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Charmless Two-body $B \to PP, VP$ decays In Soft-Collinear-Effective-Theory

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We provide the analysis of charmless two-body $B \to VP$ decays under the framework of the soft-collinear-effective-theory, where $V(P)$ denotes a light vector (pseudoscalar) meson. Using the available data, we fit 16 non-perturbative inputs responsible for the $B \to PP$ and $B \to VP$ decay channels in the χ^2 fit method. We find that chiraly enhanced penguins can change several charming penguins sizably, but most of the other non-perturbative inputs and predictions on branching ratios and CP asymmetries are not changed too much. We predict the branching fractions and CP asymmetries of other modes especially $B_s \to VP$ decays. The agreements and disagreements with results in QCD factorization and perturbative QCD approach are analyzed.

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1. Introduction

Charmless hadronic B decays are helpful for the precise test of the standard model and the search for possible new physics scenarios. In recent years, great progresses have been made in the studies of charmless two-body B decays. These decays were dynamically investigated in three popular theoretical approaches: the QCD factorization (QCDF) [1, 2, 3], the perturbative QCD (PQCD) [4, 5, 6], and the soft-collinear effective theory (SCET) [7, 8]. Despite many differences, all of them are based on power expansions in Λ_{QCD}/m_b, where m_b is the b-quark mass and Λ_{QCD} is the typical hadronic scale. Factorization of the hadronic matrix elements is proved to hold to the leading power in Λ_{QCD}/m_b in a number of decays.

SCET provides an elegant theoretical tool to separate the physics at different scales. The matching from QCD onto SCET is always performed in two stages. The fluctuations with off-shellness $\mathcal{O}(m_b^2)$ is firstly integrated out and one results in the intermediate effective theory SCET$_I$. In SCET$_I$, the generic factorization formula for $B \to M_1 M_2$ is written by:

$$\langle M_1 M_2 | O_i | B \rangle = T(u) \otimes \phi_{M_1}(u) \zeta^{B\to M_2} + T_J(u,z) \otimes \phi_{M_1}(u) \otimes \zeta_J^{B\to M_2}(z), \tag{1.1}$$

where T and T_J are perturbatively calculable Wilson coefficients. In the second step, the fluctuations with typical off-shellness $m_b\Lambda_{QCD}$ are integrated out and one reaches SCET$_{II}$. In SCET$_{II}$, end-point singularities prohibit the factorization of ζ, while the function ζ_J can be further factorized into the convolution of a hard kernel (jet function) with light-cone distribution amplitudes. In the phenomenological framework proposed in Ref. [9], the expansion at the intermediate scale $\mu_{hc} = \sqrt{m_b \Lambda_{QCD}}$ is not used. Instead the experimental data are used to fit the non-perturbative inputs. This method is firstly applied to $B \to K\pi$, $B \to KK$ and $B \to \pi\pi$ decays [9]. Subsequently, it is applied to charmless two-body $B \to PP$ decays involving the iso-singlet mesons η and η' [10].

In our work [11], we extend this method to the $B \to VP$ decays and use a wealth of the experimental data to fit the non-perturbative inputs (in our analysis, we also take the $B \to PP$ decays into account). Besides leading power contributions, we also take into account a part of chiraly enhanced penguin whose operator basis and the factorization formulae are derived in Ref. [12, 13].

2. Decay amplitudes of $B \to M_1 M_2$ in SCET

In SCET, the factorization formula for $B \to M_1 M_2$ is easily proved to hold to all order in α_s: the amplitudes have the form of a convolution of the universal light-cone distribution amplitudes and the perturbative hard kernels. Using the perturbative expansion in $\alpha_s(\sqrt{m_b\Lambda})$ for the jet functions and in $\alpha_s(m_b)$ for the Wilson coefficients, one can predict the branching ratios, CP asymmetries and other observables for $B \to M_1 M_2$ decays. One can also use another parallel method: the non-perturbative parameters can be fitted by experimental measurements on the $B \to M_1 M_2$ decays. This approach is especially useful at leading order in α_s, since then the hard kernels $T_1(u)$ are constants, while $T_{1J}(u,z)$ are functions of u only. Furthermore at this order, terms with hard kernels $T_{1J}^g(u,z)$, $T_1^g(u)$, $T_{1Jg}^g(u,z)$, $T_{1g}^g(u)$ do not contribute at all. Thus the decay amplitudes of $B \to M_1 M_2$ decays at LO in $\alpha_s(m_b)$ are written by:

$$A(B \to M_1 M_2) = \frac{G_F}{\sqrt{2}} m_B^2 \left\{ f_{M_1} \left[\zeta_J^{BM_2} \int du \phi_{M_1}(u) T_{1J}(u) + \zeta_{Jg}^{BM_2} \int du \phi_{M_1}(u) T_{1Jg}(u) \right] \right.$$

$$+f_{M_1}(T_1\zeta^{BM_2}+T_{1g}\zeta_g^{BM_2})+\lambda_c^{(f)}A_{cc}^{M_1M_2}+(1\leftrightarrow 2)\Big\}, \tag{2.1}$$

where $A_{cc}^{M_1M_2}$ denotes the non-perturbative charming penguins. T_i are hard kernels which can be calculated using perturbation theory. Based on the flavor structure of the four-body operators and five-body operators, it is possible to construct master equations for hard kernels T_i [11]. The four functions ζ^{BM_1}, ζ_g and $\zeta_J^{BM_2}, \zeta_{Jg}^{BM_2}$ are treated as non-perturbative parameters to be fitted from experiment measurements.

Power corrections are expected to be suppressed at least by the factor Λ_{QCD}/m_b, but chiraly enhanced penguins are large enough to compete with the leading power QCD penguins as the suppression factor becomes $2\mu_P/m_b$, where $\mu_P \sim 2$ GeV is the chiral scale parameter. Thus in both of QCDF [1, 2, 3] and PQCD [4, 5, 6] approaches, it has been incorporated in the phenomenological analysis. In the framework of SCET, the complete operator basis and the corresponding factorization formulae for the chiraly enhanced penguin are recently derived in Ref. [12, 13]. The factorization formula will introduce a new form factor ζ_χ and a new light-cone distribution amplitude ϕ^{pp}. As shown in Ref. [13], the term proportional to ζ_χ does not give sizable contributions. Thus in our analysis, we neglect it and only consider the remanent terms:

$$\begin{aligned}A^\chi(B\to M_1M_2) &= \pm\frac{G_F}{\sqrt{2}}m_B^2\left(-\frac{2\mu_{M_1}f_{M_1}}{m_B}\right)\Big\{T_1^\chi\zeta^{BM_2}+T_{1J}^\chi\zeta_J^{BM_2}+T_{1g}^\chi\zeta_g^{BM_2}+T_{1Jg}^\chi\zeta_{Jg}^{BM_2}\\ &\quad +(1\leftrightarrow 2)\Big\}.\end{aligned} \tag{2.2}$$

For $B\to PP$ decays, the chiraly enhanced penguin takes a plus sign; while in $B\to VP$ decays, when emitting a pseudoscalar meson, the amplitude take a minus sign; when a vector meson emitted, there is no contribution from chiraly enhanced penguin since $\mu_V = 0$.

Under the assumption of flavor SU(3) symmetry for B to light meson form factors and charming penguin terms, the 16 real inputs responsible for $B\to PP$ and $B\to VP$ decays are summarized as

$$\zeta^{BP},\quad \zeta_J^{BP},\quad \zeta_g,\quad \zeta_{Jg},\quad \zeta^{BV},\quad \zeta_J^{BV},\quad A_{cc}^{PP},\quad A_{cc}^{PV},\quad A_{cc}^{VP},\quad A_{ccg}^{PP},\quad A_{ccg}^{VP}. \tag{2.3}$$

3. Numerical analysis of $B \to VP$ decays

With these data for branching fractions and CP asymmetries, χ^2 fit method can be used to determine the non-perturbative inputs: form factors and charming penguins. Straightforwardly, we obtain the two solutions for numerical results of the 16 non-perturbative inputs [11] at the leading power. After the inclusion of chiraly enhanced penguins, several parameters in there two solutions are changed. As shown in Fig. 1, chiraly enhanced penguins have the same topology with the charming penguins. The former two diagrams do not only contribute to decays without iso-singlet mesons η or η' but also decays with these mesons. The two diagrams in the lower line only contribute to decays involving η or η', where $q = q'$. The inclusion of chiraly enhanced penguin will mainly change the size of three charming penguins A_{cc}^{PP}, A_{ccg}^{PP}, A_{cc}^{PV}. Predictions for branching fractions and CP asymmetries are not changed sizably.

Our predictions on branching fractions of $\bar{B}^0 \to \pi^\pm\rho^\mp$ decays are smaller than those in QCDF [3]. The main reason is the smaller $B\to P$ and $B\to V$ form factors predicted by the SCET, while

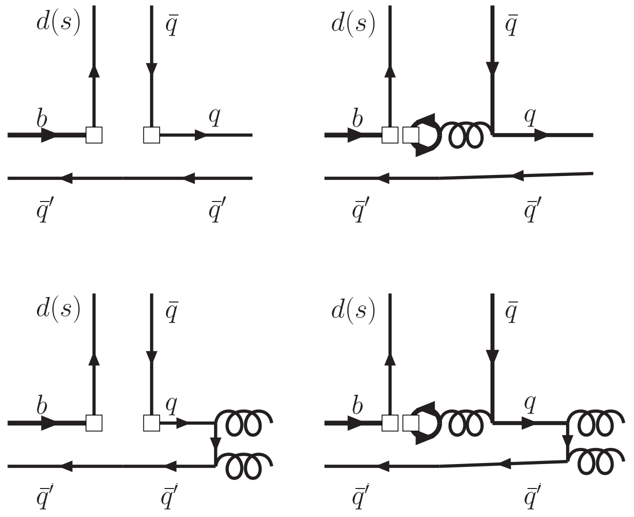

Figure 1: Feynman diagrams for chiraly enhanced penguins (left) and charming penguins (right). The two diagrams in the lower line only contribute to decays involving η or η', where $q = q'$.

QCDF uses much larger form factors. In the SCET, $\mathscr{BR}(\bar{B}^0 \to \rho^+\pi^-)$ is a bit smaller than $\mathscr{BR}(\bar{B}^0 \to \rho^-\pi^+)$. In the first solution, the fitted $B \to V$ form factor $A_0 = 0.233$ is almost equal with the $B \to P$ form factor $F = 0.206$. Since the decay constant of ρ meson is much larger than that of π: $0.209/0.131 \sim 1.5$, we expect $\mathscr{BR}(\bar{B}^0 \to \rho^+\pi^-)$ is only one half of $\mathscr{BR}(\bar{B}^0 \to \rho^-\pi^+)$. Charming penguins A_{cc}^{VP} and A_{cc}^{PV} can slightly change the ratio: the charming penguin A_{cc}^{PV} in $\bar{B}^0 \to \rho^+\pi^-$ gives a constructive contribution, while A_{cc}^{VP} in $\bar{B}^0 \to \rho^-\pi^+$ gives a destructive contribution. In the second solution, contributions proportional to form factors are almost equal with each other, as the $B \to V$ form factor $A_0^{B\to V} = 0.291$ is much larger than $F^{B\to P} = 0.198$ which can compensate differences caused by decay constants. But unlike in the first solution, the role of charming penguin totally changes: the charming penguin in $\bar{B}^0 \to \rho^+\pi^-$ gives a destructive contribution, while A_{cc}^{VP} in $\bar{B}^0 \to \rho^-\pi^+$ can give a constructive contribution. It is reasonable, since the charming penguins A_{cc}^{VP} and A_{cc}^{PV} almost interchanges the phases.

Our predictions for branching ratios of $\bar{B}^0 \to \pi^0\rho^0$ are larger than that in QCDF. In this channel, two kinds of charming penguin almost cancel with each other, since they have similar magnitudes but different signs. The tree contribution proportional to the soft form factor ζ is color-suppressed (the Wilson coefficient $C_2 + \frac{C_1}{N_c} \sim 0.12$ is small compared with that of $\bar{B}^0 \to \rho^\pm\pi^\mp$: $C_1 + \frac{C_2}{N_c} \sim 1.03$), thus the branching fractions of $\bar{B}^0 \to \pi^0\rho^0$ in QCDF approach and PQCD approach are muchsmaller than $\mathscr{BR}(\bar{B}^0 \to \rho^\pm\pi^\mp)$. One important feature of the SCET framework is: the hard-scattering form factor ζ_J is relatively large and comparable with the soft form factor ζ. Besides, since this term has a large Wilson coefficient $b_1^f = C_2 + \frac{1}{N_c}(1 - \frac{m_b}{\omega_3})C_1 \sim 1.23$, it can give larger production rates which are consistent with the present experimental data.

In $b \to s$ decay amplitudes, tree operators are highly CKM-suppressed, but the CKM matrix elements for the rest two kinds of contributions (penguin operators and charming penguins) are in similar size. Together with the hierarchy in Wilson coefficients: $C_{1,2} \gg C_{3-10}$, charming penguins will provide a dominant contribution. For example, the penguin operators in $B^- \to \pi^-\bar{K}^0$ decay process is proportional to $a_4 + r_\chi a_6$, $B^- \to \pi^- \bar{K}^{*0}$ is proportional to a_4 while $B^- \to \rho^- \bar{K}^0$ is proportional to $a_4 - r_\chi a_6$, where $a_{4,6} = C_{4,6} + C_{3,5}/N_c$ and $r_\chi = 2\mu_P/m_b$. If we only consider the emission diagrams, $\mathscr{BR}(B^- \to \pi^- \bar{K}^0) > \mathscr{BR}(B^- \to \pi^- \bar{K}^{*0}) > \mathscr{BR}(B^- \to \rho^- \bar{K}^0)$ holds, since $a_4 \sim a_6$ and $r_\chi \sim 1$. But in the present framework, contributions from penguin operators proportional to $V_{tb}V_{ts}^*$ do not play the most important role. Compared with charming penguins in two solutions, we find penguin operators are smaller than charming penguins. According to the size of charming penguins, we expect the relation $\mathscr{BR}(B^- \to \rho^- \bar{K}^0) \sim \mathscr{BR}(B^- \to \pi^- \bar{K}^{*0})$. This is well consistent with the experimental data.

4. Comparisons with the PQCD approach

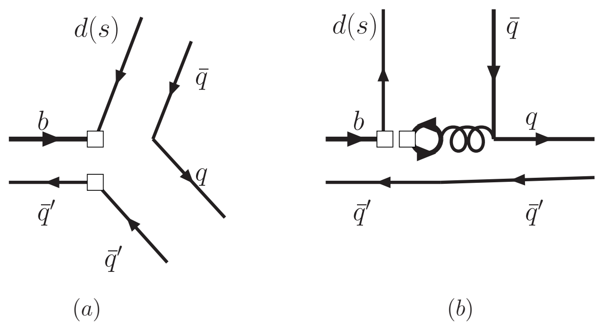

Figure 2: Feynman diagrams for the $(S-P)(S+P)$ annihilation operators in PQCD approach and charming penguins in SCET.

PQCD approach is based on k_T factorization, where one keeps the intrinsic transverse momentum of quark degrees of freedom. The intrinsic transverse momentum can smear the end-point singularities which often appear in collinear factorization. Resummation of double logarithms results in the Sudakov factor which suppresses contributions from the end-point region to make the PQCD approach more self-consistent. This approach can explain many problems to achieve great successes. In PQCD approach, annihilation diagrams can be directly calculated. Among them, the $(S-P)(S+P)$ annihilation penguin operators (from the Fierz transformation of $(V-A)(V+A)$ operators) are the most important one. According to the power counting in PQCD approach, annihilation diagrams are suppressed by Λ_{QCD}/m_b but the suppression for $(S-P)(S+P)$ annihilation penguin operators is $2r_\chi$. This factor is comparable with 1. Thus annihilations play a very important role in PQCD approach. Phenomenologically, the large annihilations can explain the correct branching ratios and direct CP asymmetries of $B^0 \to \pi^+\pi^-$ and $\bar{B}^0 \to K^-\pi^+$ [14], the polarization problem of $B \to \phi K^*$ [15], etc. In Fig. 2(a), we draw the Feynman diagrams for this term. Comparing with charming penguins, we can see they have the same topologies in flavor space. Generally speaking, charming penguins in SCET as shown in Fig. 2(b) have the same role with $(S-P)(S+P)$ annihilation penguin operators in PQCD. Both of them are essential to explain the branching ratios in these two different approaches. But there are indeed some differences in predictions on other parameters such as direct CP asymmetries and mixing-induced CP asymmetries.

First of all, the CKM matrix elements associated with charming penguins and $(S-P)(S+P)$ annihilation penguin operators are different. If we consider $\bar{B}$ decays in which a b quark annihilates, the $(S-P)(S+P)$ annihilation penguin operators are proportional to $V_{tb}V_{tD}^*$, while charming penguins are proportional to $V_{cb}V_{cD}^*$. The differences in the CKM matrix elements will affect direct CP asymmetries and mixing-induced CP asymmetries sizably in some channels.

In PQCD approach, contributions from the $(S-P)(S+P)$ annihilation penguin operators can be calculated using perturbation theory. These contributions are expressed as the convolution of light-cone distribution amplitudes and a hard kernel. We can also include SU(3) symmetry breaking effects in the calculation in PQCD approach. In SCET, charming penguins are from the charm quark loops. Since the charm quark is heavy, one can not factorize charming penguins. In the present work based on SCET, we have assumed SU(3) symmetries for the contributions from charming penguins. The magnitudes and strong phases of charming penguins can not be calculated using perturbation theory which obtained by fitting the experimental data.

The third difference is the magnitudes of charming penguins in SCET and contributions from the $(S-P)(S+P)$ annihilation penguin operators in PQCD approach. This difference arises from the different power counting in the two approaches. We take $b \to s$ transitions to illustrate the difference. In PQCD approach, the $(S-P)(S+P)$ annihilation penguins are enhanced to be of the same order with penguins in emission diagrams. In SCET, charming penguins are more important. Charming penguins in SCET always larger than contributions from emission penguin diagrams.

In PQCD approach, the $(S-P)(S+P)$ annihilation penguin operators are chiraly enhanced and the dominant contribution is from the imaginary part. The main strong phases in PQCD approach which are essential to explain the large CP asymmetries in many channels are also produced through from these operators. But in SCET, strong phases of charming penguins are not too large. Accordingly, our predictions on direct CP asymmetries are smaller compared with predictions in PQCD approach.

5. conclusions

We provide the analysis of charmless two-body $B \to VP$ decays under the framework of soft-collinear-effective theory. Besides the leading power contributions, we also take some power corrections (chiraly enhanced penguins) into account. In this framework, decay amplitudes of $B \to PP$ and $B \to VP$ decay channels are expressed in terms of 16 non-perturbative inputs: 6 form factors and 5 complex (10 real) charming penguins. Using the $B \to PP$ and $B \to VP$ experimental data on branching fractions and CP asymmetry variables, we find two kinds of solutions in χ^2 fit method for these 16 non-perturbative inputs. Chiraly enhanced penguin could change some charming penguins sizably, however most of other non-perturbative inputs and results of branching ratios and CP asymmetries are not changed too much. With the two sets of inputs, we predict branching fractions and CP asymmetries. Agreements and differences with results in QCD factorization and perturbative QCD approach are also analyzed.

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References

[1] M. Beneke, G. Buchalla, M. Neubert and C. T. Sachrajda, Phys. Rev. Lett. **83**, 1914 (1999).

[2] M. Beneke, G. Buchalla, M. Neubert and C. T. Sachrajda, Nucl. Phys. B **591**, 313 (2000).

[3] M. Beneke and M. Neubert, Nucl. Phys. B **675**, 333 (2003).

[4] Y. Y. Keum, H. n. Li and A. I. Sanda, Phys. Lett. B **504**, 6 (2001).

[5] Y. Y. Keum, H. N. Li and A. I. Sanda, Phys. Rev. D **63**, 054008 (2001).

[6] C. D. Lu, K. Ukai and M. Z. Yang, Phys. Rev. D **63**, 074009 (2001).

[7] C. W. Bauer, S. Fleming, D. Pirjol and I. W. Stewart, Phys. Rev. D **63**, 114020 (2001).

[8] C. W. Bauer, D. Pirjol and I. W. Stewart, Phys. Rev. Lett. **87**, 201806 (2001).

[9] C. W. Bauer, I. Z. Rothstein and I. W. Stewart, Phys. Rev. D **74**, 034010 (2006).

[10] A. R. Williamson and J. Zupan, Phys. Rev. D **74**, 014003 (2006) [Erratum-ibid. D **74**, 03901 (2006)].

[11] W. Wang, Y. M. Wang, D. S. Yang and C. D. Lu, Phys. Rev. D **78**, 034011 (2008).

[12] C. M. Arnesen, Z. Ligeti, I. Z. Rothstein and I. W. Stewart, Phys. Rev. D **77**, 054006 (2008).

[13] A. Jain, I. Z. Rothstein and I. W. Stewart, arXiv:0706.3399 [hep-ph].

[14] B. H. Hong and C. D. Lu, Sci. China **G49**, 357 (2006).

[15] H. n. Li, Phys. Lett. B **622**, 63 (2005).