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η′ PRODUCTION IN B-MESON DECAYS: THEORETICAL INCONSISTENCY WITH EXPERIMENT VERSUS NEW PHYSICS.

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Abstract: The measured branching ratio by CLEO collaboration at Cornell University in USA for B →η′K decay, with large statistical error, is not consistent with the theoretically predicted values. In this paper we discuss several important theoretical models that were presented before and after the CLEO measurement. The possibility to obtain accurate value of branching ratio and/or to know the reason of this discrepancy in near future are also discussed using the simulation data obtained by using the BELLE detector at KEK in Japan.

Keywords: CP violation, charmless decays, branching ratio, B-meson and B-factory detector.

Introduction

Almost all the phenomena observed in high-energy experiments can be explained by the Standard Model (SM) (Salam, 1968). However, for example, Higgs particle has not been understood yet perfectly. It is stated that the CP violation is one of the three necessary ingredients in explaining that the universe is made of matter, not antimatter (Sakharov, 1967). In order to understand the long-standing puzzle about the origin of CP violation several decay modes of B meson can be studied. Among them B→η′K is one of the presently surprising decay modes in several aspects. Although the presence of hadronic phases complicates extraction of the CP violation parameters, these charmless hadronic decays of B mesons will provide opportunity for direct CP violation to be observed.

Meanwhile the CLEO collaboration has recently observed significantly large branching ratio of 6.5×10^{-5} for the decay channel of $B^{\pm}\rightarrow\eta'K^{\pm}$ (Anderson, 1998). It is therefore, interesting and important to study the origin of the large branching ratio of these decay modes. Many theoretical studies have been made to explain the CLEO data. The presently available experimental data reported by the CLEO collaboration has a large relative statistical error. In order to understand the origin of this large branching ratio it is essentially important to study this branching ratio with much smaller relative statistical error. The BELLE collaboration (experimental group of National Accelerator Research Institute, Japan) is now accumulating the data to study the CP violation in the decay of B meson. Since the branching ratio of the rare decays like B→η′K is very poor (of the order of 10^{-5}) many accumulated events are necessary to study them. After getting the enough luminosity the decay mode B→η′K will be studied by BELLE collaboration. Similar studies will be made also by BABAR (BABAR collaboration, 1991) and CLEO collaborations (Anderson, 1997). However, at present almost all the theoretical models have a large theoretical uncertainty and it is difficult to understand whether any or all of these theoretical models is consistent with the experimental data reported by the CLEO collaboration.

In order to study the feasibility of the measurement of the branching ratio with smaller relative statistical error than that presently available and also the feasibility of the measurement of the direct CP violation, a Monte-Carlo simulation study has been carried out for B→η′K decay channel using the BELLE detector (Khan, 1999). In this paper some relevant theoretical studies including those of CLEO measurements and the simulated data for the BELLE detector has been reviewed.

Theoretical Prediction of the Branching Ratio

Motivated by the measurement of the large branching ratio of B→η′K many theoretical studies has been made within the standard model to explain the discrepancy between the theory and the experiment. In the following some of the theoretical prediction for B→η′K is described.

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Du and Guo (1997) suggested the mechanism of electroweak penguine effects in Charmless $B^{\pm,0} \rightarrow$ PP (PV) decays within the standard model. They showed that for some channels, the electroweak penguine effects could enhance or reduce the QCD penguine and/or tree level contributions by at least 30%, and can play a dominant role. The predicted branching ratio for $B \rightarrow \eta' K$ is 1.88×10^{-5}.

Halperin and Zhitnitsky (1997) proposed that at the quark level the $B \rightarrow \eta' K$ decay process proceeds via the $b \rightarrow ccs$ weak decay followed by a conversion of the c-quark pair directly into the η'. They evaluated this non-perturbative "intrinsic charm" content of the η' using the operator product expansion and QCD low energy theorems and argued that the calculated branching ratio is consistent with the CLEO measurement.

Cheng and Tseng (1997) proposed that the unexpectedly large branching ratio of $B^{\pm} \rightarrow \eta' K^{\pm}$ measured by the CLEO can be explained by the Cabibbo-allowed internal W emission process $b \rightarrow ccs$, $cc \rightarrow \eta'$ followed by a conversion of the cc pair into η' via gluon exchange. They obtained a branching ratio based on this mechanism for $B^{\pm} \rightarrow \eta' K^{\pm} = (5.8\text{-}6.7)\times10^{-5}$.

Ali *et al.* (1998) proposed a mechanism of the contribution of $b \rightarrow S$ (g-g) through the QCD anomaly in the exclusive $B^{\pm} \rightarrow (\eta'\eta)$ $(K^{\pm}, K^{*\pm})$ and $B^{o} \rightarrow (\eta',\eta)$ (K^{o}, K^{*o}). The mechanism is based on calculation of the amplitude for the chromomagnetic penguin process $b \rightarrow S$ (g-g) followed by the transition g-g$\rightarrow(\eta',\eta)$. The predicted theoretical branching ratio for $B^{\pm} \rightarrow \eta' K^{\pm}$ is $(2\text{-}4)\times10^{-5}$.

Ahmedy *et al.* (1998) proposed a non spectator model for the $B^{\pm} \rightarrow \eta' K^{\pm}$ process in which η' is produced via fusion of the gluon from the QCD penguin diagram $b \rightarrow Sg^{*}$ and another one emitted by the light quark inside the B meson. This mechanism is shown in Fig. -1 where the two gluons fused via QCD anomaly and form η'. The predicted value for the branching ratio for $B^{\pm} \rightarrow \eta' K^{\pm}$ is 7.0 ± 10^{-5} and was argued to consistent with the experimental value of the CLEO.

Datta *et al.* (1998) reported a model based on the effective Hamiltonian of four quark operators in the SM in the exclusive and quasi-inclusive decays. Working in the factorization assumption they found that the four quark operators can be accounted for the recently measured exclusive decay $B \rightarrow \eta'(\eta)K$ for appropriate choice of the form factors. The predicted branching ratio for $B \rightarrow \eta' K$ is $(5.33\text{-}7.83)\times10^{-5}$.

A perturbative QCD calculation was carried out by Ali and Greub (1998) in which they proposed that the decay mode $B \rightarrow (\eta',\eta)$ $(K^{\pm}, K^{*\pm})$ have an extra contribution from the decay chain $b \rightarrow Sc\text{-}c \rightarrow S$ (η,η'). The calculated branching ratio for $B^{\pm} \rightarrow \eta' K^{\pm}$ is $(2\text{-}4)\times10^{-5}$ and they argued that the existing data for $B^{\pm} \rightarrow \eta' K^{\pm}$ could be explained by this approach.

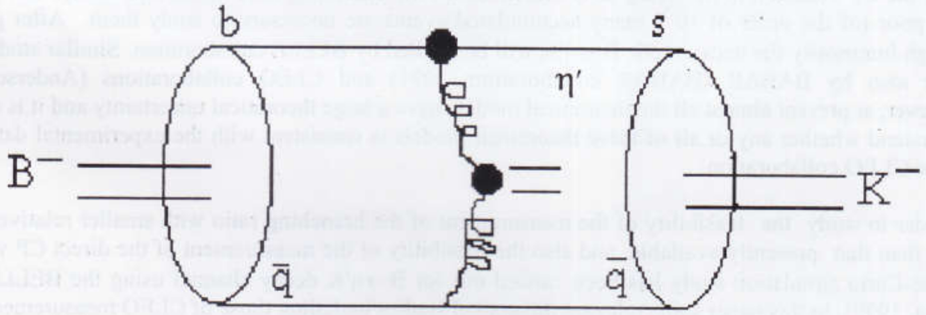

Fig. -1. The non-spectator model for the $B \rightarrow \eta' K$ process. The η' is produced via fusion of two gluon.

He *et al.* (1998) suggested that the unexpected large branching ratios for $B \rightarrow \eta' K$ $(\eta' X_s)$ decays can be explained by the gluonic origin. They studied the implications for the gluonic origins $B \rightarrow \eta K$ $(\eta' X_s)$ & $B \rightarrow PK$ (PX_s), where P is the psedoscalar glue-ball. The predicted branching ratio for $B \rightarrow \eta' K$ is $(1.2\text{-}3.2)\times10^{-5}$. In Table 1 all of these theoretical studies and the reported branching ratio are summarized.

Table 1. Theoretical values of the branching ratio for B→η′K.

Study / Model	*Branching ratio × (10^5)*
1. Enhancement of electroweak penguin effect	1.88
2. Contribution of "intrinsic charm" content	*
3. Conversion of cc pair into η′ via gluon exchange	(5.8-6.7)
4. Fusion of the gluon from the QCD penguin	7.0
5. Contribution of b→S(g-g) through QCD anomaly	(2-4)
6. Model based on the effective Hamiltonian of four quark operator.	(5.33-7.83)
7. Perturbative QCD calculations and extra contribution from the decay chain of b→S(c-c)→S(η,η′)	(2-4)
8. Implications of the gluconic origin.	(1.2-3.2)

*The authors argued that their calculated values agree with the experimental data.

B-Factory Detectors and Future Prospect on the Experimental Study on B→η′K

In order to study the long standing puzzle about the origin of the CP violation several B factories have been proposed and are being constructed around the world (BELLE collaboration, 1994; Anderson, 1997, BABAR Collaboration, 1991), where large numbers ($\sim 10^{7-8}$/year) of B meson decays will be studied. At KEK (national accelerator research organization) in Japan such an e^+e^- asymmetric collider referred to as "KEK B-Factory" is now under operation (data taking is going on) which will produce about 10^8 B meson/year. Fig.-2 shows the side view of the BELLE detector. The details of the BELLE detector can be obtained from any of the BELLE memoranda (e.g. BELLE collaboration, 1994; Khan, 1999; Suda, 1998). After getting enough luminosity (about 40 fb^{-1}) the decay chain B→η′K will be possible to study experimentally.

A Monte-Carlo simulation study was made on the decay channels of $B^\pm \to \eta' K^\pm$ (Khan, 1999) using the BELLE detector and a Fast simulator (FSIM) version 5.2 (Ozaki, 1996). The FSIM is a simulation tool for the BELLE detector in which the detector response is modeled with simple parameterization. In this section the a brief description of the simulation study, its results and future prospects are described.

In the present analysis the BELLE QQ98 event generator (Itho, 1995) in which the latest experimental results from CLEO-II are installed was used. Using this generator the two-body charmless hadronic decay events were generated and the following three different data sets corresponding to 100 fb^{-1} were prepared for the FSIM analysis.

The first data set consists of the decay mode B→η′K where one B meson decays into $\eta' \to \eta\pi^+\pi^-$ followed by $\eta \to \gamma\gamma$ and the other partner B decays through the standard decay mode. This data set contains 1340 generated events.
The second data set corresponds to the background events from the standard decays of both B mesons from ϒ(4S). This data set contains 1.2×10^8 generated events.
The third data set contains continuum background events, which don't form the ϒ(4S) resonance. For the continuum background estimation of the present study 3.5×10^8 continuum background events were generated.

The cross-section for the production of ϒ(4S) and qq pair are taken to be 1.2 nb and 3.5 nb, respectively. We assume ϒ(4S) decays into B^+B^- and B^0B^0 with an equal probability. In this study the branching ratio for the decay mode $B^\pm \to \eta' K^\pm$ is supposed to be 6.5×10^{-5} which is exactly the same as CLEO measurement. These data sets were subsequently passed through the BELLE fast simulator version 5.2 (Ozaki, 1996) using the latest information on the acceptances and performances of the BELLE detector. The information from all the sub-detectors (CDC, ACC, TOF and ECL) was used in the present analysis. After all the measured quantities (e.g. track momentum, energy, etc) were transformed into those in the CM frame of the B^+B^- pair the analysis was performed.

It has been found from the simple cut analysis method that the BELLE detector can detect the process $B^\pm \to \eta' K^\pm$ ($\eta' \to \eta\pi^+\pi^-$ followed by $\eta \to \gamma\gamma$) with an efficiency of 31.9%. If the CP asymmetry is as large as 20%, 3σ asymmetry can be observed at an integrated luminosity of ~34 fb^{-1} for this decay channel (Khan, 1999).

The relative statistical error of the branching ratio measurement at an integrated luminosity of 10 fb^{-1} is estimated to be 11.2 % (Khan, 1999). But the CLEO data comprises a relative statistical error of about 23 %. Therefore, it is expected that the BELLE detector will detect the process with much smaller relative statistical error than the CLEO ones.

From this simulation study, it is expected that, at an integrated luminosity of about 35-40 fb^{-1} in the BELLE, we will get much accurate information for the branching ratio and CP violation for the decay process of $B^{\pm} \to \eta' K^{\pm}$. Therefore, after accumulation of the enough events (corresponds to 35-40 fb^{-1}), one can expect some new physics when the branching ratio are still significantly large compared to the theoretical predictions. To explain this predicted branching ratio data, some one may cross the border of the Standard Model of high energy physics.

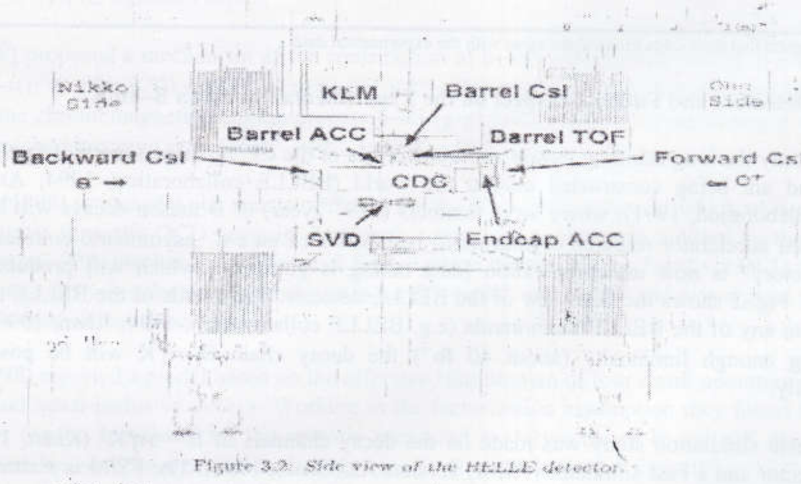

Fig. -2. Side view of the BELLE detector at KEK in Japan. The decay of B-mesons is now being studied using this detector.

Conclusion

At present it is not straight forward nor clear whether any or all of the presently available theoretical concepts and hypothesis can explain properly the CLEO data for the branching ratio measurement of $B^{\pm} \to \eta' K^{\pm}$ decay mode. Most of the theoretical studies are logical enough to accept them even though some of them have large theoretical uncertainty. It is also not clear whether one needs to find some new physics out of the Standard Model to explain the decay process properly. In the near future, the B-factory detectors such as BELLE detector will allow us to study this type of important rare decays thoroughly. Also the CP puzzle may be solved through this type of rare hadronic decays.

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