

# New Physics Effects in $B$ Decays

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## 1 Introduction

The two  $B$ -factories, Belle [1] and BaBar [2], has been played major roles in the  $B$  decays study. Their wonderful design and excellent operation enables their fruitful analysis results. Also recently the Tevatron experiments, CDF and DO, join the game with their  $B_S$  studies.

From the experimental results of  $B$  decay studies, we learn that most of measurements are consistent with the Standard Model (SM). One needs more precise measurements, which relies on large statistics and good analysis tools, to verify the theoretical predictions. Meanwhile, many unanticipated new particles, like  $X$ ,  $Y$  and  $Z$ 's, are discovered as discussed in J. Brodzicka talk. After all, we still have some small room for the New Physics. Some discrepancies from the SM has been found in the measurements of the phases and magnitudes of CKM unitary triangle [3, 4]. There are also various theoretical models that possibly give the contributions. These will rely on further validation with new experimental results.

## 2 Hints from the experiments

The hints of discrepancies between data and standard model are found in the following topics:

### 2.1 Direct CP Violation

In SM,  $CP$  violation arises via the interference of at least two processes with comparable amplitudes and difference  $CP$  phases [3]. The direct  $CP$  violation (DCPV) of  $B \rightarrow K\pi$  comes from the interference of “Tree” and “Penguin” two major processes, shown in Fig. 1.

One would expect a similar DCPV of  $B^\pm \rightarrow K^\pm\pi^0$  to  $B^0 \rightarrow K^+\pi^-$ . However, from the  $B$ -factories experimental results, the difference is of  $5.2 \sigma$  significance with the world average measurements [5, 6]. This is once called the  $K\pi$  puzzle [7] as the other

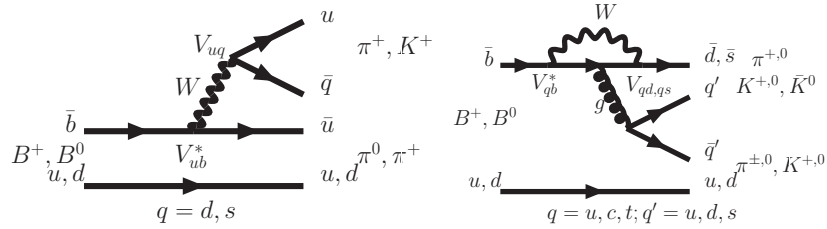


Figure 1: The Feynman diagrams of “Tree” and “Penguin” processes.

contribution processes of  $B \rightarrow K^+\pi^0$ , “Color-suppressed Tree” and “Electroweak Penguin”, are theoretically expected to be small [8]. Several theories suggest ways to enhance these two contributions [9]. However, one needs experimental validations on their predictions. A recent publication on *Nature* has a summary on this issue and this is a non-concluded problem.

## 2.2 Radiative and Electroweak Penguins

The radiative  $b \rightarrow s\gamma$  decays would be the most powerful modes to constrain new physics. The deviation would be seen from their decay rates. Experimentally, there are two methods to perform measurements: fully inclusive and semi-inclusive, which sums up the exclusive channels. Belle recently has an update with fully inclusive method and is the current most precise measurement [10]. From the comparison of experimental world averages with next-next-leading-order (NNLO) calculation [11], we find that the agreements of them has been degraded. The most consist Andersen Gardi calculation has quite large uncertainty. On the other hand, BaBar has a recent update with the semi-inclusive method which sums up 16 fully reconstructed exclusive modes [12]. They also provide a DCPV measurement with  $-0.012 \pm 0.030(stat) \pm 0.019(syst)$ .

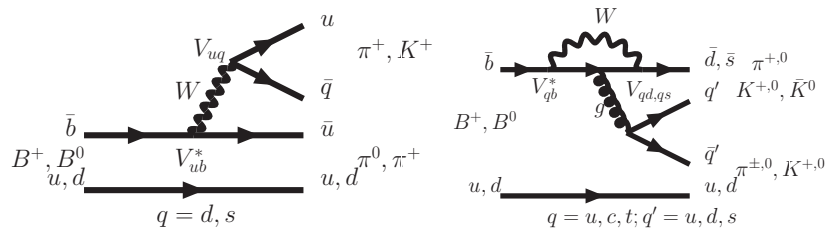


Figure 2: The Feynman diagrams of “Color-suppressed Tree” and “Electroweak Penguin” processes.

### 2.3 Time-dept. CPV in $b \rightarrow s$

The time-dependent  $CP$  violation (TCPV) measures the interference between  $B$  decays into final  $CP$  eigen state and  $B$  mixing into  $\bar{B}$  and decays into the same state. The indirect  $CP$  violation has been established in the  $b \rightarrow c\bar{c}s$  with  $B \rightarrow J/\psi K$  channel [13]. However, the recent results of various  $b \rightarrow sq\bar{q}$  channels shows deviations with a naïve average [14]. Theoretically,  $b \rightarrow sq\bar{q}$  is through “penguin” process and has similar CP values to  $b \rightarrow c\bar{c}s$  process which is of “tree” process. As there is no KM phase in  $V_{ts}$ , one would expect the same mixing induced CP measurement. This deviation would imply some non-SM particles in the loop of penguin process. The possible candidates would be the SUSY particles or the K.K. particles [15] of extra dimension. The current deviation of world average is about  $2.2\sigma$ .

### 2.4 Decays with Large Missing Energy

The leptonic  $B$  decays have sensitivity to new physics from charged Higgs as long as the  $B$  decay constant,  $f_B$  is known. For example the decay of  $B \rightarrow \tau\nu$  can be expressed like this:

$$\mathcal{B}(B^+ \rightarrow \tau^+\nu_\tau) = \frac{G_F^2 m_B}{8\pi} m_\tau^2 \left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

From the experimental point of view, the most sensitivity is from  $\tau$  modes with 1-prong. The study is rather difficult as the interesting  $B$  decays a single charged track and neutrinos which can't be seen. One needs to utilize the information from the other  $B$  pair produced in the same event. The current measurements from Belle and BaBar are a combination of  $f_B \cdot |V_{ub}|$  which is of around 1.5% level of uncertainty in average [16]. The difference between the measurements and HPQCD calculation is within  $1\sigma$  [17].

### 2.5 New results from Tevatrons

The process of  $B_S \rightarrow J/\psi\phi$  studied in the Tevatron experiments is very similar to  $B \rightarrow J/\psi K$  as shown in Fig. 3. However, the CP phase  $\phi_1^{SM}$  (or  $\beta_S^{SM}$ ) is expected to be very small:  $\phi_1^{SM} = \arg(-V_{ts}V_{tb}^*/V_{cs}V_{cb}^*) \sim 0.02$ . Therefore, a non-zero measurement would be a hint of the effect of new physics. Since  $B_S$  is of spin 0 while  $J/\psi$  and  $\phi$  are of spin 1. this leads to three angular momentum states that corresponds to CP even and CP odd states. The large CP violation mixing coefficient seen by CDF and DO indicates hints to new physics [18]. Detailed explanation can be found in S. GIAGU's talk.

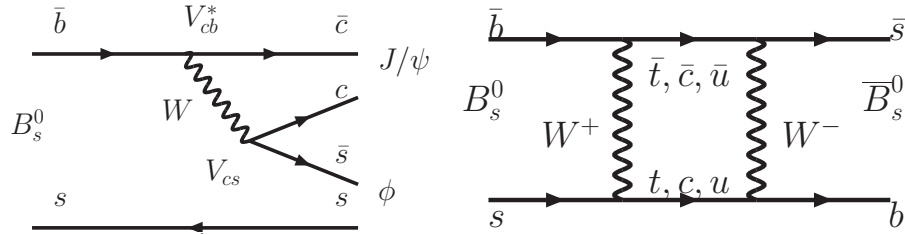


Figure 3: The Feynman diagrams of  $B_S$  mixing processes.

### 3 Summary & Conclusion

The success of  $B$ -factories have brought us many fruitful physical results. We also see some unexpected challenges to the SM. There are various hints to new physics that have been pointed out in the previous paragraphs. It's of no doubt that we still need more statistics to further clarifications. Although the operation of BaBar has come to it's end early this April, people are now proposing upgrades to the present Belle while constructing a new super  $B$ -factory. Of course, we are also looking forward to the up-coming results in the LHC era.

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