.074018 PACS numbers: 13.20.He, 13.25.Hw, 13.30.Eg

B^0 → K+ K- decay

CDF: $\mathcal{B}(B^0 \to K^+K^-) = (0.23 \pm 0.10\ (stat.) \pm 0.10\ (syst.)) \times 10^{-6}$

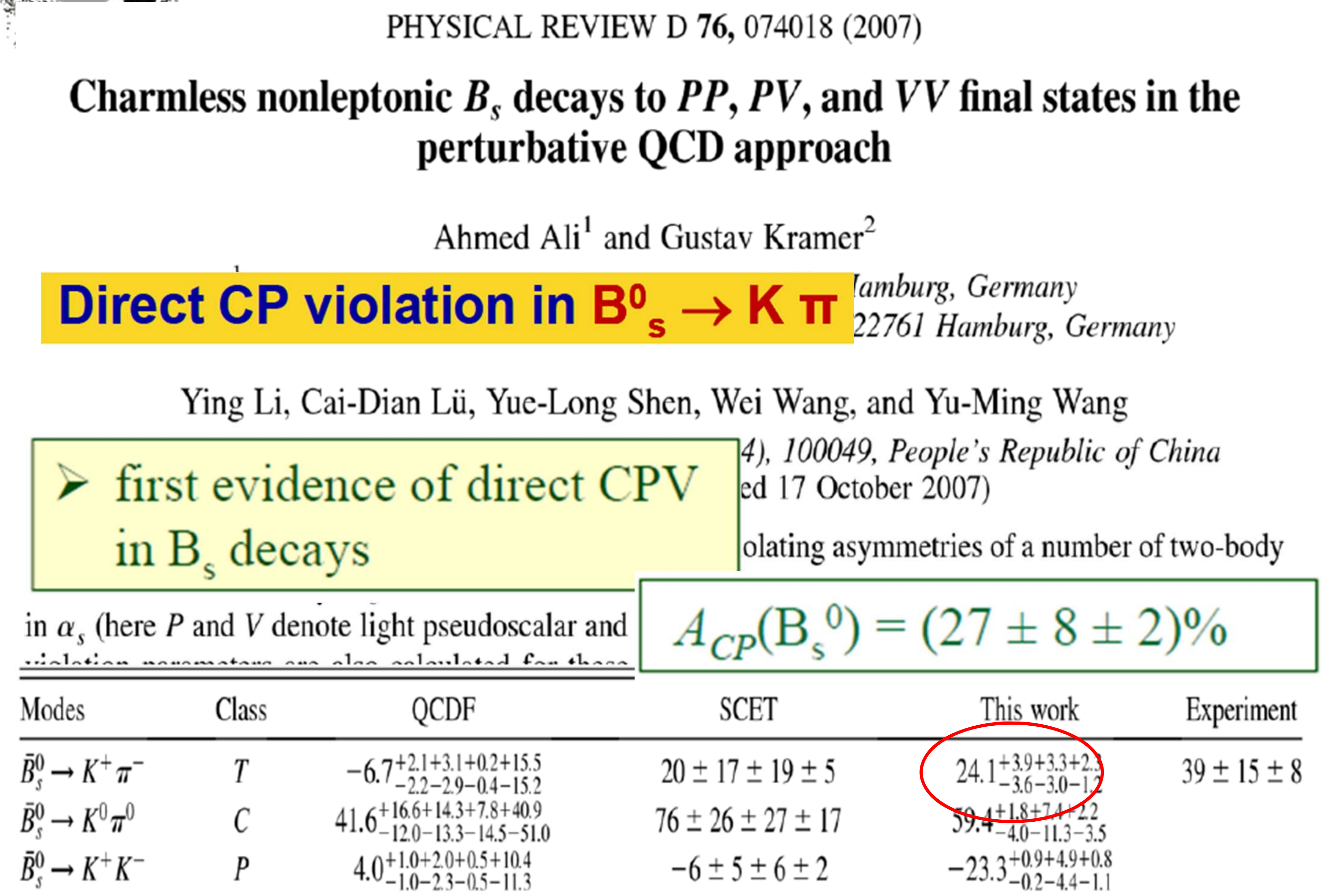
LHCb: $\mathcal{BR}(B^0 \to K^+K^-) = (0.14 \pm 0.06 \pm 0.07) \times 10^{-6}$

Zhen-Jun Xiao et al. recalculate this decay in pQCD recently, and find that

Br(B0 → K+ K-) =1.5 x 10^{-7}

Well consistent with the data!

- **hep-ph/1111.6264**



PHYSICAL REVIEW D **76,** 074018 (2007)

Charmless nonleptonic B_s decays to *PP*, *PV*, and *VV* final states in the perturbative QCD approach

Ahmed Ali[1] and Gustav Kramer[2]

Direct CP violation in $B^0_s \to K\,\pi$

lamburg, Germany

22761 Hamburg, Germany

Ying Li, Cai-Dian Lü, Yue-Long Shen, Wei Wang, and Yu-Ming Wang

4), 100049, People's Republic of China

ed 17 October 2007)

- first evidence of direct CPV in B_s decays

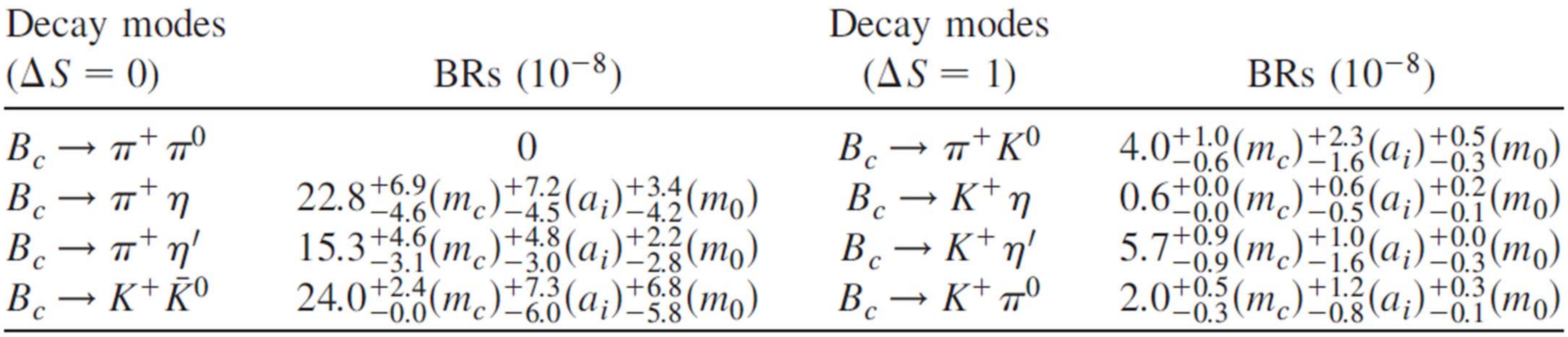
olating asymmetries of a number of two-body

in α_s (here *P* and *V* denote light pseudoscalar and

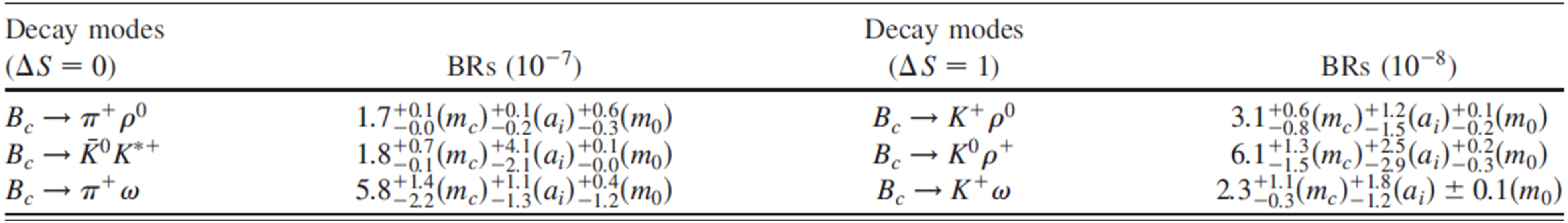
$$A_{CP}(B_s^0) = (27 \pm 8 \pm 2)\%$$

Modes	Class	QCDF	SCET	This work	Experiment
$\bar{B}^0_s \to K^+\pi^-$	T	$-6.7^{+2.1+3.1+0.2+15.5}_{-2.2-2.9-0.4-15.2}$	$20 \pm 17 \pm 19 \pm 5$	$24.1^{+3.9+3.3+2.3}_{-3.6-3.0-1.2}$	$39 \pm 15 \pm 8$
$\bar{B}^0_s \to K^0\pi^0$	C	$41.6^{+16.6+14.3+7.8+40.9}_{-12.0-13.3-14.5-51.0}$	$76 \pm 26 \pm 27 \pm 17$	$59.4^{+1.8+7.4+2.2}_{-4.0-11.3-3.5}$	
$\bar{B}^0_s \to K^+K^-$	P	$4.0^{+1.0+2.0+0.5+10.4}_{-1.0-2.3-0.5-11.3}$	$-6 \pm 5 \pm 6 \pm 2$	$-23.3^{+0.9+4.9+0.8}_{-0.2-4.4-1.1}$	

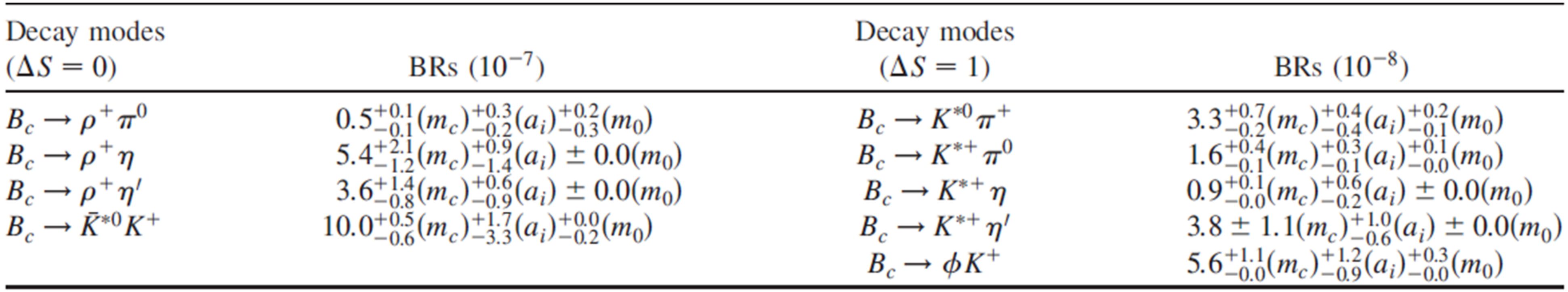
Pure annihilation type B_c decays



Decay modes ($\Delta S = 0$)	BRs (10^{-8})	Decay modes ($\Delta S = 1$)	BRs (10^{-8})
$B_c \to \pi^+ \pi^0$	0	$B_c \to \pi^+ K^0$	$4.0^{+1.0}_{-0.6}(m_c)^{+2.3}_{-1.6}(a_i)^{+0.5}_{-0.3}(m_0)$
$B_c \to \pi^+ \eta$	$22.8^{+6.9}_{-4.6}(m_c)^{+7.2}_{-4.5}(a_i)^{+3.4}_{-4.2}(m_0)$	$B_c \to K^+ \eta$	$0.6^{+0.0}_{-0.0}(m_c)^{+0.6}_{-0.5}(a_i)^{+0.2}_{-0.1}(m_0)$
$B_c \to \pi^+ \eta'$	$15.3^{+4.6}_{-3.1}(m_c)^{+4.8}_{-3.0}(a_i)^{+2.2}_{-2.8}(m_0)$	$B_c \to K^+ \eta'$	$5.7^{+0.9}_{-0.9}(m_c)^{+1.0}_{-1.6}(a_i)^{+0.0}_{-0.3}(m_0)$
$B_c \to K^+ \bar{K}^0$	$24.0^{+2.4}_{-0.0}(m_c)^{+7.3}_{-6.0}(a_i)^{+6.8}_{-5.8}(m_0)$	$B_c \to K^+ \pi^0$	$2.0^{+0.5}_{-0.3}(m_c)^{+1.2}_{-0.8}(a_i)^{+0.3}_{-0.1}(m_0)$



Decay modes ($\Delta S = 0$)	BRs (10^{-7})	Decay modes ($\Delta S = 1$)	BRs (10^{-8})
$B_c \to \pi^+ \rho^0$	$1.7^{+0.1}_{-0.0}(m_c)^{+0.1}_{-0.2}(a_i)^{+0.6}_{-0.3}(m_0)$	$B_c \to K^+ \rho^0$	$3.1^{+0.6}_{-0.8}(m_c)^{+1.2}_{-1.5}(a_i)^{+0.1}_{-0.2}(m_0)$
$B_c \to \bar{K}^0 K^{*+}$	$1.8^{+0.7}_{-0.1}(m_c)^{+4.1}_{-2.1}(a_i)^{+0.1}_{-0.0}(m_0)$	$B_c \to K^0 \rho^+$	$6.1^{+1.3}_{-1.5}(m_c)^{+2.5}_{-2.9}(a_i)^{+0.2}_{-0.3}(m_0)$
$B_c \to \pi^+ \omega$	$5.8^{+1.4}_{-2.2}(m_c)^{+1.1}_{-1.3}(a_i)^{+0.4}_{-1.2}(m_0)$	$B_c \to K^+ \omega$	$2.3^{+1.1}_{-0.3}(m_c)^{+1.8}_{-1.2}(a_i) \pm 0.1(m_0)$



Decay modes ($\Delta S = 0$)	BRs (10^{-7})	Decay modes ($\Delta S = 1$)	BRs (10^{-8})
$B_c \to \rho^+ \pi^0$	$0.5^{+0.1}_{-0.1}(m_c)^{+0.3}_{-0.2}(a_i)^{+0.2}_{-0.3}(m_0)$	$B_c \to K^{*0} \pi^+$	$3.3^{+0.7}_{-0.2}(m_c)^{+0.4}_{-0.4}(a_i)^{+0.2}_{-0.1}(m_0)$
$B_c \to \rho^+ \eta$	$5.4^{+2.1}_{-1.2}(m_c)^{+0.9}_{-1.4}(a_i) \pm 0.0(m_0)$	$B_c \to K^{*+} \pi^0$	$1.6^{+0.4}_{-0.1}(m_c)^{+0.3}_{-0.1}(a_i)^{+0.1}_{-0.0}(m_0)$
$B_c \to \rho^+ \eta'$	$3.6^{+1.4}_{-0.8}(m_c)^{+0.6}_{-0.9}(a_i) \pm 0.0(m_0)$	$B_c \to K^{*+} \eta$	$0.9^{+0.1}_{-0.0}(m_c)^{+0.6}_{-0.2}(a_i) \pm 0.0(m_0)$
$B_c \to \bar{K}^{*0} K^+$	$10.0^{+0.5}_{-0.6}(m_c)^{+1.7}_{-3.3}(a_i)^{+0.0}_{-0.2}(m_0)$	$B_c \to K^{*+} \eta'$	$3.8 \pm 1.1(m_c)^{+1.0}_{-0.6}(a_i) \pm 0.0(m_0)$
		$B_c \to \phi K^+$	$5.6^{+1.1}_{-0.0}(m_c)^{+1.2}_{-0.9}(a_i)^{+0.3}_{-0.0}(m_0)$

Pure annihilation type B_c decays with longitudinal polarization fractions

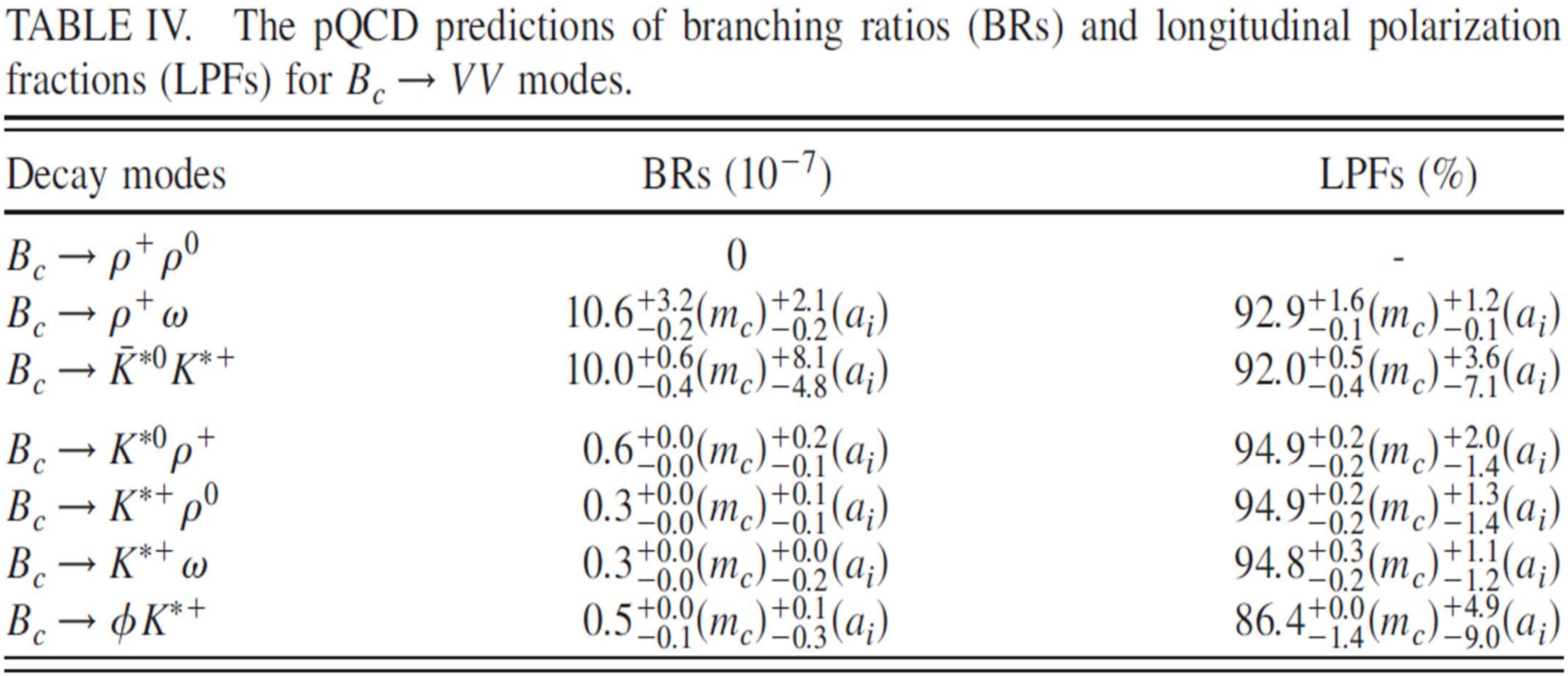
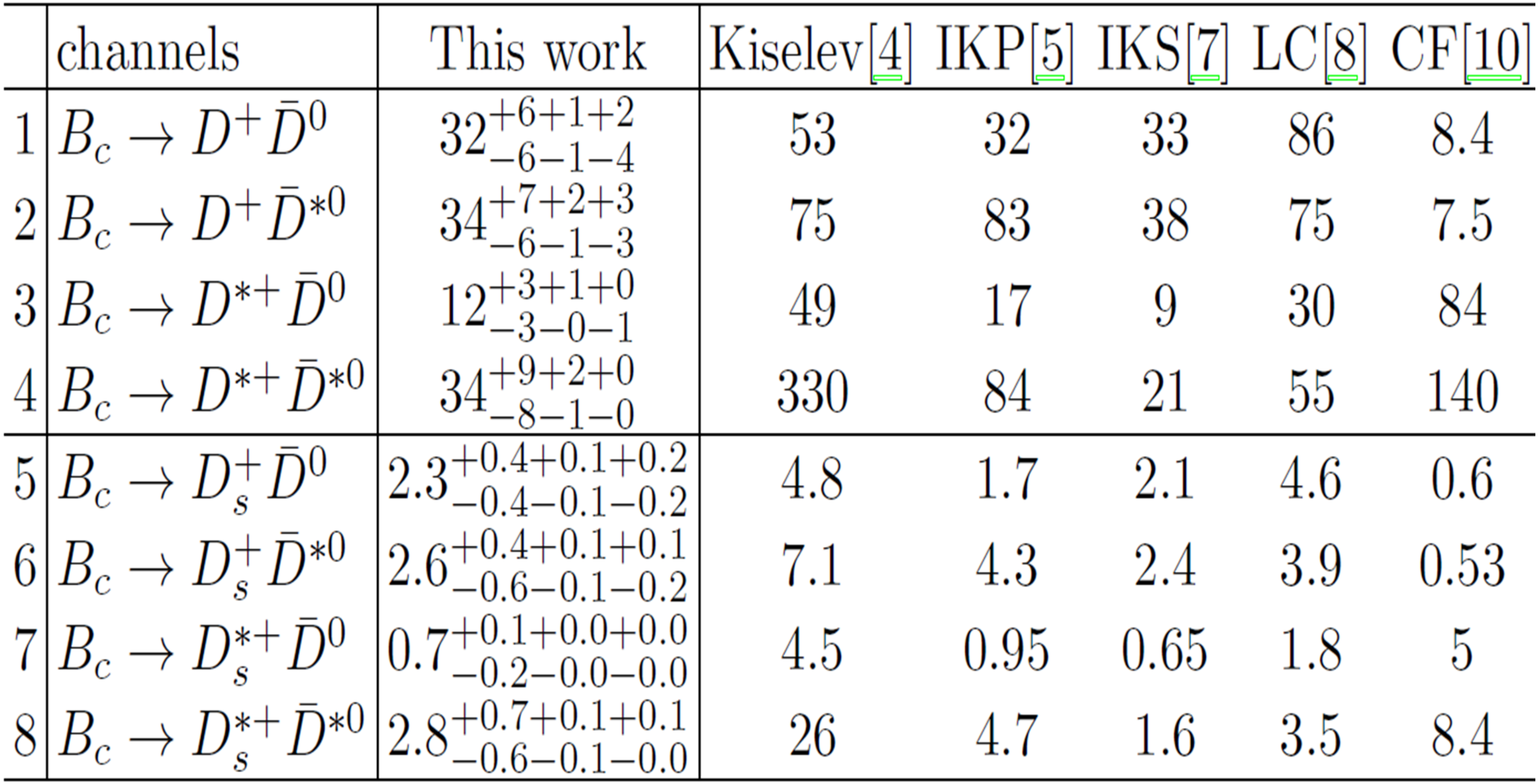


TABLE IV. The pQCD predictions of branching ratios (BRs) and longitudinal polarization fractions (LPFs) for $B_c \to VV$ modes.

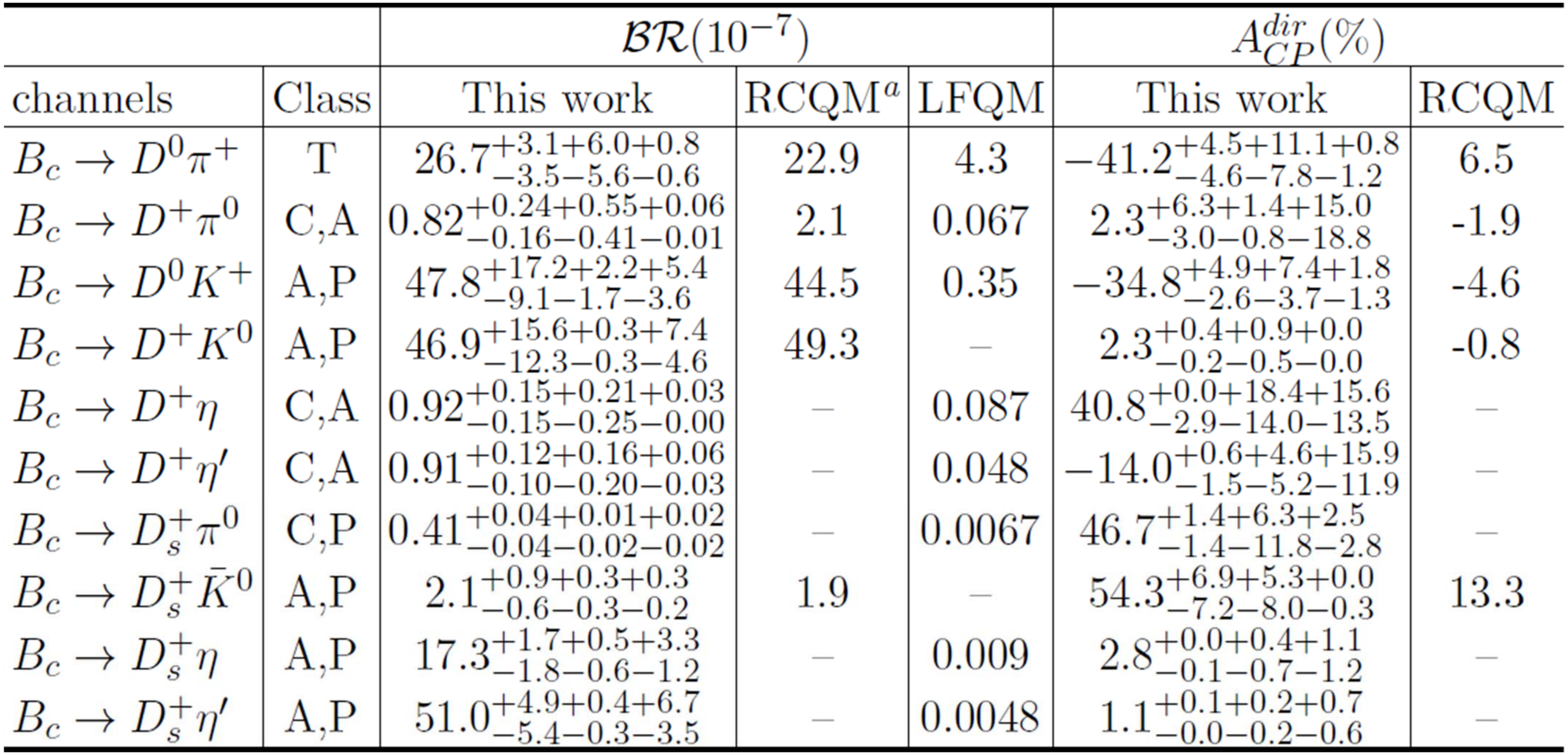
Decay modes	BRs (10^{-7})	LPFs (%)
$B_c \to \rho^+ \rho^0$	0	-
$B_c \to \rho^+ \omega$	$10.6^{+3.2}_{-0.2}(m_c)^{+2.1}_{-0.2}(a_i)$	$92.9^{+1.6}_{-0.1}(m_c)^{+1.2}_{-0.1}(a_i)$
$B_c \to \bar{K}^{*0} K^{*+}$	$10.0^{+0.6}_{-0.4}(m_c)^{+8.1}_{-4.8}(a_i)$	$92.0^{+0.5}_{-0.4}(m_c)^{+3.6}_{-7.1}(a_i)$
$B_c \to K^{*0} \rho^+$	$0.6^{+0.0}_{-0.0}(m_c)^{+0.2}_{-0.1}(a_i)$	$94.9^{+0.2}_{-0.2}(m_c)^{+2.0}_{-1.4}(a_i)$
$B_c \to K^{*+} \rho^0$	$0.3^{+0.0}_{-0.0}(m_c)^{+0.1}_{-0.1}(a_i)$	$94.9^{+0.2}_{-0.2}(m_c)^{+1.3}_{-1.4}(a_i)$
$B_c \to K^{*+} \omega$	$0.3^{+0.0}_{-0.0}(m_c)^{+0.0}_{-0.2}(a_i)$	$94.8^{+0.3}_{-0.2}(m_c)^{+1.1}_{-1.2}(a_i)$
$B_c \to \phi K^{*+}$	$0.5^{+0.0}_{-0.1}(m_c)^{+0.1}_{-0.3}(a_i)$	$86.4^{+0.0}_{-1.4}(m_c)^{+4.9}_{-9.0}(a_i)$

Bc→DD decays with contributions from both emission and annihilation diagrams calculated in Perturbative QCD approach (Zhou R, Zou ZT, CDL, arXiv: 1203.2303)



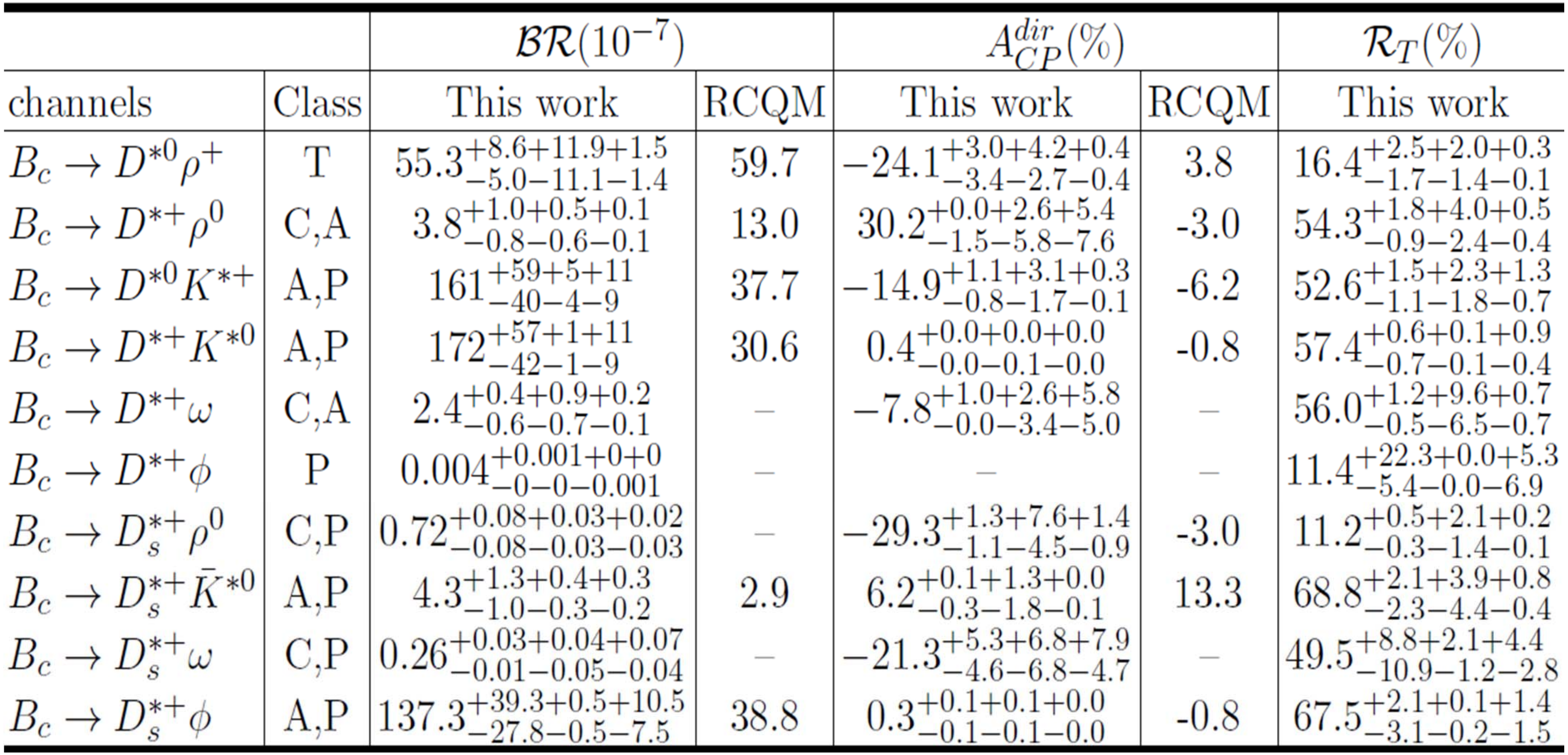
	channels	This work	Kiselev[4]	IKP[5]	IKS[7]	LC[8]	CF[10]
1	$B_c \to D^+ \bar{D}^0$	32^{+6+1+2}_{-6-1-4}	53	32	33	86	8.4
2	$B_c \to D^+ \bar{D}^{*0}$	34^{+7+2+3}_{-6-1-3}	75	83	38	75	7.5
3	$B_c \to D^{*+} \bar{D}^0$	12^{+3+1+0}_{-3-0-1}	49	17	9	30	84
4	$B_c \to D^{*+} \bar{D}^{*0}$	34^{+9+2+0}_{-8-1-0}	330	84	21	55	140
5	$B_c \to D_s^+ \bar{D}^0$	$2.3^{+0.4+0.1+0.2}_{-0.4-0.1-0.2}$	4.8	1.7	2.1	4.6	0.6
6	$B_c \to D_s^+ \bar{D}^{*0}$	$2.6^{+0.4+0.1+0.1}_{-0.6-0.1-0.2}$	7.1	4.3	2.4	3.9	0.53
7	$B_c \to D_s^{*+} \bar{D}^0$	$0.7^{+0.1+0.0+0.0}_{-0.2-0.0-0.0}$	4.5	0.95	0.65	1.8	5
8	$B_c \to D_s^{*+} \bar{D}^{*0}$	$2.8^{+0.7+0.1+0.1}_{-0.6-0.1-0.0}$	26	4.7	1.6	3.5	8.4

Bc→DP decays calculated in Perturbative QCD approach (Zhou R, Zou ZT, CDL, arXiv: 1112.1257)



		$\mathcal{BR}(10^{-7})$			$A_{CP}^{dir}(\%)$	
channels	Class	This work	RCQM[a]	LFQM	This work	RCQM
$B_c \to D^0\pi^+$	T	$26.7^{+3.1+6.0+0.8}_{-3.5-5.6-0.6}$	22.9	4.3	$-41.2^{+4.5+11.1+0.8}_{-4.6-7.8-1.2}$	6.5
$B_c \to D^+\pi^0$	C,A	$0.82^{+0.24+0.55+0.06}_{-0.16-0.41-0.01}$	2.1	0.067	$2.3^{+6.3+1.4+15.0}_{-3.0-0.8-18.8}$	-1.9
$B_c \to D^0K^+$	A,P	$47.8^{+17.2+2.2+5.4}_{-9.1-1.7-3.6}$	44.5	0.35	$-34.8^{+4.9+7.4+1.8}_{-2.6-3.7-1.3}$	-4.6
$B_c \to D^+K^0$	A,P	$46.9^{+15.6+0.3+7.4}_{-12.3-0.3-4.6}$	49.3	–	$2.3^{+0.4+0.9+0.0}_{-0.2-0.5-0.0}$	-0.8
$B_c \to D^+\eta$	C,A	$0.92^{+0.15+0.21+0.03}_{-0.15-0.25-0.00}$	–	0.087	$40.8^{+0.0+18.4+15.6}_{-2.9-14.0-13.5}$	–
$B_c \to D^+\eta'$	C,A	$0.91^{+0.12+0.16+0.06}_{-0.10-0.20-0.03}$	–	0.048	$-14.0^{+0.6+4.6+15.9}_{-1.5-5.2-11.9}$	–
$B_c \to D_s^+\pi^0$	C,P	$0.41^{+0.04+0.01+0.02}_{-0.04-0.02-0.02}$	–	0.0067	$46.7^{+1.4+6.3+2.5}_{-1.4-11.8-2.8}$	–
$B_c \to D_s^+\bar{K}^0$	A,P	$2.1^{+0.9+0.3+0.3}_{-0.6-0.3-0.2}$	1.9	–	$54.3^{+6.9+5.3+0.0}_{-7.2-8.0-0.3}$	13.3
$B_c \to D_s^+\eta$	A,P	$17.3^{+1.7+0.5+3.3}_{-1.8-0.6-1.2}$	–	0.009	$2.8^{+0.0+0.4+1.1}_{-0.1-0.7-1.2}$	–
$B_c \to D_s^+\eta'$	A,P	$51.0^{+4.9+0.4+6.7}_{-5.4-0.3-3.5}$	–	0.0048	$1.1^{+0.1+0.2+0.7}_{-0.0-0.2-0.6}$	–

Bc→DP decays calculated in Perturbative QCD approach (Zhou R, Zou ZT, CDL, arXiv: 1112.1257)

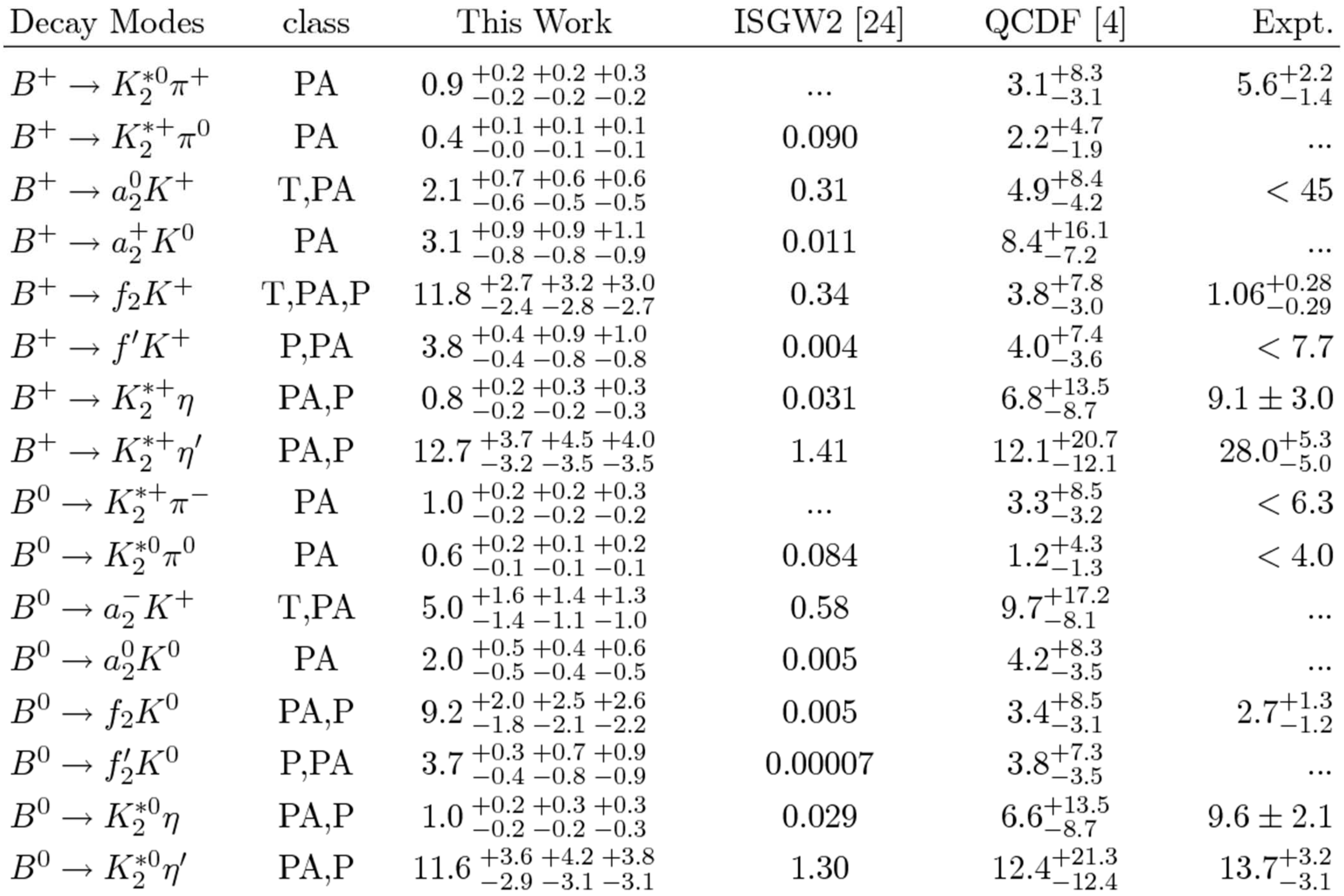


		$\mathcal{BR}(10^{-7})$		$A_{CP}^{dir}(\%)$		$\mathcal{R}_T(\%)$
channels	Class	This work	RCQM	This work	RCQM	This work
$B_c \to D^{*0}\rho^+$	T	$55.3^{+8.6+11.9+1.5}_{-5.0-11.1-1.4}$	59.7	$-24.1^{+3.0+4.2+0.4}_{-3.4-2.7-0.4}$	3.8	$16.4^{+2.5+2.0+0.3}_{-1.7-1.4-0.1}$
$B_c \to D^{*+}\rho^0$	C,A	$3.8^{+1.0+0.5+0.1}_{-0.8-0.6-0.1}$	13.0	$30.2^{+0.0+2.6+5.4}_{-1.5-5.8-7.6}$	-3.0	$54.3^{+1.8+4.0+0.5}_{-0.9-2.4-0.4}$
$B_c \to D^{*0}K^{*+}$	A,P	$161^{+59+5+11}_{-40-4-9}$	37.7	$-14.9^{+1.1+3.1+0.3}_{-0.8-1.7-0.1}$	-6.2	$52.6^{+1.5+2.3+1.3}_{-1.1-1.8-0.7}$
$B_c \to D^{*+}K^{*0}$	A,P	$172^{+57+1+11}_{-42-1-9}$	30.6	$0.4^{+0.0+0.0+0.0}_{-0.0-0.1-0.0}$	-0.8	$57.4^{+0.6+0.1+0.9}_{-0.7-0.1-0.4}$
$B_c \to D^{*+}\omega$	C,A	$2.4^{+0.4+0.9+0.2}_{-0.6-0.7-0.1}$	–	$-7.8^{+1.0+2.6+5.8}_{-0.0-3.4-5.0}$	–	$56.0^{+1.2+9.6+0.7}_{-0.5-6.5-0.7}$
$B_c \to D^{*+}\phi$	P	$0.004^{+0.001+0+0}_{-0-0-0.001}$	–	–	–	$11.4^{+22.3+0.0+5.3}_{-5.4-0.0-6.9}$
$B_c \to D_s^{*+}\rho^0$	C,P	$0.72^{+0.08+0.03+0.02}_{-0.08-0.03-0.03}$	–	$-29.3^{+1.3+7.6+1.4}_{-1.1-4.5-0.9}$	-3.0	$11.2^{+0.5+2.1+0.2}_{-0.3-1.4-0.1}$
$B_c \to D_s^{*+}\bar{K}^{*0}$	A,P	$4.3^{+1.3+0.4+0.3}_{-1.0-0.3-0.2}$	2.9	$6.2^{+0.1+1.3+0.0}_{-0.3-1.8-0.1}$	13.3	$68.8^{+2.1+3.9+0.8}_{-2.3-4.4-0.4}$
$B_c \to D_s^{*+}\omega$	C,P	$0.26^{+0.03+0.04+0.07}_{-0.01-0.05-0.04}$	–	$-21.3^{+5.3+6.8+7.9}_{-4.6-6.8-4.7}$	–	$49.5^{+8.8+2.1+4.4}_{-10.9-1.2-2.8}$
$B_c \to D_s^{*+}\phi$	A,P	$137.3^{+39.3+0.5+10.5}_{-27.8-0.5-7.5}$	38.8	$0.3^{+0.1+0.1+0.0}_{-0.1-0.1-0.0}$	-0.8	$67.5^{+2.1+0.1+1.4}_{-3.1-0.2-1.5}$

B→ PT decays

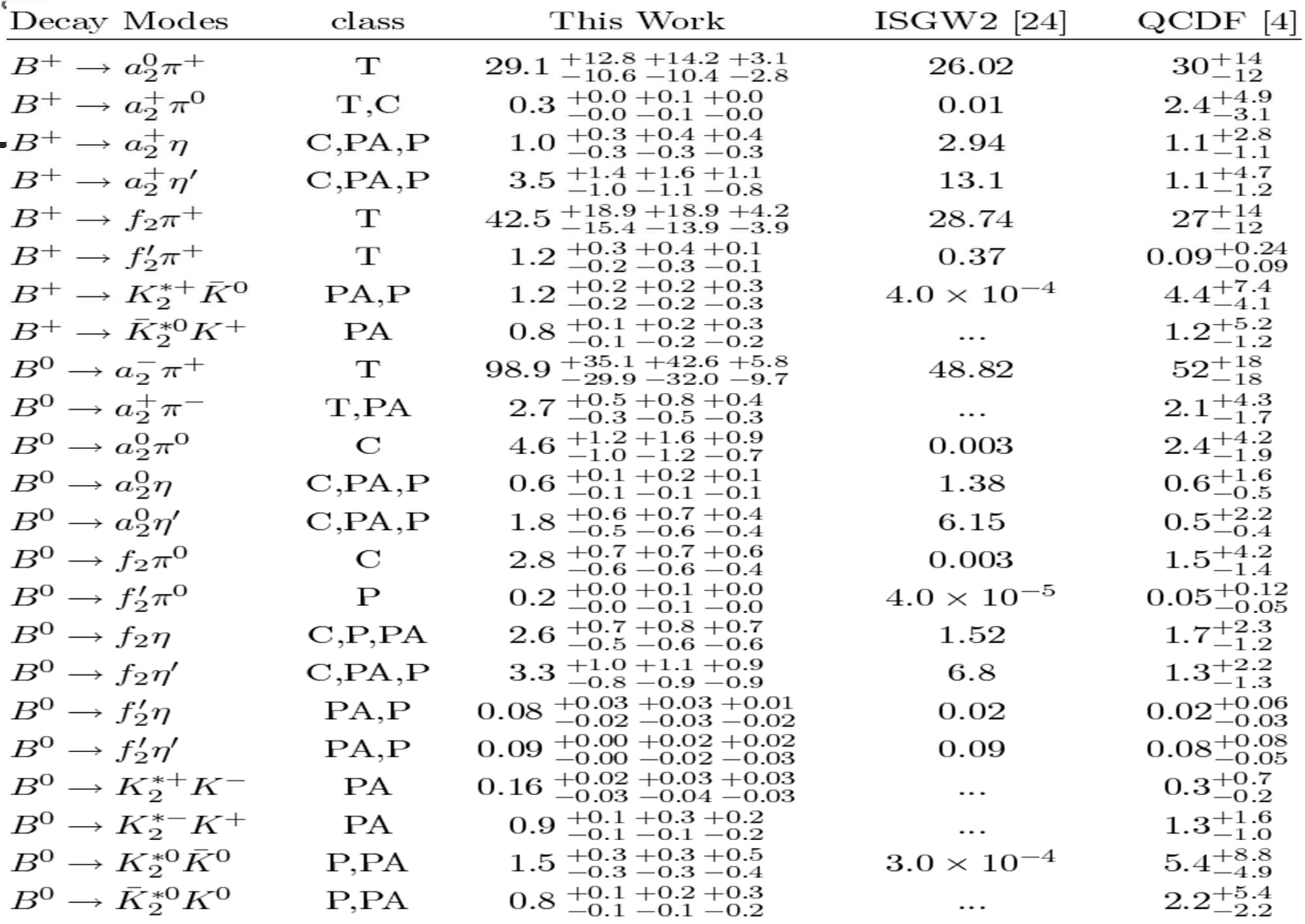
($\Delta S=1$ modes)(10^{-7})

HY Cheng, KC Yang, PRD83, 034001(2008) & ZT Zou, X Yu, CDL, **arXiv:1203.4120**



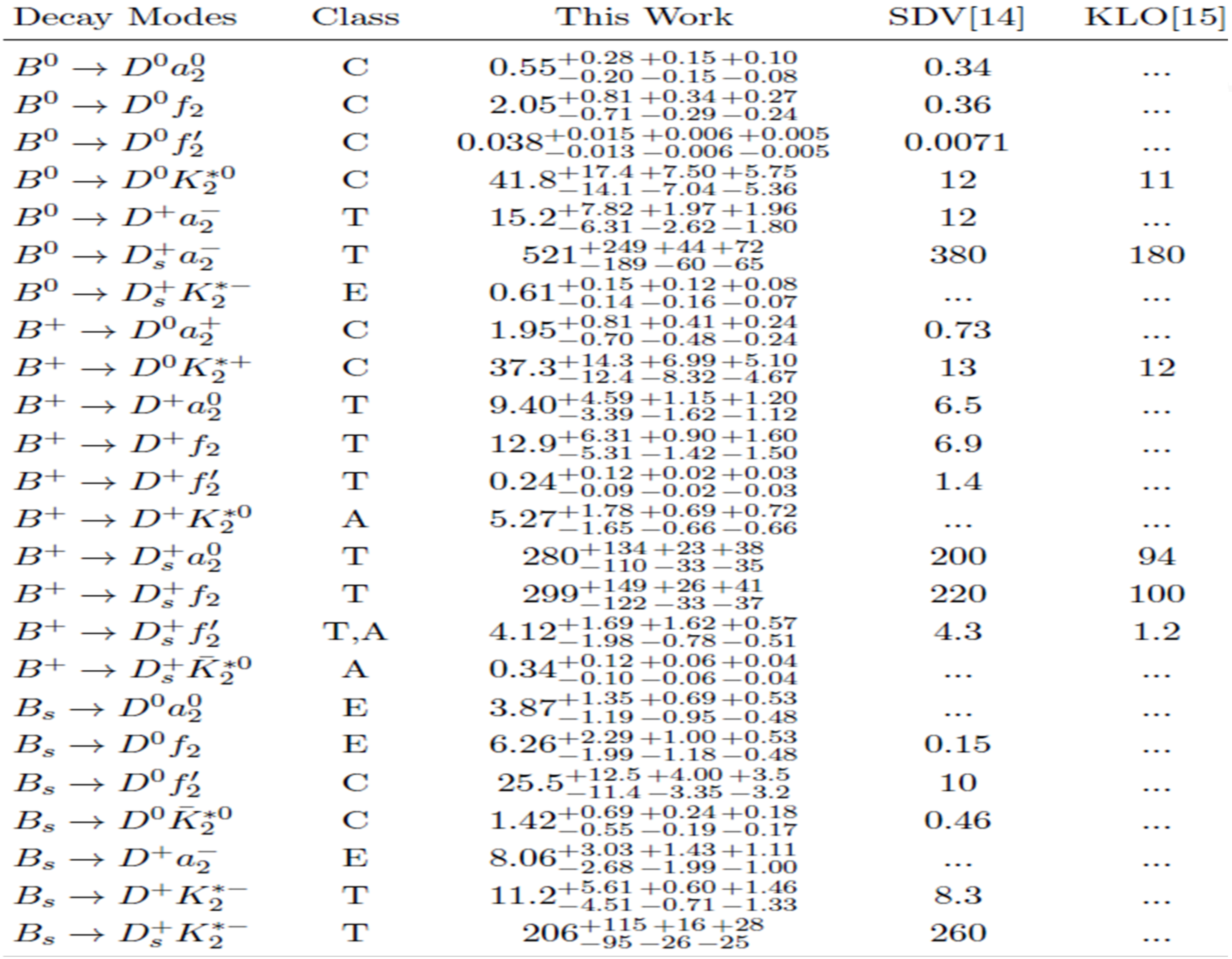
Decay Modes	class	This Work	ISGW2 [24]	QCDF [4]	Expt.
$B^+ \to K_2^{*0}\pi^+$	PA	$0.9^{+0.2+0.2+0.3}_{-0.2-0.2-0.2}$	...	$3.1^{+8.3}_{-3.1}$	$5.6^{+2.2}_{-1.4}$
$B^+ \to K_2^{*+}\pi^0$	PA	$0.4^{+0.1+0.1+0.1}_{-0.0-0.1-0.1}$	0.090	$2.2^{+4.7}_{-1.9}$	...
$B^+ \to a_2^0 K^+$	T,PA	$2.1^{+0.7+0.6+0.6}_{-0.6-0.5-0.5}$	0.31	$4.9^{+8.4}_{-4.2}$	< 45
$B^+ \to a_2^+ K^0$	PA	$3.1^{+0.9+0.9+1.1}_{-0.8-0.8-0.9}$	0.011	$8.4^{+16.1}_{-7.2}$	...
$B^+ \to f_2 K^+$	T,PA,P	$11.8^{+2.7+3.2+3.0}_{-2.4-2.8-2.7}$	0.34	$3.8^{+7.8}_{-3.0}$	$1.06^{+0.28}_{-0.29}$
$B^+ \to f' K^+$	P,PA	$3.8^{+0.4+0.9+1.0}_{-0.4-0.8-0.8}$	0.004	$4.0^{+7.4}_{-3.6}$	< 7.7
$B^+ \to K_2^{*+}\eta$	PA,P	$0.8^{+0.2+0.3+0.3}_{-0.2-0.2-0.3}$	0.031	$6.8^{+13.5}_{-8.7}$	9.1 ± 3.0
$B^+ \to K_2^{*+}\eta'$	PA,P	$12.7^{+3.7+4.5+4.0}_{-3.2-3.5-3.5}$	1.41	$12.1^{+20.7}_{-12.1}$	$28.0^{+5.3}_{-5.0}$
$B^0 \to K_2^{*+}\pi^-$	PA	$1.0^{+0.2+0.2+0.3}_{-0.2-0.2-0.2}$	...	$3.3^{+8.5}_{-3.2}$	< 6.3
$B^0 \to K_2^{*0}\pi^0$	PA	$0.6^{+0.2+0.1+0.2}_{-0.1-0.1-0.1}$	0.084	$1.2^{+4.3}_{-1.3}$	< 4.0
$B^0 \to a_2^- K^+$	T,PA	$5.0^{+1.6+1.4+1.3}_{-1.4-1.1-1.0}$	0.58	$9.7^{+17.2}_{-8.1}$	...
$B^0 \to a_2^0 K^0$	PA	$2.0^{+0.5+0.4+0.6}_{-0.5-0.4-0.5}$	0.005	$4.2^{+8.3}_{-3.5}$	...
$B^0 \to f_2 K^0$	PA,P	$9.2^{+2.0+2.5+2.6}_{-1.8-2.1-2.2}$	0.005	$3.4^{+8.5}_{-3.1}$	$2.7^{+1.3}_{-1.2}$
$B^0 \to f_2' K^0$	P,PA	$3.7^{+0.3+0.7+0.9}_{-0.4-0.8-0.9}$	0.00007	$3.8^{+7.3}_{-3.5}$	...
$B^0 \to K_2^{*0}\eta$	PA,P	$1.0^{+0.2+0.3+0.3}_{-0.2-0.2-0.3}$	0.029	$6.6^{+13.5}_{-8.7}$	9.6 ± 2.1
$B^0 \to K_2^{*0}\eta'$	PA,P	$11.6^{+3.6+4.2+3.8}_{-2.9-3.1-3.1}$	1.30	$12.4^{+21.3}_{-12.4}$	$13.7^{+3.2}_{-3.1}$

B→PT (ΔS=0)(10^{-7}) HY Cheng, KC Yang, PRD83, 034001(2008) & ZT Zou, X Yu, CDL, **arXiv:1203.4120**



Decay Modes	class	This Work	ISGW2 [24]	QCDF [4]
$B^+ \to a_2^0\pi^+$	T	$29.1^{+12.8+14.2+3.1}_{-10.6-10.4-2.8}$	26.02	30^{+14}_{-12}
$B^+ \to a_2^+\pi^0$	T,C	$0.3^{+0.0+0.1+0.0}_{-0.0-0.1-0.0}$	0.01	$2.4^{+4.9}_{-3.1}$
$B^+ \to a_2^+\eta$	C,PA,P	$1.0^{+0.3+0.4+0.4}_{-0.3-0.3-0.3}$	2.94	$1.1^{+2.8}_{-1.1}$
$B^+ \to a_2^+\eta'$	C,PA,P	$3.5^{+1.4+1.6+1.1}_{-1.0-1.1-0.8}$	13.1	$1.1^{+4.7}_{-1.2}$
$B^+ \to f_2\pi^+$	T	$42.5^{+18.9+18.9+4.2}_{-15.4-13.9-3.9}$	28.74	27^{+14}_{-12}
$B^+ \to f_2'\pi^+$	T	$1.2^{+0.3+0.4+0.1}_{-0.2-0.3-0.1}$	0.37	$0.09^{+0.24}_{-0.09}$
$B^+ \to K_2^{*+}\bar{K}^0$	PA,P	$1.2^{+0.2+0.2+0.3}_{-0.2-0.2-0.3}$	4.0×10^{-4}	$4.4^{+7.4}_{-4.1}$
$B^+ \to \bar{K}_2^{*0}K^+$	PA	$0.8^{+0.1+0.2+0.3}_{-0.1-0.2-0.2}$	...	$1.2^{+5.2}_{-1.2}$
$B^0 \to a_2^-\pi^+$	T	$98.9^{+35.1+42.6+5.8}_{-29.9-32.0-9.7}$	48.82	52^{+18}_{-18}
$B^0 \to a_2^+\pi^-$	T,PA	$2.7^{+0.5+0.8+0.4}_{-0.3-0.5-0.3}$	...	$2.1^{+4.3}_{-1.7}$
$B^0 \to a_2^0\pi^0$	C	$4.6^{+1.2+1.6+0.9}_{-1.0-1.2-0.7}$	0.003	$2.4^{+4.2}_{-1.9}$
$B^0 \to a_2^0\eta$	C,PA,P	$0.6^{+0.1+0.2+0.1}_{-0.1-0.1-0.1}$	1.38	$0.6^{+1.6}_{-0.5}$
$B^0 \to a_2^0\eta'$	C,PA,P	$1.8^{+0.6+0.7+0.4}_{-0.5-0.6-0.4}$	6.15	$0.5^{+2.2}_{-0.4}$
$B^0 \to f_2\pi^0$	C	$2.8^{+0.7+0.7+0.6}_{-0.6-0.6-0.4}$	0.003	$1.5^{+4.2}_{-1.4}$
$B^0 \to f_2'\pi^0$	P	$0.2^{+0.0+0.1+0.0}_{-0.0-0.1-0.0}$	4.0×10^{-5}	$0.05^{+0.12}_{-0.05}$
$B^0 \to f_2\eta$	C,P,PA	$2.6^{+0.7+0.8+0.7}_{-0.5-0.6-0.6}$	1.52	$1.7^{+2.3}_{-1.2}$
$B^0 \to f_2\eta'$	C,PA,P	$3.3^{+1.0+1.1+0.9}_{-0.8-0.9-0.9}$	6.8	$1.3^{+2.2}_{-1.3}$
$B^0 \to f_2'\eta$	PA,P	$0.08^{+0.03+0.03+0.01}_{-0.02-0.03-0.02}$	0.02	$0.02^{+0.06}_{-0.03}$
$B^0 \to f_2'\eta'$	PA,P	$0.09^{+0.00+0.02+0.02}_{-0.00-0.02-0.03}$	0.09	$0.08^{+0.08}_{-0.05}$
$B^0 \to K_2^{*+}K^-$	PA	$0.16^{+0.02+0.03+0.03}_{-0.03-0.04-0.03}$	...	$0.3^{+0.7}_{-0.2}$
$B^0 \to K_2^{*-}K^+$	PA	$0.9^{+0.1+0.3+0.2}_{-0.1-0.1-0.2}$	...	$1.3^{+1.6}_{-1.0}$
$B^0 \to K_2^{*0}\bar{K}^0$	P,PA	$1.5^{+0.3+0.3+0.5}_{-0.3-0.3-0.4}$	3.0×10^{-4}	$5.4^{+8.8}_{-4.9}$
$B^0 \to \bar{K}_2^{*0}K^0$	P,PA	$0.8^{+0.1+0.2+0.3}_{-0.1-0.1-0.2}$	...	$2.2^{+5.4}_{-2.2}$

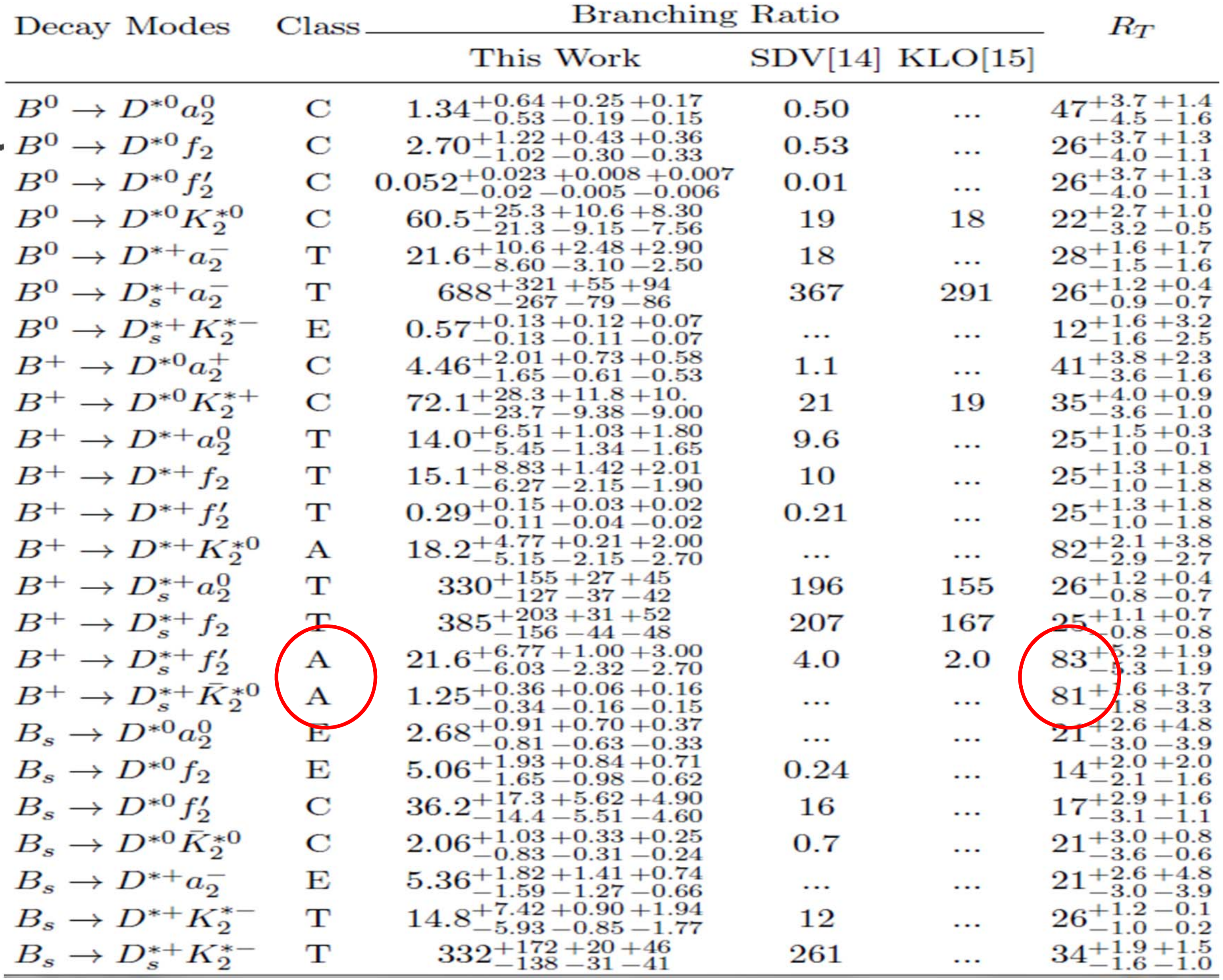
$B_{(s)}$ →DT decays (10^{-7})(CKM suppressed by V_{ub})



Decay Modes	Class	This Work	SDV[14]	KLO[15]
$B^0 \to D^0 a_2^0$	C	$0.55^{+0.28}_{-0.20}{}^{+0.15}_{-0.15}{}^{+0.10}_{-0.08}$	0.34	...
$B^0 \to D^0 f_2$	C	$2.05^{+0.81}_{-0.71}{}^{+0.34}_{-0.29}{}^{+0.27}_{-0.24}$	0.36	...
$B^0 \to D^0 f_2'$	C	$0.038^{+0.015}_{-0.013}{}^{+0.006}_{-0.006}{}^{+0.005}_{-0.005}$	0.0071	...
$B^0 \to D^0 K_2^{*0}$	C	$41.8^{+17.4}_{-14.1}{}^{+7.50}_{-7.04}{}^{+5.75}_{-5.36}$	12	11
$B^0 \to D^+ a_2^-$	T	$15.2^{+7.82}_{-6.31}{}^{+1.97}_{-2.62}{}^{+1.96}_{-1.80}$	12	...
$B^0 \to D_s^+ a_2^-$	T	$521^{+249}_{-189}{}^{+44}_{-60}{}^{+72}_{-65}$	380	180
$B^0 \to D_s^+ K_2^{*-}$	E	$0.61^{+0.15}_{-0.14}{}^{+0.12}_{-0.16}{}^{+0.08}_{-0.07}$	...	...
$B^+ \to D^0 a_2^+$	C	$1.95^{+0.81}_{-0.70}{}^{+0.41}_{-0.48}{}^{+0.24}_{-0.24}$	0.73	...
$B^+ \to D^0 K_2^{*+}$	C	$37.3^{+14.3}_{-12.4}{}^{+6.99}_{-8.32}{}^{+5.10}_{-4.67}$	13	12
$B^+ \to D^+ a_2^0$	T	$9.40^{+4.59}_{-3.39}{}^{+1.15}_{-1.62}{}^{+1.20}_{-1.12}$	6.5	...
$B^+ \to D^+ f_2$	T	$12.9^{+6.31}_{-5.31}{}^{+0.90}_{-1.42}{}^{+1.60}_{-1.50}$	6.9	...
$B^+ \to D^+ f_2'$	T	$0.24^{+0.12}_{-0.09}{}^{+0.02}_{-0.02}{}^{+0.03}_{-0.03}$	1.4	...
$B^+ \to D^+ K_2^{*0}$	A	$5.27^{+1.78}_{-1.65}{}^{+0.69}_{-0.66}{}^{+0.72}_{-0.66}$	...	...
$B^+ \to D_s^+ a_2^0$	T	$280^{+134}_{-110}{}^{+23}_{-33}{}^{+38}_{-35}$	200	94
$B^+ \to D_s^+ f_2$	T	$299^{+149}_{-122}{}^{+26}_{-33}{}^{+41}_{-37}$	220	100
$B^+ \to D_s^+ f_2'$	T,A	$4.12^{+1.69}_{-1.98}{}^{+1.62}_{-0.78}{}^{+0.57}_{-0.51}$	4.3	1.2
$B^+ \to D_s^+ \bar{K}_2^{*0}$	A	$0.34^{+0.12}_{-0.10}{}^{+0.06}_{-0.06}{}^{+0.04}_{-0.04}$	...	...
$B_s \to D^0 a_2^0$	E	$3.87^{+1.35}_{-1.19}{}^{+0.69}_{-0.95}{}^{+0.53}_{-0.48}$	...	...
$B_s \to D^0 f_2$	E	$6.26^{+2.29}_{-1.99}{}^{+1.00}_{-1.18}{}^{+0.53}_{-0.48}$	0.15	...
$B_s \to D^0 f_2'$	C	$25.5^{+12.5}_{-11.4}{}^{+4.00}_{-3.35}{}^{+3.5}_{-3.2}$	10	...
$B_s \to D^0 \bar{K}_2^{*0}$	C	$1.42^{+0.69}_{-0.55}{}^{+0.24}_{-0.19}{}^{+0.18}_{-0.17}$	0.46	...
$B_s \to D^+ a_2^-$	E	$8.06^{+3.03}_{-2.68}{}^{+1.43}_{-1.99}{}^{+1.11}_{-1.00}$	...	...
$B_s \to D^+ K_2^{*-}$	T	$11.2^{+5.61}_{-4.51}{}^{+0.60}_{-0.71}{}^{+1.46}_{-1.33}$	8.3	...
$B_s \to D_s^+ K_2^{*-}$	T	$206^{+115}_{-95}{}^{+16}_{-26}{}^{+28}_{-25}$	260	...

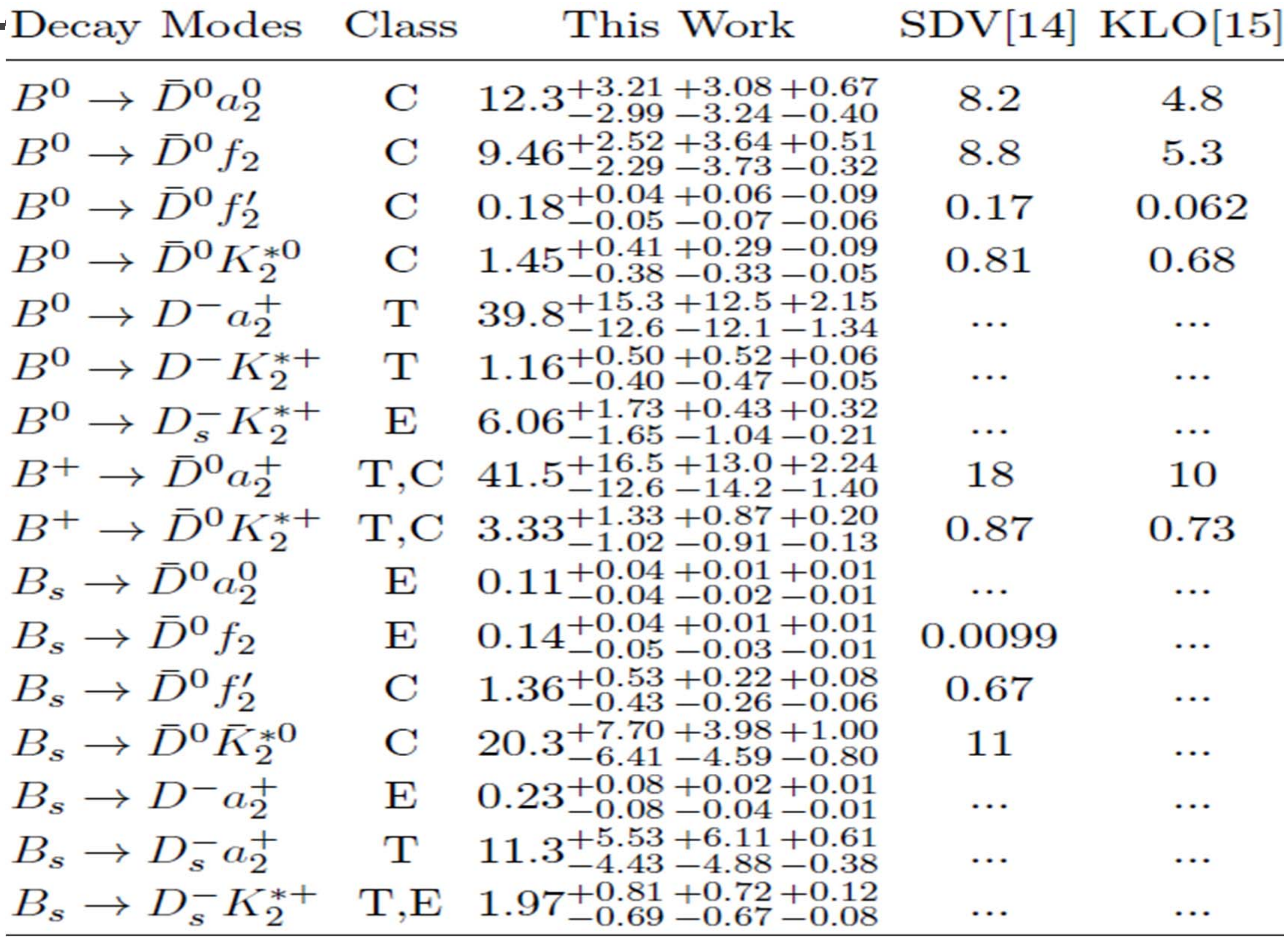
ZT Zou,
X Yu,
CDL,
arXiv:1205.2971
Poster session

$B_{(s)} \to D^{*}T$ decays (10^{-7}) (CKM suppressed by V_{ub})



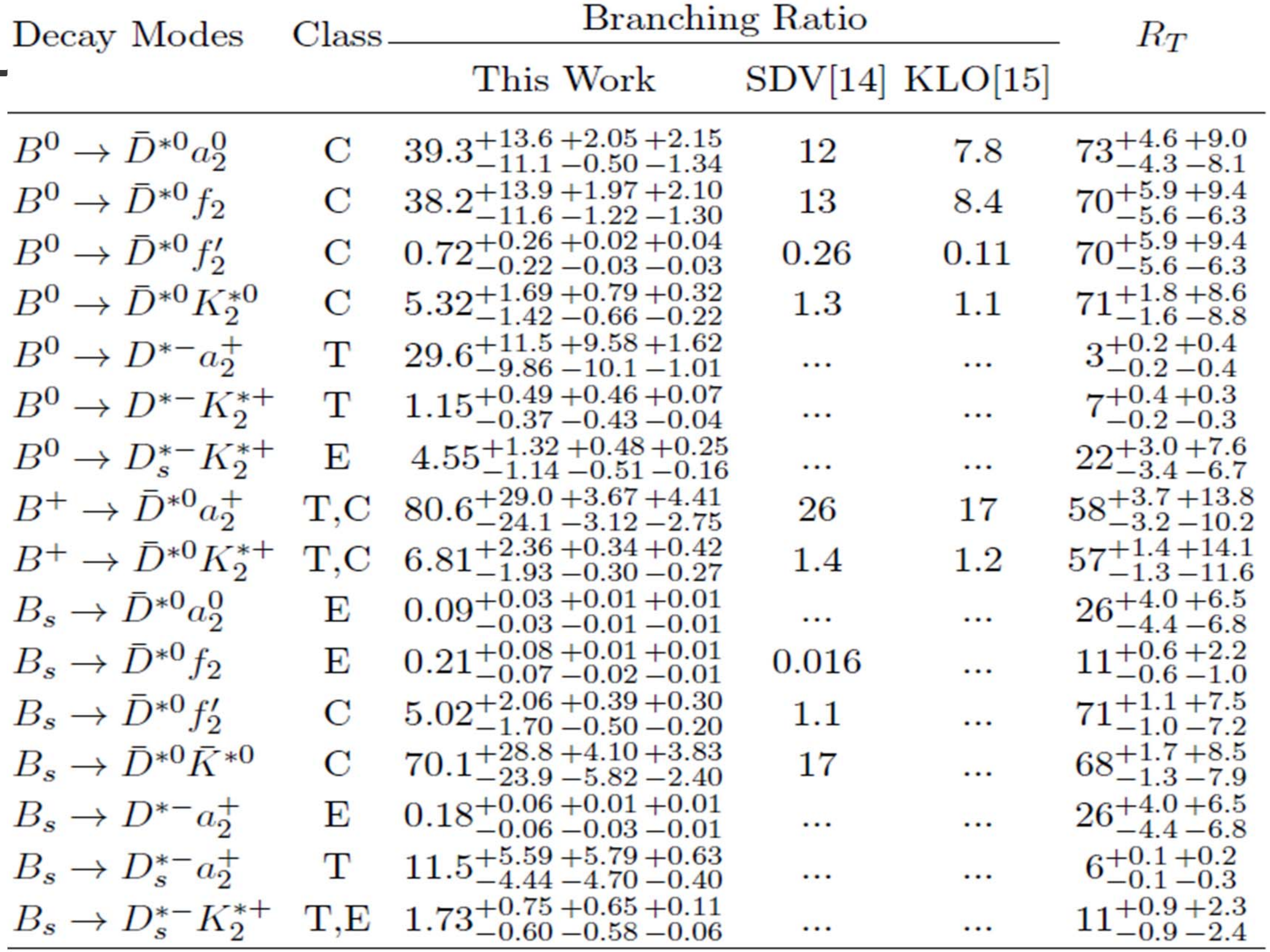
Decay Modes	Class	Branching Ratio			R_T
		This Work	SDV[14]	KLO[15]	
$B^0 \to D^{*0} a_2^0$	C	$1.34^{+0.64+0.25+0.17}_{-0.53-0.19-0.15}$	0.50	...	$47^{+3.7+1.4}_{-4.5-1.6}$
$B^0 \to D^{*0} f_2$	C	$2.70^{+1.22+0.43+0.36}_{-1.02-0.30-0.33}$	0.53	...	$26^{+3.7+1.3}_{-4.0-1.1}$
$B^0 \to D^{*0} f_2'$	C	$0.052^{+0.023+0.008+0.007}_{-0.02-0.005-0.006}$	0.01	...	$26^{+3.7+1.3}_{-4.0-1.1}$
$B^0 \to D^{*0} K_2^{*0}$	C	$60.5^{+25.3+10.6+8.30}_{-21.3-9.15-7.56}$	19	18	$22^{+2.7+1.0}_{-3.2-0.5}$
$B^0 \to D^{*+} a_2^-$	T	$21.6^{+10.6+2.48+2.90}_{-8.60-3.10-2.50}$	18	...	$28^{+1.6+1.7}_{-1.5-1.6}$
$B^0 \to D_s^{*+} a_2^-$	T	$688^{+321+55+94}_{-267-79-86}$	367	291	$26^{+1.2+0.4}_{-0.9-0.7}$
$B^0 \to D_s^{*+} K_2^{*-}$	E	$0.57^{+0.13+0.12+0.07}_{-0.13-0.11-0.07}$	...	...	$12^{+1.6+3.2}_{-1.6-2.5}$
$B^+ \to D^{*0} a_2^+$	C	$4.46^{+2.01+0.73+0.58}_{-1.65-0.61-0.53}$	1.1	...	$41^{+3.8+2.3}_{-3.6-1.6}$
$B^+ \to D^{*0} K_2^{*+}$	C	$72.1^{+28.3+11.8+10.}_{-23.7-9.38-9.00}$	21	19	$35^{+4.0+0.9}_{-3.6-1.0}$
$B^+ \to D^{*+} a_2^0$	T	$14.0^{+6.51+1.03+1.80}_{-5.45-1.34-1.65}$	9.6	...	$25^{+1.5+0.3}_{-1.0-0.1}$
$B^+ \to D^{*+} f_2$	T	$15.1^{+8.83+1.42+2.01}_{-6.27-2.15-1.90}$	10	...	$25^{+1.3+1.8}_{-1.0-1.8}$
$B^+ \to D^{*+} f_2'$	T	$0.29^{+0.15+0.03+0.02}_{-0.11-0.04-0.02}$	0.21	...	$25^{+1.3+1.8}_{-1.0-1.8}$
$B^+ \to D^{*+} K_2^{*0}$	A	$18.2^{+4.77+0.21+2.00}_{-5.15-2.15-2.70}$	...	...	$82^{+2.1+3.8}_{-2.9-2.7}$
$B^+ \to D_s^{*+} a_2^0$	T	$330^{+155+27+45}_{-127-37-42}$	196	155	$26^{+1.2+0.4}_{-0.8-0.7}$
$B^+ \to D_s^{*+} f_2$	T	$385^{+203+31+52}_{-156-44-48}$	207	167	$25^{+1.1+0.7}_{-0.8-0.8}$
$B^+ \to D_s^{*+} f_2'$	A	$21.6^{+6.77+1.00+3.00}_{-6.03-2.32-2.70}$	4.0	2.0	$83^{+5.2+1.9}_{-5.3-1.9}$
$B^+ \to D_s^{*+} \bar{K}_2^{*0}$	A	$1.25^{+0.36+0.06+0.16}_{-0.34-0.16-0.15}$	...	...	$81^{+1.6+3.7}_{-1.8-3.3}$
$B_s \to D^{*0} a_2^0$	E	$2.68^{+0.91+0.70+0.37}_{-0.81-0.63-0.33}$	...	...	$21^{+2.6+4.8}_{-3.0-3.9}$
$B_s \to D^{*0} f_2$	E	$5.06^{+1.93+0.84+0.71}_{-1.65-0.98-0.62}$	0.24	...	$14^{+2.0+2.0}_{-2.1-1.6}$
$B_s \to D^{*0} f_2'$	C	$36.2^{+17.3+5.62+4.90}_{-14.4-5.51-4.60}$	16	...	$17^{+2.9+1.6}_{-3.1-1.1}$
$B_s \to D^{*0} \bar{K}_2^{*0}$	C	$2.06^{+1.03+0.33+0.25}_{-0.83-0.31-0.24}$	0.7	...	$21^{+3.0+0.8}_{-3.6-0.6}$
$B_s \to D^{*+} a_2^-$	E	$5.36^{+1.82+1.41+0.74}_{-1.59-1.27-0.66}$	...	...	$21^{+2.6+4.8}_{-3.0-3.9}$
$B_s \to D^{*+} K_2^{*-}$	T	$14.8^{+7.42+0.90+1.94}_{-5.93-0.85-1.77}$	12	...	$26^{+1.2-0.1}_{-1.0-0.2}$
$B_s \to D_s^{*+} K_2^{*-}$	T	$332^{+172+20+46}_{-138-31-41}$	261	...	$34^{+1.9+1.5}_{-1.6-1.0}$

$B_{(s)} \rightarrow \underline{D}T$ decays (10^{-5})(CKM enhanced by V_{cb})



Decay Modes	Class	This Work	SDV[14]	KLO[15]
$B^0 \to \bar{D}^0 a_2^0$	C	$12.3^{+3.21}_{-2.99}{}^{+3.08}_{-3.24}{}^{+0.67}_{-0.40}$	8.2	4.8
$B^0 \to \bar{D}^0 f_2$	C	$9.46^{+2.52}_{-2.29}{}^{+3.64}_{-3.73}{}^{+0.51}_{-0.32}$	8.8	5.3
$B^0 \to \bar{D}^0 f_2'$	C	$0.18^{+0.04}_{-0.05}{}^{+0.06}_{-0.07}{}^{-0.09}_{-0.06}$	0.17	0.062
$B^0 \to \bar{D}^0 K_2^{*0}$	C	$1.45^{+0.41}_{-0.38}{}^{+0.29}_{-0.33}{}^{-0.09}_{-0.05}$	0.81	0.68
$B^0 \to D^- a_2^+$	T	$39.8^{+15.3}_{-12.6}{}^{+12.5}_{-12.1}{}^{+2.15}_{-1.34}$	...	...
$B^0 \to D^- K_2^{*+}$	T	$1.16^{+0.50}_{-0.40}{}^{+0.52}_{-0.47}{}^{+0.06}_{-0.05}$	...	...
$B^0 \to D_s^- K_2^{*+}$	E	$6.06^{+1.73}_{-1.65}{}^{+0.43}_{-1.04}{}^{+0.32}_{-0.21}$	...	...
$B^+ \to \bar{D}^0 a_2^+$	T,C	$41.5^{+16.5}_{-12.6}{}^{+13.0}_{-14.2}{}^{+2.24}_{-1.40}$	18	10
$B^+ \to \bar{D}^0 K_2^{*+}$	T,C	$3.33^{+1.33}_{-1.02}{}^{+0.87}_{-0.91}{}^{+0.20}_{-0.13}$	0.87	0.73
$B_s \to \bar{D}^0 a_2^0$	E	$0.11^{+0.04}_{-0.04}{}^{+0.01}_{-0.02}{}^{+0.01}_{-0.01}$	...	...
$B_s \to \bar{D}^0 f_2$	E	$0.14^{+0.04}_{-0.05}{}^{+0.01}_{-0.03}{}^{+0.01}_{-0.01}$	0.0099	...
$B_s \to \bar{D}^0 f_2'$	C	$1.36^{+0.53}_{-0.43}{}^{+0.22}_{-0.26}{}^{+0.08}_{-0.06}$	0.67	...
$B_s \to \bar{D}^0 \bar{K}_2^{*0}$	C	$20.3^{+7.70}_{-6.41}{}^{+3.98}_{-4.59}{}^{+1.00}_{-0.80}$	11	...
$B_s \to D^- a_2^+$	E	$0.23^{+0.08}_{-0.08}{}^{+0.02}_{-0.04}{}^{+0.01}_{-0.01}$	...	...
$B_s \to D_s^- a_2^+$	T	$11.3^{+5.53}_{-4.43}{}^{+6.11}_{-4.88}{}^{+0.61}_{-0.38}$	...	...
$B_s \to D_s^- K_2^{*+}$	T,E	$1.97^{+0.81}_{-0.69}{}^{+0.72}_{-0.67}{}^{+0.12}_{-0.08}$	...	...

$B_{(s)} \rightarrow \underline{D^*}T$ decays (10^{-5})(CKM enhanced by V_{cb})



Decay Modes	Class	Branching Ratio			R_T
		This Work	SDV[14]	KLO[15]	
$B^0 \to \bar{D}^{*0} a_2^0$	C	$39.3^{+13.6\,+2.05\,+2.15}_{-11.1\,-0.50\,-1.34}$	12	7.8	$73^{+4.6\,+9.0}_{-4.3\,-8.1}$
$B^0 \to \bar{D}^{*0} f_2$	C	$38.2^{+13.9\,+1.97\,+2.10}_{-11.6\,-1.22\,-1.30}$	13	8.4	$70^{+5.9\,+9.4}_{-5.6\,-6.3}$
$B^0 \to \bar{D}^{*0} f_2'$	C	$0.72^{+0.26\,+0.02\,+0.04}_{-0.22\,-0.03\,-0.03}$	0.26	0.11	$70^{+5.9\,+9.4}_{-5.6\,-6.3}$
$B^0 \to \bar{D}^{*0} K_2^{*0}$	C	$5.32^{+1.69\,+0.79\,+0.32}_{-1.42\,-0.66\,-0.22}$	1.3	1.1	$71^{+1.8\,+8.6}_{-1.6\,-8.8}$
$B^0 \to D^{*-} a_2^+$	T	$29.6^{+11.5\,+9.58\,+1.62}_{-9.86\,-10.1\,-1.01}$	...	...	$3^{+0.2\,+0.4}_{-0.2\,-0.4}$
$B^0 \to D^{*-} K_2^{*+}$	T	$1.15^{+0.49\,+0.46\,+0.07}_{-0.37\,-0.43\,-0.04}$	...	...	$7^{+0.4\,+0.3}_{-0.2\,-0.3}$
$B^0 \to D_s^{*-} K_2^{*+}$	E	$4.55^{+1.32\,+0.48\,+0.25}_{-1.14\,-0.51\,-0.16}$	...	...	$22^{+3.0\,+7.6}_{-3.4\,-6.7}$
$B^+ \to \bar{D}^{*0} a_2^+$	T,C	$80.6^{+29.0\,+3.67\,+4.41}_{-24.1\,-3.12\,-2.75}$	26	17	$58^{+3.7\,+13.8}_{-3.2\,-10.2}$
$B^+ \to \bar{D}^{*0} K_2^{*+}$	T,C	$6.81^{+2.36\,+0.34\,+0.42}_{-1.93\,-0.30\,-0.27}$	1.4	1.2	$57^{+1.4\,+14.1}_{-1.3\,-11.6}$
$B_s \to \bar{D}^{*0} a_2^0$	E	$0.09^{+0.03\,+0.01\,+0.01}_{-0.03\,-0.01\,-0.01}$	...	...	$26^{+4.0\,+6.5}_{-4.4\,-6.8}$
$B_s \to \bar{D}^{*0} f_2$	E	$0.21^{+0.08\,+0.01\,+0.01}_{-0.07\,-0.02\,-0.01}$	0.016	...	$11^{+0.6\,+2.2}_{-0.6\,-1.0}$
$B_s \to \bar{D}^{*0} f_2'$	C	$5.02^{+2.06\,+0.39\,+0.30}_{-1.70\,-0.50\,-0.20}$	1.1	...	$71^{+1.1\,+7.5}_{-1.0\,-7.2}$
$B_s \to \bar{D}^{*0} \bar{K}^{*0}$	C	$70.1^{+28.8\,+4.10\,+3.83}_{-23.9\,-5.82\,-2.40}$	17	...	$68^{+1.7\,+8.5}_{-1.3\,-7.9}$
$B_s \to D^{*-} a_2^+$	E	$0.18^{+0.06\,+0.01\,+0.01}_{-0.06\,-0.03\,-0.01}$	...	...	$26^{+4.0\,+6.5}_{-4.4\,-6.8}$
$B_s \to D_s^{*-} a_2^+$	T	$11.5^{+5.59\,+5.79\,+0.63}_{-4.44\,-4.70\,-0.40}$	...	...	$6^{+0.1\,+0.2}_{-0.1\,-0.3}$
$B_s \to D_s^{*-} K_2^{*+}$	T,E	$1.73^{+0.75\,+0.65\,+0.11}_{-0.60\,-0.58\,-0.06}$	...	...	$11^{+0.9\,+2.3}_{-0.9\,-2.4}$

Summary (1)

- The theoretical calculation for hadronic B decays is a tough work
- The theoretical calculation has been reached the NLO or NNLO order at α_s expansion
- More and more power correction have been taken into account
- A lot of work is still missing to be done

Summary (2)

- **Color favored tree (T) – We do know what we expected to know**
- **color suppressed Tree (C) – We do not exactly know what we expected to know**
- **Annihilations (A,E,PA,SP) – We do know now what we did not expect to know**
- **Penguins (P, P_{EW}) – We hope we really understand so many kinds of**

谢谢！

Thanks!

Nambu-Goldstone boson

(H.-n. Li, S. Mishima, e-Print: arXiv:0901.1272)

- Pion as a qq bound state and as a massless Nambu-Goldstone boson?
- Massless boson => huge spacetime=> large separation between qq => high mass under confinement => contradiction!
- Reconciliation: leading qq state like that in rho, higher Fockstate gives soft cloud