PROCEEDINGS OF SCIENCE

Improved Measurement of the Electroweak Penguin Process $B \to X_s \ell^+ \ell^-$

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We have performed a search for the decay $B \to X_s \ell^+ \ell^-$ using a pseudo-inclusive reconstruction technique. Using a data sample of 657×10^6 $B\overline{B}$ pairs, we observe a clear signal, including $238.3 \pm 26.4 \pm 2.3$ events in the mass region $M(X_s) < 2.0\,\mathrm{GeV}/c^2$. The measured branching fraction is $\mathscr{B}(B \to X_s \ell\ell) = (3.33 \pm 0.80(\mathrm{stat})^{+0.19}_{-0.24}(\mathrm{syst})) \times 10^{-6}$; this result is restricted to the region $M(\ell^+\ell^-) > 0.2\,\mathrm{GeV}/c^2$.

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1. Introduction

In the Standard Model (SM), the rare decay $B \to X_s \ell^+ \ell^-$ $(\ell = e, \mu)$ proceeds through a $b \to s\ell^+\ell^-$ transition, which is forbidden at tree level. On the other hand, the flavor-changing neutral current (FCNC) process can occur at higher order via electroweak penguin and W^+W^- box diagrams. Since only Wilson coefficients $\mathcal{O}_7$, $\mathcal{O}_9$ and $\mathcal{O}_{10}$ appear in the effective Hamiltonian, we can constrain these coefficients by $b \to s\ell^+\ell^-$ transition and thus probe New Physics [1, 2]. Recently, the Belle and BaBar collaborations have both observed exclusive $B \to K\ell^+\ell^-$ and $B \to K^*\ell^+\ell^-$ decays [3, 4, 5, 6, 7], the inclusive $B \to X_s\ell^+\ell^-$ decays are also measured [8, 9]. In this report, we improve the measurement of $B \to X_s\ell^+\ell^-$ using a data sample of 657×10^6 BB pairs.

2. Event selection and signal extraction

We reconstruct inclusive $B \to X_s\ell^+\ell^-$ decays with a dilepton pair $\ell^+\ell^-$ (e^+e- or $\mu^+\mu^-$), and one of eighteen reconstructed hadronic states X_s. The hadronic states X_s consists of one $K^\pm$ or K_s and up to four pions (at most one pion can be neutral): $K^\pm$, $K^\pm\pi^0$, $K^\pm\pi^\mp$, $K^\pm\pi^\mp\pi^0$, $K^\pm\pi^\mp\pi^\pm$, $K^\pm\pi^\mp\pi^\pm\pi^0$, $K^\pm\pi^\mp\pi^\pm\pi^\mp$, $K^\pm\pi^\mp\pi^\pm\pi^\mp\pi^0$, $K^\pm\pi^\mp\pi^\pm\pi^\mp\pi^\pm$, K_s^0, $K_s^0\pi^0$, $K_s^0\pi^\pm$, $K_s^0\pi^\pm\pi^0$, $K_s^0\pi^\pm\pi^\mp$, $K_s^0\pi^\pm\pi^\mp\pi^0$, $K_s^0\pi^\pm\pi^\mp\pi^\mp$, $K_s^0\pi^\pm\pi^\mp\pi^\mp\pi^0$, and $K_s^0\pi^\pm\pi^\mp\pi^\mp\pi^\pm$. Signal event candidates are characterized by the kinematic variable: the beam-energy-constrained mass, $M_{\rm bc} = \sqrt{E_{\rm beam}^2 - P_B^{*2}}$, where $E_{\rm beam}$ is the run-dependent beam energy, and P_B^* is the momentum of the B candidate in the $\Upsilon(4S)$ center-of-mass (CM) frame.

Since there are large peaking backgrounds from charmonium B decays to X_sJ/ψ or $X_s\psi(2S)$, we remove these candidates with a dilepton mass in the regions $M_{ee(\gamma)} - M_{J/\psi} \in [-0.4,\ 0.15]$ GeV$/c^2$, $M_{ee(\gamma)} - M_{\psi(2S)} \in [-0.25,\ 0.1]$ GeV$/c^2$, $M_{\mu\mu} - M_{J/\psi} \in [-0.25,\ 0.1]$ GeV$/c^2$ and $M_{\mu\mu} - M_{\psi(2S)} \in [-0.15,\ 0.1]$ GeV$/c^2$. We also require $M_{e^+e^-} > 0.2$ GeV$/c^2$ to remove the possible background from the radiative $B \to X_s\gamma$ decays or π^0 Dalitz decays. Another background source is from random combinations with semileptonic B decays ($b \to c \to s, d$). In this case, at least one of the leptons in $X_s\ell^+\ell^-$ reconstruction is misidentified from another conjugate B decays. Since most of the semileptonic B decays produce a neutrino, we reject this background using missing mass, missing energy information, and the distance of two leptons along the positron beam (z axis). For continuum background $e^+e^- \to q\bar{q}$ ($q = u, d, s$ and c) events, we use modified Fox-Wolfram moments [10] that are combined into a Fisher discriminant. This discriminant is subsequently combined with the probabilities for the cosine of the B flight direction in the CM frame, the energy difference $\Delta E = E_B^* - E_{\rm beam}$ [E_B^* is the energy of the B candidate in the $\Upsilon(4S)$ CM frame] and χ^2 value for the B decay vertex to form a likelihood ratio $\mathcal{R} = \mathcal{L}_s/(\mathcal{L}_s + \mathcal{L}_{q\bar{q}})$. Here, $\mathcal{L}_s$ ($\mathcal{L}_{q\bar{q}}$) is a likelihood function for signal (continuum) events that is obtained from the signal (continuum) MC simulation.

We perform an extended unbinned maximum likelihood fit to the $M_{\rm bc}$ distribution in the region $M_{\rm bc} > 5.20$ GeV/c^2 to extract the signal. Other interesting measurements are the branching fraction of $B \to X_s\ell^+\ell^-$ versus M_{X_s} and $q^2(M^2_{\ell^+\ell^-})$ variables, we divide M_{X_s} and q^2 into several regions and use $M_{\rm bc}$ fit to determine their branching fractions, these results are shown on Fig. 1.

3. Summary

We have measured the branching fraction of $B \to X_s\ell^+\ell^-$ to be $(3.33 \pm 0.8^{+0.19}_{-0.24}) \times 10^{-6}$ with

10.1σ significance. The distributions of $\mathrm{d}\mathscr{B}(B \to X_s \ell^+ \ell^-)$ *vs*. $\mathrm{d}M_{X_s}$ and $\mathrm{d}\mathscr{B}(B \to X_s \ell^+ \ell^-)$ *vs*. $\mathrm{d}q^2$ are consistent with SM predictions. We have also measured the branching fractions of $B \to X_s e^+ e^-$ and $B \to X_s \mu^+ \mu^-$ to be $(4.56 \pm 1.15^{+0.33}_{-0.4}) \times 10^{-6}$ and $(1.91 \pm 1.02^{+0.16}_{-0.18}) \times 10^{-6}$, respectively. The ratio of measured branching fraction $\mathscr{B}(B \to X_s e^+ e^-)/\mathscr{B}(B \to X_s \mu^+ \mu^-)$ is 2.39 ± 1.41. This value with its error bar is within our MC assumption: $\mathscr{B}(B \to X_s e^+ e^-)/\mathscr{B}(B \to X_s \mu^+ \mu^-) = 1$; although the difference, the systematic error for $B \to X_s \ell^+ \ell^-$ efficiency is considered to be small.

The systematic errors (in the unit of percentage) are summarized in Table 1. There are three major sources of systematic errors: peaking backgrounds [from $B \to X_s J/\psi, X_s \psi(2S), X_s \psi(3770)$, $X_s \psi(4040)$ and $X_s \psi(4160)$ decays], detector systematics (tracking and particle identification efficiencies) and MC modeling systematics [$\mathscr{B}(B \to K^{(*)} \ell^+ \ell^-)$ assumption, $K^* - X_s$ transition and X_s decay fractions], etc.

Table 1: Systematic errors (in the unit of percentage) on the $B \to X_s e^+ e^-$ and $B \to X_s \mu^+ \mu^-$ branching fraction measurements.

Source	$B \to X_s e^+ e^-$	$B \to X_s \mu^+ \mu^-$
Signal PDF	± 0.3	± 0.1
$B \to X_s J/\psi,\ X_s \psi(2S)$	± 1.2	± 0.9
$B \to X_s \psi(3770),\ X_s \psi(4040),\ X_s \psi(4160)$	± 0.9	± 0.9
$B \to X_s \pi\pi,\ X_s \pi \ell \nu$	$^{+0.4}_{-0.5}$	$^{+0.2}_{-0.3}$
Self-cross-feed	± 0.1	± 0.1
Tracking efficiency	± 3.6	± 3.6
$\ell^\pm$ efficiency	± 2.1	± 2.2
$K^\pm$ efficiency	± 0.4	± 1.0
$\pi^\pm$ efficiency	± 3.4	± 3.0
K_s^0 efficiency	± 0.9	± 0.9
π^0 efficiency	± 0.5	± 0.5
$\mathscr{R}$ requirement	± 5.3	± 2.6
Fermi motion model	$^{+1.3}_{-4.9}$	$^{+0.6}_{-2.0}$
$K^* - X_s$ transition	$^{+2.3}_{-6.8}$	$^{+2.7}_{-7.1}$
X_s decay fractions	± 5.8	± 5.8
X_s decay fractions with two or more kaons	± 1.7	± 1.7
MC statistics	<0.1	<0.1
$B\overline{B}$ number	± 1.4	± 1.4

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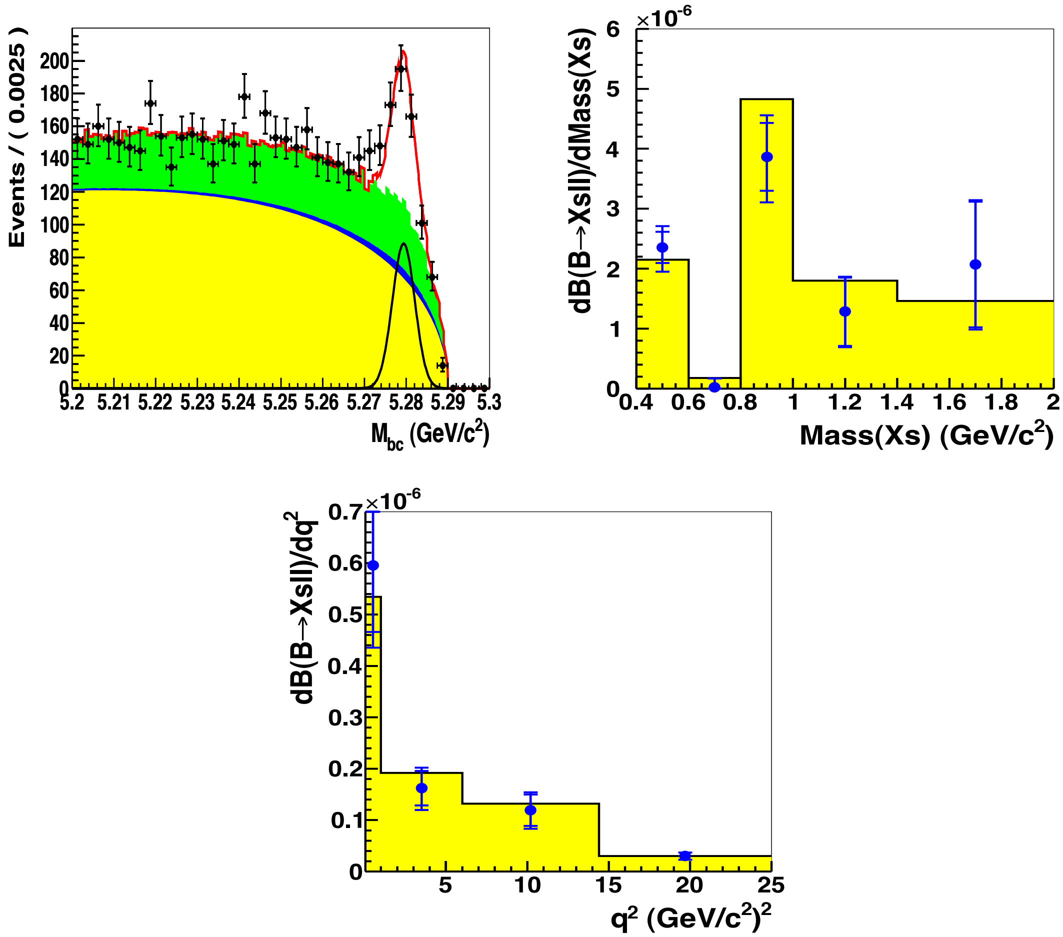

Figure 1: Upper left: Projection of the $M_{\rm bc}$ fit with a data sample containing 657×10^6 $B\overline{B}$ pairs. The signal component $B \to X_s \ell^+ \ell^-$ is shown in black line, the background ($b \to c \to s,d$ and continuum), peaking background [$B \to X_s J/\psi$, $X_s\psi(2S)$, $X_s\psi(3770)$, $X_s\psi(4040)$ and $X_s\psi(4160)$], self-cross-feed components are shown in yellow, green, and blue solid shaded regions, respectively. Upper right: The $\mathrm{d}\mathscr{B}(B \to X_s \ell^+ \ell^-)/\mathrm{d}M_{X_s}$ distribution, the dot with error bars are data, the yellow shaded region is MC simulation. Lower: The $\mathrm{d}\mathscr{B}(B \to X_s \ell^+ \ell^-)/\mathrm{d}q^2$ ($M^2_{\ell^+\ell^-}$) distribution, the dot with error bars are data, the yellow shaded region is MC simulation.

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