PROCEEDINGS OF SCIENCE

$\mathbf{B \to K^{(*)}\ell\ell}$ (and $\mathbf{B \to X_s\gamma}$) measurements at Belle

S. Watanuki*
Laboratoire de l'accélérateur linéaire, Orsay 91440
E-mail: watanuki@lal.in2p3.fr

We report on recent measurements of flavor-changing-neutral-current $b \to s$ transitions at Belle experiment. Lepton universality tests using $B \to K^{(*)} l^+ l^-$ and measurements of the CP asymmetry difference (ΔA_{CP}) and isospin asymmetry (Δ_{0-}) using sum of exclusive $B \to X_s \gamma$ are reviewed. All of the measurements are performed on the full $711 fb^{-1}$ data sample recorded by the Belle experiment at the $\Upsilon(4S)$ resonance.

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*Speaker.

1. Introduction

Flavor-changing-neutral-current (FCNC) such as $b \to s$ transition are very impotant mode for new physics (NP) indirect search. They are significantly suppressed in the standard model (SM) due to GIM mechanism and therefore any deviations from SM (branching ratios, CP asymmetries, ...) of these FCNC are very sensitive to NP effects.

Recently LHCb reported a deviation of 2.5σ in $B^+ \to K^+l^+l^-$ mode and 2.1-2.3σ (2.4-2.5σ) for lower-q^2 (higher-q^2) region in $B^0 \to K^{*0}l^+l^-$ mode for lepton flavor universality test, denoted as $R_{K^{(*)}}$ [1][2][3]. This observable is defined as the ratio between branching fractions with $l = e$ and $l = \mu$ modes. We report on the updated measurements of $R_{K^{(*)}}$ using the full data set of the Belle experiment recorded at the $\Upsilon(4S)$ resonance[5][6]. In addition, isospin asymmetry (A_I) is reported with $B \to Kl^+l^-$ mode.

Radiative mode $b \to s\gamma$ allows for precise measurements because of its higher statistics. Thanks to the clean environment of a B factory, it is possible to measure this decay any mode with a semi-inclusive method (denoted as $B \to X_s\gamma$), where as many final states of the s quark hadronization (X_s) are reconstructed as possible. This reduces the uncertainty due to the form factor. We report on measurements of two observables: CP asymmetry difference (ΔA_{CP}) between B^+ and B^0, and isospin asymmetry (Δ_{0-})[7].

2. Measurements of $B \to K^*ll$

As described in the previous section, $R_{K^{(*)}}$ measured by Belle full data set is crucial to verify the consistency with the recent LHCb measurements. $B \to K^*l^+l^-$ is reconstructed with 4 K^* decay modes: $K^+\pi^0$, $K_s^0\pi^+$, $K^+\pi^-$, and $K_s^0\pi^0$. There are various sources of background: $q\bar{q}$ continuum background, $B\bar{B}$ combinatorial background, peaking background, and cross-feed (miss reconstructed signal) background. Charmonium veto is applied for q^2 regions of J/ψ and $\psi(2S)$, where q^2 is defined as the invariant mass squared of the di-lepton system. Continuum and combinatorial background is suppressed with Neural Network (NN) calculated in the hierarchical structure; 1st stage NN is calculated based on information on final states particles ($l^\pm$, $K^\pm$, and $\pi^\pm$), and the 2nd stage (K^*) and the final stage (B) are calculated using outputs from previous stages. Peaking and cross-feed background are treated as systematic uncertainty.

Fitting is performed on the beam constrained mass (M_{bc}) to extract the number of signal events (figure 1). The results of the R_{K^*} measurements are shown in figure 2. Main systematic uncertainty arises from lepton selection efficiency uncertainty caused by correction for lepton identification. It is consistent with SM as well as with the LHCb [1] and the BaBar [4] measurements.

3. Measurements of $B \to Kll$

The reconstructed modes in this measurements are $K^\pm ll$ and K_sll. The selection criteria is optimized for Kll mode.

A NN is trained to suppress continuum and combinatorial background. The main input parameters for NN are Fox-Wolfram moments, B flight direction θ_B, and the angle between the

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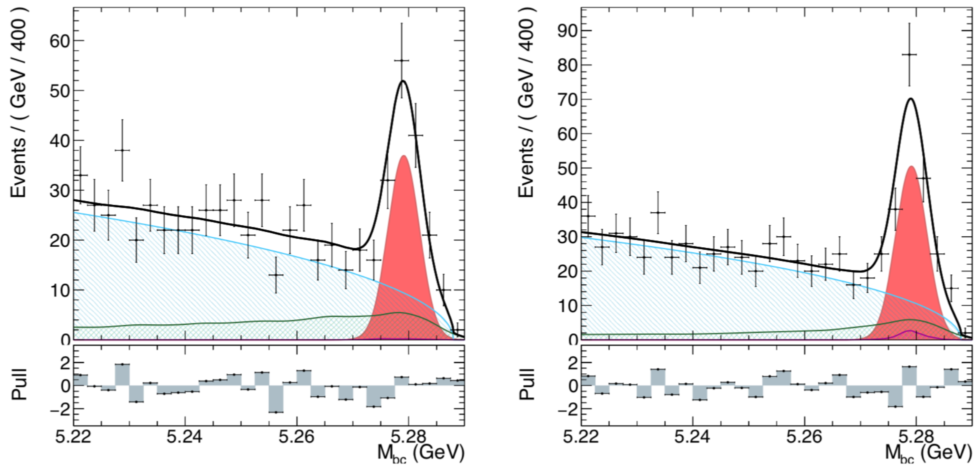

Figure 1: M_{bc} fitting for R_{K^*} study. $B^+ \to K^{*+}ll$(left) and $B^0 \to K^{*0}ll$(right).

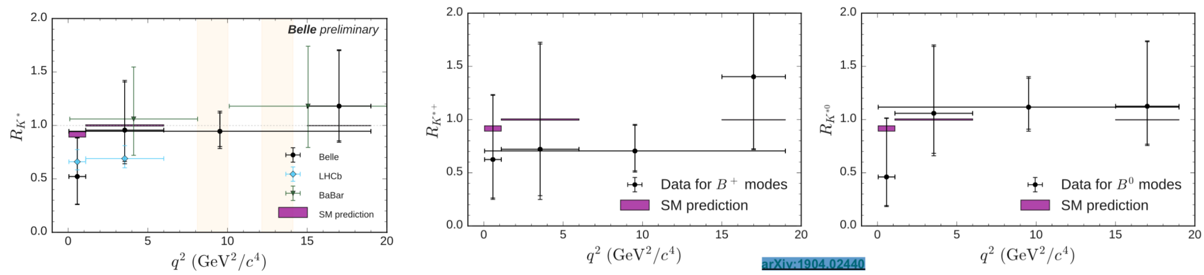

Figure 2: R_{K^*} results. All decay modes with K^*'s mode (left) and charged/neutral B separated (center and right).

thrust axis of B meson final state and rest of event. The NN output ($\mathcal{O}$) is transformed according to $\mathcal{O}' = log[\frac{\mathcal{O}-\mathcal{O}_{min}}{\mathcal{O}_{max}-\mathcal{O}}]$ for easier distribution modeling. In order to suppress the background from $B^- \to D^0\pi^+\pi^-$, which leads to a peak in the signal region because of double misidentification, D veto is applied; $M[K^+\mu^-] \notin (1.85, 1.88)\, GeV/c^2$. J/ψ veto is applied for $B \to J/\psi K$ background. Additional J/ψ veto is applied to suppress $B^- \to K^- J/\psi(\mu^+\mu^-)$ with double misidentification ($K^- \to \mu^-$, $\mu^- \to K^-$); $M[K^-\mu^+] \notin (3.06, 3.13)\, GeV/c^2$.

To extract the number of signal events, simultaneous fit is performed to M_{bc}, ΔE, and $\mathcal{O}'$ distributions (figure3). The measurement results are shown in figure 4. They are consistent with both SM and LHCb measurement. Since the statistical uncertainty is dominant, measurement with BelleII will be very interesting.

Figure 5 shows the results of A_I measurement. A deviation from 0 by 2.7σ is observed for $B \to K\mu^+\mu^-$ in $q^2\,(1.0, 6.0)\, GeV^2/c^4$.

4. Measurements of $B \to X_s\gamma$

Radiative FCNC decay $b \to s\gamma$ is dominated by a loop diagram, and is hence sensitive to NP which appears in the loop; examples include chargino ($\tilde{\chi}$) and scalar top ($\tilde{t}$) exchange in SUSY,

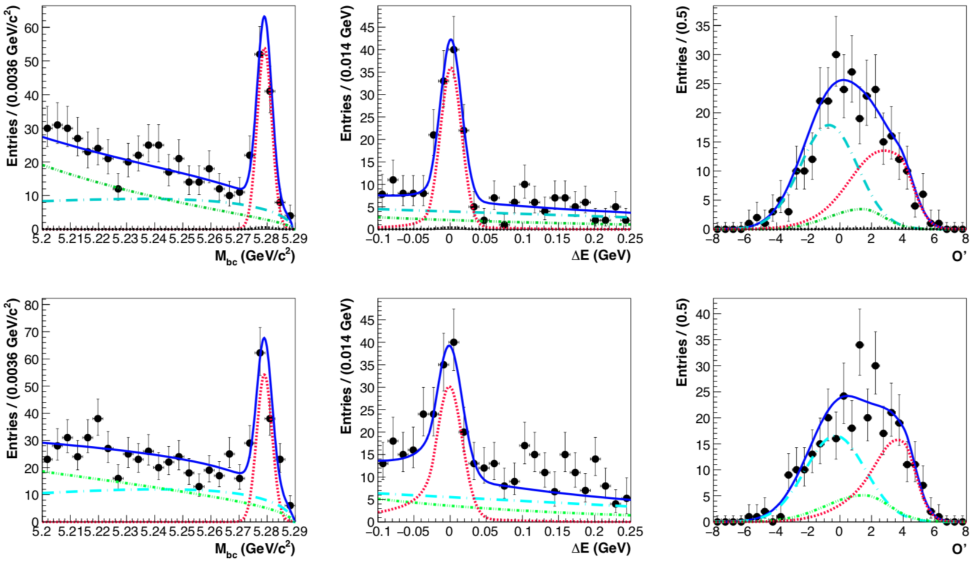

Figure 3: M_{bc}, ΔE, and $\mathcal{O}'$ fitting for R_K study. $B^+ \to K^+\mu\mu$ (top) and $B^+ \to K^+ee$ (bottom).

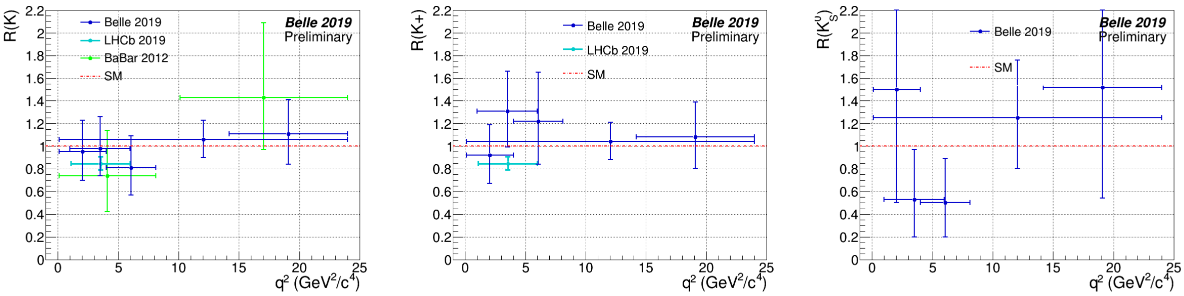

Figure 4: R_K results. All decay modes with K (left) and charged/neutral B separated (center and right).

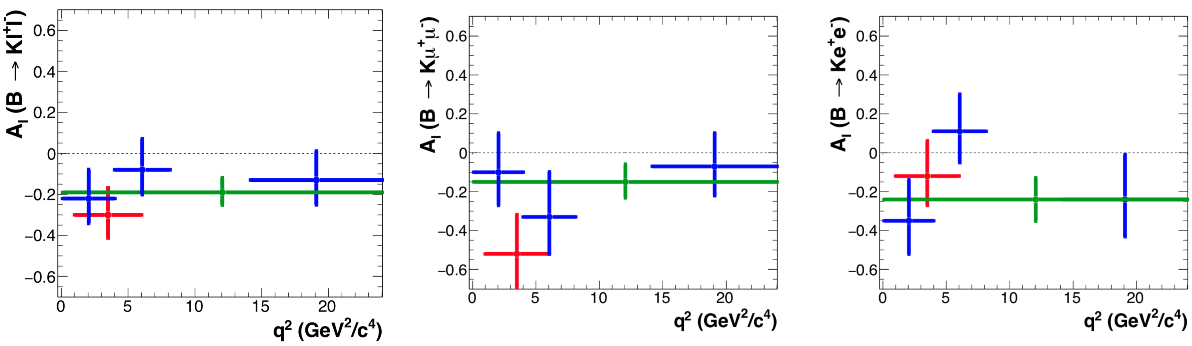

Figure 5: A_I results. All decay modes with K (left) and $\mu\mu$/ee separated (center and right).

charged Higgs ($H^{\pm}$) exchange in 2HDM, and others. The branching fraction of semi-inclusive $B \to X_s\gamma$ provides a strong upper limit for type II 2HDM charged Higgs boson mass [16]. Current measurements [17][18][19][20][21] are consistent with SM prediction [15].

Belle II experiment will allow us to achieve a higher sensitivity on the branching fraction. In current situation, however, theoretical uncertainty is comparable to the statistical one. Therefore the reduction of theoretical uncertainty is an essential task for the measurement at Belle II. The dominant source of theoretical uncertainty comes from the long distance effects caused by the interference between electroweek penguin (O_7) and chromomagnetic penguin (O_8). The study [14] shows that this kind of uncertainty can be written by the form proportional to the isospin asymmetry (Δ_{0-}) of $b \to s\gamma$; if Δ_{0-} is close to zero, the uncertainty can be safely assumed to be negligible.

We also report on the measurement of CP asymmetry difference between the charged and the neutral mode in $B \to X_s\gamma$ (ΔA_{CP}). According to the study [8], CP asymmetry in $b \to s\gamma$ has a large uncertainty caused by the same source as explained above. Since the uncertainty is common between the charged and the neutral mode, it cancels in the difference between the two. In general beyond the SM, ΔA_{CP} can be written in the form propotional to the imaginary part of the ratio between C_7 and C_8, which should be zero in the SM. Thus the measurement of ΔA_{CP} provides a precise test of the SM. A non-zero ΔA_{CP} can be expected in several NP models such as [9], which is suggested to explain also a recent 2.8σ deviation in $\varepsilon'/\varepsilon_K$ [10][11][12][13].

BaBar measured the ΔA_{CP} [22] and Δ_{0-} [23]. ΔA_{CP} is consistent with the SM prediction (0). Δ_{0-} is consistent with 0, but the measurement has been performed on a part of the available data only.

In this analysis, 38 X_s final states are reconstructed: $Kn\pi$ with $n = 1 \sim 4$, 3K modes, and η modes. Since un-flavored neutral particles (π^0 and η) lead to a large uncertainty, two particles are allowed in the final states at most. Main background from $q\bar{q}$ events is rejected using a Neural Network output trained by a high statistics MC sample. Combinatorial $B\bar{B}$ background is rejected using a D mass veto for any combination of reconstructed X_s children. The remaining peaking background is estimated by the sideband region of π^0 probability distribution, calculated using the primary photon of $X_s\gamma$.

Individual X_s decay fractions in signal MC are adjusted to real data sample. At first fractions of reconstructed 38 modes are calculated by M_{bc} distribution fits. X_s mass distribution is treated using the Kagan-Neubert model [24].

ΔA_{CP} and Δ_{0-} are calculated from simultaneous fits to M_{bc} distributions, divided for five decay types: B^+, B^-, B^0, $\bar{B}^0$, and B^0_{fns} (figure 6). The latter type is defined as flavor non-specific mode such as $K^0_s\pi^0\gamma$. Off-resonance data sample is also included in fitting to determine the background shape parameter.

The results of measurements are:

- $\Delta A_{CP} = (3.69 \pm 2.65 \pm 0.76)\,\%$
- $\Delta_{0-} = (-0.48 \pm 1.49 \pm 0.97 \pm 1.15)\,\%$

where the first and the second error are statistical and systematic uncertainty, respectively. For Δ_{0-}, the third error corresponds to the uncertainty of f_{+-}/f_{00}. Both measurements are the most precise determinations of these variables so far. The ΔA_{CP} measurement provides a constraint

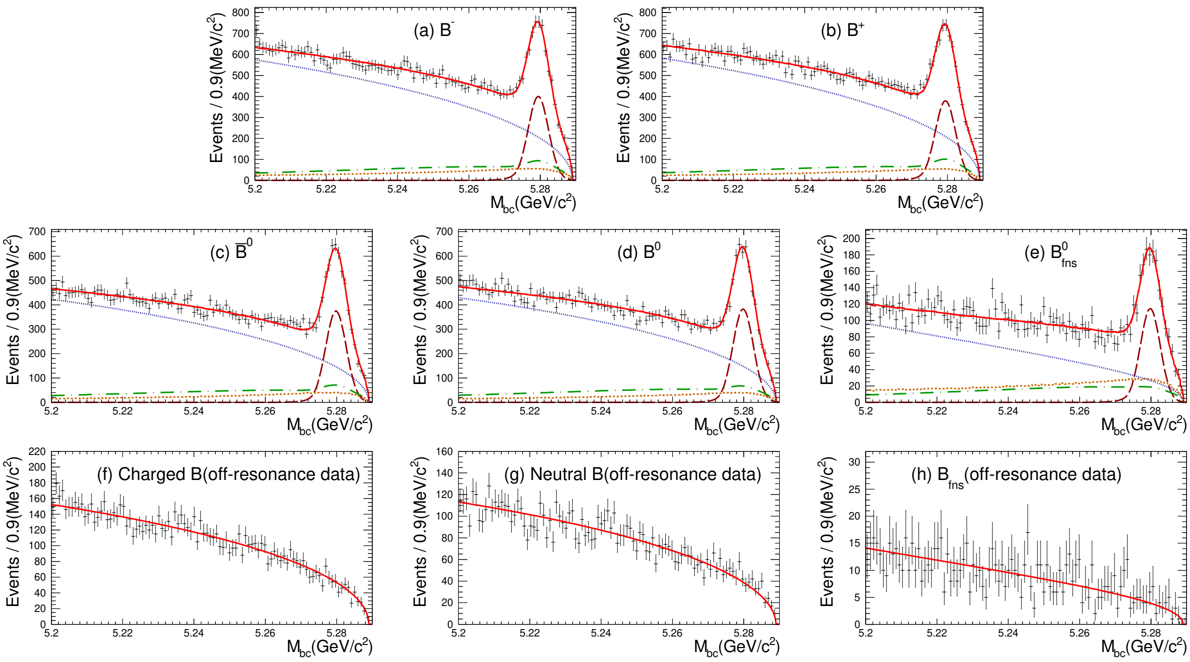

Figure 6: M_{bc} fits for $B \to X_s\gamma$ study.

on $Im\,(C_8/C_7)$ versus the hadronic parameter $\tilde{\Lambda}_{78}$ described in [8] (figure 7). On the other hand,

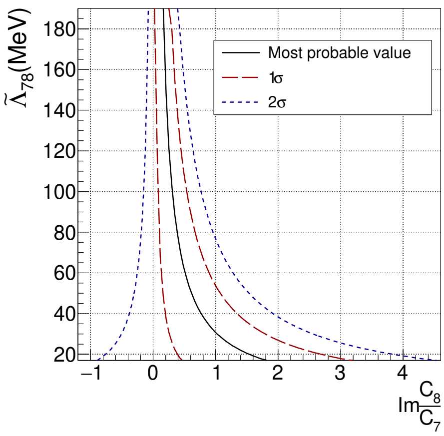

Figure 7: Constraint on $Im\,(C_8/C_7)$

the Δ_{0-} measurement provides an upper limit on the theoretical uncertainty for the $BR\,(B \to X_s\gamma)$, arising from the interference between C_7 and C_8. The uncertainty is 1.45% and no longer represents the dominant uncertainty contribution.

5. Summary

Measurements of FCNC transition $b \to s\gamma$ are of great importance in the search of beyond the

SM physics because NP effect can be comparably significant for loop diagram. Recently lepton flavor universality tests in $B \to K^{(*)}ll$ were reported using the Belle full data sample [5][6]. The results are consistent with both, the SM prediction and previous measurements by LHCb and BaBar. Isospin asymmetry is also reported in [6] and a deviation from 0 is seen; $A_I(B \to K\mu^+\mu^-)$ in $q^2\,(1.0, 6.0)\,GeV^2/c^4$ deviates from 0 by 2.7σ. On the other hand, CP asymmetry difference ΔA_{CP} and isospin asymmetry Δ_{0-} are measured with sum of exclusive $B \to X_s\gamma$ decays [7]. ΔA_{CP} is consistent with both, the SM prediction (0) and BaBar measurements, and provides the constraint on $Im(C_8/C_7)$. Δ_{0-} is consistent with 0 within a high accuracy, which indicates that theoretical uncertainty on the branching ratio of $B \to X_s\gamma$ caused by the interference between O_7 and O_8 can be treated as small.

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