Recent progress in B physics

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We first address the recent efforts on calculations of the next-to-leading order corrections to the color-suppressed tree amplitude in QCD factorization method which may be essential to solve the puzzles in B! and K decays. Then we discuss the polarization puzzles in B! K and K. The impacts of the new B+ measured B S, B S mixing and B 0 ! ' on the CKM unitarity triangle global setting are mentioned. We also briefly review the recent measurement of the new resonances at BaBar and Belle. Finally, some new results from hadron colliders, especially the b-avoided hadron spectra, are discussed.

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INTRODUCTION

The study of B meson decays plays an important role in determining the CP-violating parameters in the Standard Model (SM) and discovering new physics in the Flavor-changing processes. In particular, B non-leptonic two-body decays provide an abundant source of information about the CKM matrix. For example, the most prominent measurement of sin^2 2( and are three angles in the unitarity triangle) is from measurement of the time-dependent CP-asymmetry in B^0 ! J= K S, B ! ' and are also very important for determining sin^2 2. However, the theoretical calculation of these hadronic decays suffers from the complicated strong interactions which complicate the precision of the determination of the CKM matrix elements from the experimental data. Thus the higher order calculation of such decays is essential for a better understanding of the CP violations.

Besides the non-leptonic decays, the new measurement of B S, B S mixing and B 0 ! ' have a great impact on constraining the unitarity triangle. Both of these decay modes are also sensitive to new physics.

The B decays offer us a good place to study the strong interaction dynamics in heavy quark systems. In the abundant decay products of B mesons, experimentists observed a lot of new hadron resonances at BaBar and Belle. They are mainly excited (or exotic) charm mesons and charm quark states.

The excited B mesons and b-baryons can be only studied at the hadron colliders. We will briefly review the spectrum of the excited B mesons and b-avoided baryons from the measurement at TEVATRON.

B! AND K PUZZLES

B! and K are the most popularly studied two-body decay modes in B physics in addition to B! J= K S. The big experimental achievement is that the direct CP asymmetries in these decays have been observed. The latest world averages are

\[ A_{CP}(^+ \! J)_{\text{exp}} = 0.38 \pm 0.07; \]
\[ A_{CP}(^0 K)_{\text{exp}} = 0.095 \pm 0.013; \]

both of which are away from zero.

B! are dominated by tree amplitudes. Due to the isospin symmetry, the decay amplitudes of tree B! modes can be parameterized graphically as the following

\[ A(\! J) = T e^{i \theta} + P; \]
\[ A(\! K) = (T + C) e^{i \varphi} \;
\]

where T, C and P stand for the color-allowed, color-suppressed tree amplitude and penguin amplitude respectively. According to the naive factorization, the ratios \[ J-T \text{ and } P-T \text{ are expected to be small. This leads to that } \]

\[ 10^6 \text{Br}(^+ \! J)_{\text{exp}} = 5.16 \pm 0.22; \]
\[ 10^6 \text{Br}(^0 K)_{\text{exp}} = 57 \pm 4; \]

\[ 10^6 \text{Br}(^0 K)_{\text{exp}} = 131 \pm 21; \]

which implies \[ J-T \approx 0.7. \] It means that the color-suppression is not valid any more.

For B! K decays, the similar graphical parameterization can be written as

\[ A(\! K) = P_0; \]
\[ A(\! K) = \left[ P_0^0 + P_{\text{EW}}^0 \right] e^{i \phi} + \left[ P_0^0 + C \right]. \]

in which penguin amplitude P_0^0 dominates comparing with the color-allowed tree amplitude T_0^0, color-suppressed tree amplitude C_0 and the electroweak penguin P_{\text{EW}}. A_{CP}(^0 K) \text{ and } A_{CP}(^+ K) \text{ is expected if}
### TABLE I: Predictions in QCDF with NLO HSI vs. experiment data.

| Br | G$_4$ | Exp. | A$_{CP}$ | G$_4$ | Exp. |
|----|-------|------|----------|-------|------|
| 0  | 5 ± 7 | 0.04 | 0.06     | 0 ± 0 | 0.04 |
| 0  | 5.7  | 0.22 | 0.04     | 0.28  | 0.07 |
| 0  | 0.82 | 0.21 | 0.93     | 0.36  | 0.33 |
| K  | 22±6 | 0.05 | 0.05     | 0.05  | 0.05 |
| K  | 1.9 ± 0.6 | 4 | 0.05 | 0.047 | 0.05 |
| K  | 21 ± 0.6 | 4 | 0.02 | 0.095 | 0.013 |
| K  | 91 ± 10 | 0.92 | 0.92 | 0.1 |

The accidental cancellation between the leading order (LO) and next-to-leading order (NLO) vertex corrections ($V_2$) makes the hard spectator interaction (HSI) very important. The NLO corrections to the HSI are recently studied by Beneke, Jager and Yang [4, 5, 6, 7]. In their papers, the corrections from the two scale regions are encoded into the jet function and hard core cion respectively, both of which enhance the color-suppressed amplitude effectively.

In Table I, the predictions in QCDF with NLO HSI in a certain parameter setting ($G_4$) is shown. The agreement between the prediction and experimental data is very good except for the direct CP asymmetry $A_{CP}$. It means that the strong phases still need further study. Recently, the efforts towards the NLO corrections to the imaginary part of the amplitude has started. In [2], the next-to-leading order vertex corrections has been considered.

### B ! V V AND POLARIZATION PUZZLES

B decays to two light vector mesons is one abundant observables than B ! PP and PV since the non-vectors can be polarized both longitudinally and transversely. The fact of the V A dominance in the Standard Model (SM) shows the hierarchy of the helicity amplitudes for B ! V V

\[ A_0 : A_+, 1 : m_b : m_b \]

with simple estimation by the naive factorization. This argument leads to the expectation that B ! V V is dominated by longitudinal polarization. However, experimentally, such hierarchy is broken in the tree-dominate decays (B ! and ! ), but violated in penguin dominated B ! K system [9]. This attracts a lot of attentions from the theorists. Many solutions are on the table, such as new physics (scales, tensor coupling, ...) at the mass insertion, changing penguin, the form-factor tuning, large penguin annihilation etc.

The more puzzling case happens in B ! K system which are penguin-dominated, in which both transverse polarization is enhanced in B ! K but suppressed in B ! 0K [10].

An analogue to B ! PP and PV, QCD factorization formula for B ! V V reads [11]

\[ H_{V1} V_{1b} \phi_{1b} B = F B \phi_{V1} V_{1b} T_{V1}^{(1)} T_{V2}^{(2)} + T_{V2}^{(1)} T_{V1}^{(2)} + O(\Lambda_m b) \]

1) For the tree-dominate decays which are dominated by longitudinal polarization, the penguin amplitude gives small contribution to the branching ratios. As a result, we could have a better determination of sin2 or from B ! than B ! and .

2) For the penguin dominated decays, the negative-helicity amplitude could be (need not to be) large. This can be an solution for the B ! K polarization puzzle. However, in this case, QCD factorization loses its predictive power.

The decay amplitudes for B ! K system could be parametrized graphically as Eq. (4) except for each amplitude replaced by the one noted by helicity. To explain the polarization fraction in B ! K system, we need large electro weak penguin for negative-helicity amplitude. Such enhancement can be obtained if consider the electromagnetic dipole operator in the effective weak Hamiltonian

\[ H_e = \frac{G_F}{\sqrt{2}} X^{(D)} X C_7 Q^a + \ldots \]

\[ Q_7 = \frac{C_7}{\Lambda_m b} \]

\[ B \rightarrow \pi^0 \pi^0 \]

\[ (l + \bar{\nu} l) \]

\[ b \]

\[ (l + \bar{\nu} l) \]

\[ b \]
where $P^{QCD} = V_{pS} V_{OD}$. This effect is neglected in any calculation of $B^+ VV$ before [12]. In Figure 1, the small virtuality of the photon cannot be cancelled when the neutral vector $V_2$ is transversely polarized. This results in the enhancement of the electroweak penguin in negative-helicity amplitude.

In Table II, we can see this effect obviously where the penguin amplitudes are extracted from the experimental data.

In Table III, the predictions for $B^+ VV$ by $K$ and $K$ by QCD factorization are listed. ($^{C}$ from data” means the penguin of negative-helicity amplitude is extracted from the experimental). One can see that the predictions agree with the experimental data very well. It reproduces the polarization pattern of the penguin-dominated $B^+ VV$ decays as well.

- Table III: QCD factorization predictions for $B^+ VV$ by $K$ and $K$ vs. experimental data.

## Table III: QCD factorization predictions for $B^+ VV$ by $K$ and $K$ vs. experimental data.

| Observable | Theory | Experiment |
|------------|--------|------------|
| $B^{\pm} VV$ | $10^{-5}$ | $10^{-4}$ |
| $K^0$ | $97.7$ | $97.7$ |
| $K^0$ | $97.7$ | $97.7$ |
| $K^0$ | $92.5$ | $92.5$ |
| $K^0$ | $95.9$ | $95.9$ |
| $K^0$ | $90.8$ | $90.8$ |
| $K^0$ | $< 61$ | $< 61$ |
| $K^0$ | $< 61$ | $< 61$ |
| $K^0$ | $50.7$ | $50.7$ |
| $K^0$ | $49.8$ | $49.8$ |
| $K^0$ | $48.8$ | $48.8$ |
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| $K^0$ | $48.8$ | $48.8$ |
| $K^0$ | $48.8$ | $48.8$ |

## Table II: The enhanced electroweak penguin in $B^+ VV$.

| $X$ | $X^*_{\text{with}}$ | $X^*_{\text{without}}$ | Experiment |
|-----|---------------------|------------------------|------------|
| $B^{\pm} VV$ | $10^{-5}$ | $10^{-4}$ | $10^{-4}$ |
| $K^0$ | $50.7$ | $50.7$ | $50.7$ |
| $K^0$ | $49.8$ | $49.8$ | $49.8$ |
| $K^0$ | $48.8$ | $48.8$ | $48.8$ |
| $K^0$ | $48.8$ | $48.8$ | $48.8$ |
| $K^0$ | $48.8$ | $48.8$ | $48.8$ |

## Table I: Leading contributions to $P_{\text{SM}}(V_1 V_2)$ defined in the text.

$B^{+} K^0$ with $P^{QCD}$ without $P^{QCD}$ experiment

$B^{+} VV$ | $10^{-5}$ | $10^{-4}$ | $10^{-4}$ |
|-----|---------------------|------------------------|------------|
| $K^0$ | $50.7$ | $50.7$ | $50.7$ |
| $K^0$ | $49.8$ | $49.8$ | $49.8$ |
| $K^0$ | $48.8$ | $48.8$ | $48.8$ |
| $K^0$ | $48.8$ | $48.8$ | $48.8$ |
| $K^0$ | $48.8$ | $48.8$ | $48.8$ |

## Figure 1: Leading contributions to $P_{\text{SM}}(V_1 V_2)$ defined in the text.

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| $K^0$ | $48.8$ | $48.8$ | $48.8$ |
| $K^0$ | $48.8$ | $48.8$ | $48.8$ |
| $K^0$ | $48.8$ | $48.8$ | $48.8$ |
In the above analysis, BaBar also found another D K resonance X (2690) at m = (2688 ± 4 3 M eV=c² with the decay width = (112 7 36 M eV. Belle confirmed this state D sJ (2700) in B⁺ ! D⁺ K⁺ in which D⁺ K⁺ invariant mass peaks at m = (2715 ± 11 ± 14 M eV=c² with the decay width = 47 7 10 M eV. This could be a radial excitation of D sJ (2317).

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3) X (3940), Y (3940) and Z (3930) (cc mesons):
Belle observed the X (3940) resonance in e⁺ e⁻ ! J= X (3940): m = (3943 6 6 M eV=c² = (15±4 10±1 M eV

X (3940) could be the radially excited charmonium c(3s)[3 1S0].
Belle also found that in B⁺ ! K⁺ , J= ! invariant mass peaks at Y (3940): m = (3943 11 13 M eV=c² = (87 2 26 M eV

Y (3940) could be ⁰ c(3s)[3 3P1].
In D D , D D invariant mass peaks at Z (3930): m = (3929 5 2 M eV=c² = (29 10 2 M eV

Z (3930) could be ⁰ c(3s)[3 3P2].
4) X (3872):
Belle found this resonance in B⁺ ! X (3872)K

J= ! invariant mass peaks at m = (3871±1 0.36 M eV=c² with narrow decay width < 2.3 M eV.

5) Y (4260):
BaBar observed this resonance in e⁺ e⁻ ! ic(J= ) (i for initial state radiated). The J= invariant mass peaks at
m = (4295 \times 10^{-10}) \text{ MeV} = c^2 \text{ with the decay width } = (88 \times 23) \text{ MeV}. \text{ It is con m ed by Belle and CLEO.}

Belle : \quad m = (4295 \times 10^{-10}) \text{ MeV} = c^2 = (133 \pm 13) \text{ MeV}

CLEO : \quad m = (4283 \pm 17) \text{ MeV} = c^2

b-FLAVORED HADRON SPECTRUM

B factories are unable to produce the heavy b-avowed hadrons such as B_s, excited B mesons, and b-baryons. These hadronic states can only be accessible at the hadron colliders.

We collect the recent m easur e ments on the spectr a of b-avowed baryons as the following [13]:

\begin{align*}
\text{m (b)} & = 5619.7 \pm 12 \text{ MeV } \\
\text{m (b)} & = 58152.7^{+1.0}_{-1.2} \pm 1.7 \text{ MeV } \\
\text{m (b)} & = 58075.4^{+1.9}_{-2.2} \pm 1.7 \text{ MeV } \\
\text{m (b)} & = 58367.7^{+2.0}_{-2.3} \pm 1.7 \text{ MeV } \\
\text{m (b)} & = 58292.7^{+1.6}_{-1.7} \pm 1.7 \text{ MeV } \\
\text{m (b)} & = (5774 \pm 11 \pm 15) \text{ MeV }
\end{align*}

The status of the excited L = 1, J^P = 3-2 of B mesons (B_J, B_{2J}) m ass (MeV) are listed in Table IV.

| \text{B}_J | \text{B}_{2J} |
|---|---|
| CDF 5734 | 3 24 |
| D0 5720 | (2.7 5.2 5.9 5.4) |
| B_{2J} | B_{2J} |
| CDF 5829 | 4 0 5839 0 4 0 5 8 5 1 14 15 |

TABLE IV: Excited B meson spectra.

LHC will run in next year, B physics will enter a new era. We can fully explore all the b-avowed hadrons and their decays. Theorists will nd m ore interesting subjects there.

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