$B \to X_s \ell^+ \ell^-$ at Belle

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1 Introduction

The electroweak penguin mediated $B \to X_s \ell^+ \ell^-$ decay is a good probe to study beyond the Standard Model physics at low energy. The effect of new physics could be observed as corrections to the branching fraction, di-lepton invariant mass spectrum, and to the Wilson coefficients such as C_9, C_{10}, and a phase of C_7 [1-10]. Experimentally, the exclusive $B \to K \ell^+ \ell^-$ decay was observed by the Belle collaboration for the first time [11] and has also recently confirmed by the BABAR collaboration [12]. We present here a preliminary result on a search for the inclusive $B \to X_s \ell^+ \ell^-$ decay, which can be calculated more reliably than exclusive decay modes.

2 Analysis

The data sample used in this analysis consists of 43 fb^{-1} of e^+e^- collisions at the $\Upsilon(4S)$ resonance collected by the Belle detector [13] at the KEKB storage ring.

The signal is identified as $X_s \ell^+ \ell^-$, where X_s is defined to be a $K^\pm$ or K_S accompanying 0 to 4 pions including one π^0 at most, and $\ell^+ \ell^-$ is an oppositely charged electron or muon pair. Charged tracks are required to originate from the interaction point and be well identified by the Belle particle identification devices. Electrons are identified using the ratio between the energy deposited in the electromagnetic calorimeter and the measured track momentum(E/p). Electrons are required to have momenta above 0.5 GeV/c. Muon candidates are required to reach the iron flux return and have momenta greater than 1.0 GeV/c. The muon identification efficiency is about 80 to 85 % with a fake rate of 1 to 2 %. Charged hadrons are identified by the combined response of aerogel counters, time of flight, and dE/dx measured in the drift chamber. For charged kaons, we have an efficiency of 85 to 90% and a pion fake rate that is less than 10%. Candidate π^0's are identified from pairs of photons with energy deposits of at least 50 MeV and an invariant mass within 10 MeV/c^2 of the nominal π^0 mass.

Events with leptons from charmonia, such as J/ψ and ψ' are vetoed if the dilepton mass lies around the nominal charmonia masses.

Background from $q\bar{q}$ continuum events is suppressed by requiring the ratio of the second to zeroth Fox-Wolfram moments $R_2 \equiv H_2/H_0 < 0.35$ and $|\cos\theta_{thrust}| < 0.85$, where θ_{thrust} is the angle between the thrust axis of the B candidate and that of the rest of the event. The $|\cos\theta_{thrust}|$ distribution of continuum events peaks at 1 while that of signal events is flat.

To reduce backgrounds further and select the best candidate in an event, we introduce four kinematic variables: the angles between the K and $\ell^+(\theta_{K\ell^+})$, and the K and $\ell^-(\theta_{K\ell^-})$, the B flight direction(θ_B), and the energy difference($\Delta E = E_B - E_{beam}$). If the K meson and $\ell^+\ell^-$ pair originated from a photon or Z boson; since these are emitted in opposite directions, the sum of $\cos\theta_{K\ell^+}$ and $\cos\theta_{K\ell^-}$ should be negative for the signal. The polar angle of B flight direction has a $1-\cos^2\theta_B$ distribution while background is flat. The signal ΔE distribution peaks at zero.

A likelihood ratio LR is determined by parameterizing distributions of three kinematic variables with Monte Carlo simulation for both the signal and background. It is expressed as $LR = p_{sig}/(p_{sig} + p_{BG})$, where p_{sig} and p_{BG} are probability density functions for the signal and background distributions, respectively. An LR selection requirement is chosen to maximize the figure of merit $S/\sqrt{S+N}$ in the signal region where S is the expected signal yield assuming the SM prediction and N is the number of expected background events.

The invariant mass of the X_s must satisfy $M_{X_s} < 2.1$ GeV/c^2 in order to reject combinatorial background.

After the application of all selection requirements, the reconstruction efficiencies are estimated by Monte Carlo simulation based on the inclusive model in the recent paper by Ali *et al.*,[1] and based on the exclusive $B \to K\ell^+\ell^-$ and $B \to K^*\ell^+\ell^-$ model by Greub *et al.*,[2]. The nominal reconstruction efficiencies are determined to be 3.6 % for $B \to X_s e^+e^-$ and 3.8 % for $B \to X_s\mu^+\mu^-$.

Most of the background is combinatorial background from B and D decays. The background is determined by fitting the distribution of beam constrained mass M_{bc}. The beam constrained mass is expressed as $M_{bc} = \sqrt{(E_{beam})^2 - (p_B)^2}$, where p_B is the B candidate's center-of-mass momentum vector and E_{beam} is the center-of-mass energy of B meson, respectively. In this distribution, the signal peaks at the B meson mass and is fitted by a Gaussian function while the combinatorial background is parameterized by a phase space function with a kinematic threshold (the ARGUS function).

Background from $B \to X_s\pi^+\pi^-$ decay can make a small contribution to the signal peak in the M_{bc} distribution when both the π^+ and π^- are misidentified as muons. The muon misidentification rate is determined to be 1 to 2 % in the laboratory momentum range $p_\mu > 1.0$GeV/c. To estimate the contamination in the signal region, a $B \to X_s\pi^+\pi^-$ sample is selected by applying all the signal selection requirements except for the muon identification. The yield is multiplied by the momentum dependent fake rate for each pion. This $B \to X_s \pi^+ \pi^-$ background is estimated to be 2.4 events and subtracted from the yield of the signal fit.

3 Results and discussion

Figure 1 shows the M_{bc} distribution for $B \to X_s e^+ e^-$, $B \to X_s \mu^+ \mu^-$, and for the combined $B \to X_s \ell^+ \ell^-$ samples, respectively. The $B \to X_s e^\pm \mu^\mp$ sample is used to check the background parameterization. The fit results, signal yields, branching fractions, and statistical significances are shown in Table 1.

Systematic uncertainties in this measurement are listed in Table 2. The largest contribution to the systematic uncertainty is the decay modeling for $B \to X_s e^+ e^-$ and $B \to X_s \mu^+ \mu^-$ decays.

We measure the inclusive $B \to X_s \ell^+ \ell^-$ decay branching fraction for the first time with a statistical significance of greater than 4σ. Preliminary results for branching fractions are $\mathcal{B}(B \to X_s \mu^+ \mu^-) = (8.9^{+2.3+1.6}_{-2.1-1.7}) \times 10^{-6}$ and $\mathcal{B}(B \to X_s \ell^+ \ell^-) = (7.1^{+1.6+1.4}_{-1.6-1.2}) \times 10^{-6}$, where the first error is statistical and the second is systematic.

The branching fractions and upper limits determined by this study agree well with theoretical predictions in the SM framework. We expect that both the theoretical and experimental errors will decrease so that theories based on SM can be tested with precision measurements in the near future.

The M_{X_s} and dilepton invariant mass plots are shown in Figures 2 and 3, respectively. The M_{X_s} distribution extends beyond the K and K^* mass region. The dips around $3.1\text{GeV}/c^2$ and $3.7\text{GeV}/c^2$ in the $M_{\ell\ell}$ distribution are due to J/ψ and ψ' vetoes. The experimental and theoretical uncertainties are expected to improve as more data is accumulated. Precision measurements can be done for SM and beyond SM predictions.

In summary, evidence for the inclusive $B \to X_s \ell^+ \ell^-$ decay has been presented for the first time. The experimental and theoretical uncertainties are expected to decrease with time. Precision measurements can be done in near future that test the Standard Model and Beyond the Standard Model predictions.

References

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Mode	#signal	B.F.($\times 10^{-6}$)	Signif.
$X_s e^+e^-$	$16.6^{+8.0+3.9}_{-7.3-3.8}$	< 11.0	2.1
$X_s \mu^+\mu^-$	$30.7^{+7.9+5.4}_{-7.4-3.8}$	$8.9^{+2.3+1.6}_{-2.1-1.7}$	4.4
$X_s \ell^+\ell^-$	$47.6^{+11.0+9.6}_{-10.4-8.0}$	$7.1^{+1.6+1.4}_{-1.6-1.2}$	4.8

Table 1: Preliminary results for $B \to X_s e^+e^-$, $X_s\mu^+\mu^-$, and combined $X_s\ell^+\ell^-$. Significance is extracted from the statistical error only. Only a 90% confidence level upper limit is shown for the $B \to X_s e^+e^-$ process.

Source	$X_s e^+e^-$	$X_s \mu^+\mu^-$
Tracking	8.1 %	8.0 %
Kaon ID	1.9 %	2.0 %
Pion ID	0.8 %	0.8 %
Lepton ID	3.6 %	4.4 %
K_S detection	2.1 %	1.5 %
π^0 detection	2.0 %	1.6 %
MC stat.	3.9 %	4.1 %
Decay model	$^{+14\%}_{-9\%}$	$^{+16\%}_{-12\%}$
Total	$^{+18\%}_{-14\%}$	$^{+19\%}_{-16\%}$

Table 2: Systematic uncertainty summary.

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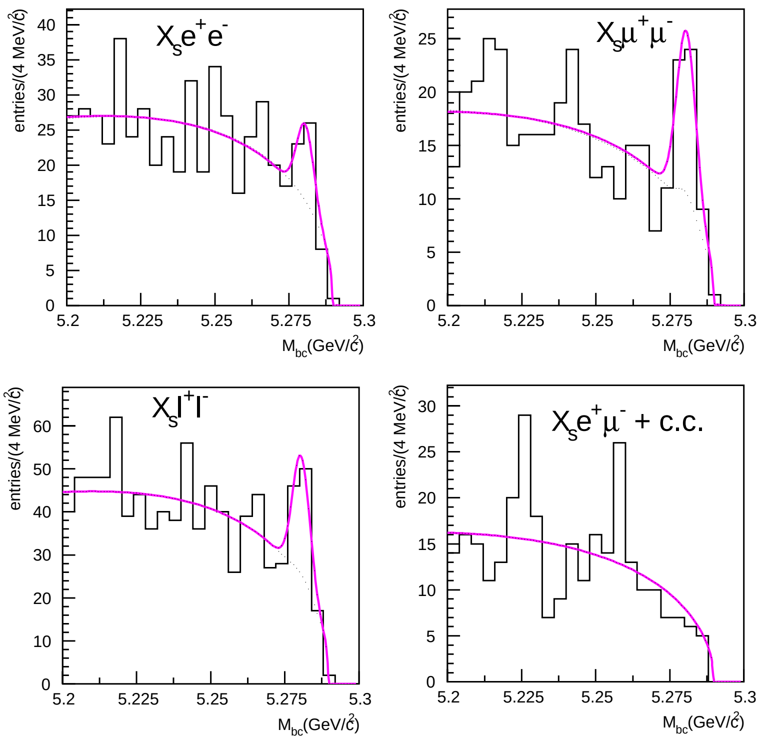

Figure 1: M_{bc} distributions and fit results. Top-left: $X_s e^+ e^-$ candidates, top-right: $X_s \mu^+ \mu^-$ candidates, bottom-left: $X_s \ell^+ \ell^- = (X_s e^+ e^-) + (X_s \mu^+ \mu^-)$ candidates, and bottom-right: $X_s e^\pm \mu^\mp$ to estimate combinatorial background. The significance is determined from the statistical error only.

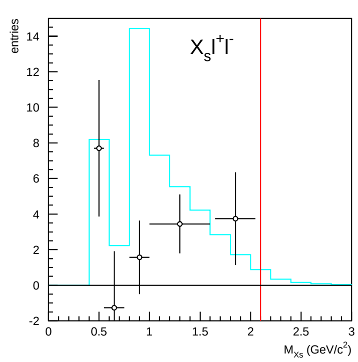

Figure 2: Comparison of the M_{X_s} distribution for data and MC.

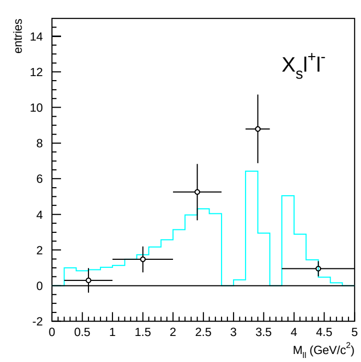

Figure 3: Comparison of the $M_{\ell\ell}$ distribution for data and MC.