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Inclusive $B_s \to D_s X$ decays with B_s semi-leptonic tagging at Belle

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We present an analysis of the inclusive decay $B_s \to D_s X$ tagged with semi-inclusive decay $B_s \to D_s X l \nu$, where X denotes a final state that may consist of additional hadrons or photons and l is an electron or muon. The analysis methods are demonstrated and the results with generic MC are shown in this proceedings.

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1. Introduction

Study of the B_s meson properties at the $\Upsilon(5S)$ resonance, together with those of the lighter B^0 and B^+ decays, may provide important insights into the CKM matrix and hadronic structure, as well as sensitivity to new physics phenomena [1, 2, 3]. The branching fraction of the inclusive decay $B_s \to D_s X$ plays an important role for the determination of the B_s production rate in the $\Upsilon(5S)$ decays. The measurement of the B_s production rate f_s is necessary to compare with theoretical models of b-hadron production.

Two experiments, ALEPH [4] and OPAL [5] from LEP, have measured the combined branching fraction of $B(\overline{b} \to B_s^0) \cdot B(B_s^0 \to D_s X)$. By using $B(\overline{b} \to B_s^0)$ from theory predictions, the branching fraction $B(B_s^0 \to D_s X)$ has been measured, although with large uncertainties from statistics and theory. Belle has measured the branching fraction of $\Upsilon(5S) \to D_s X$ [6] with data of 1.86 fb^{-1} collected near the $\Upsilon(5S)$ energy.

The average branching fraction of the previous measurements is (93 ± 25) % from PDG 2018 [7]. The methods these measurements used are not direct measurements, and their results depend on other measurements and have large uncertainties. In this proceedings, we present a direct measurement of $B_s \to D_s X$ decay using a B_s semi-leptonic tagging method.

We use the data sample of 121.4 fb^{-1} that was collected with the Belle detector [8] at the KEKB asymmetric-energy e^+e^- collider [9] operating near the $\Upsilon(5S)$ resonance. The Belle detector is a general purpose large-solid-angle spectrometer consisting of a silicon vertex detector (SVD), a central drift chamber (CDC), an array of aerogel threshold Cherenkov counters (ACC), a barrel-like arrangement of time-of-flight scintillation counters (TOF), and an electromagnetic calorimeter (ECL) located inside a superconducting solenoid coil that provides a 1.5 T magnetic field. Outside the coil, an iron flux-return yoke is instrumented to detect K_L^0 mesons and to identify muons (KLM). A detailed description of the detector can be found in Ref. [8].

2. Analysis Stragety

In this analysis, the B_s semi-leptonic decay $B_s \to D_s X l \nu$ is used to tag $B_s^0 \overline{B_s^0}$ events. Particles in one event are separated to two sides: tag side and signal side.

In the tag side, D_s is reconstructed with two decay modes: $D_s^\pm \to \phi\pi^\pm$, $\phi \to K^+K^-$ and $D_s^\pm \to K_S^0 K^\pm$, $K_S^0 \to \pi^+\pi^-$. Other than the D_s meson, a charged lepton (e or μ) is also reconstructed. The missing mass square of $B_s \to D_s X l \nu$, (l = e or μ) is used to tag the B_s meson:

$$M_{miss}^2 = (E_{Beam}^* - E_{D_s l}^*)^2 - p_{D_s l}^{*2}, \tag{2.1}$$

where $E_{Beam}^* = \frac{\sqrt{s}}{2}$. The energy and momentum of the D_s and lepton system are used in the calculation of missing mass square ($E_{D_s l}^*$ and $p_{D_s l}^*$). The number of tagged (N_{tag}) events is obtained by fitting the missing mass square distribution using shapes determined via MC.

In the signal side, one D_s is constructed by using the same decay modes selection rules for tag side D_s with one additional decay mode $D_s^\pm \to K^{*0}K^\pm$, $K^{*0} \to K^\pm\pi^\mp$ to increase signal statistics. It should also have no shared charged tracks with the tag side tracks. The number of signal events (N_{sig}) is obtained by fitting the D_s invariant masses in tag side and signal side, together with the missing mass square after the signal side event selection.

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The branching fraction of $B_s \to D_s X$ can be calculated as:

$$B(B_s \to D_s X)_{measured} = \frac{N_{sig}}{N_{tag} \cdot \varepsilon_{rec}}, \tag{2.2}$$

where ε_{rec} is the signal side D_s reconstruction efficiency.

In this analysis, the tagging mode, $B_s \to D_s l \nu X$, is part of the signal mode, $B_s \to D_s X$. The following correction needs to be applied to the measured branching fraction:

$$B(B_s \to D_s X) = \frac{(2 - B_{semi}) \cdot B_{meas} + B_{semi}}{2}, \tag{2.3}$$

where B_{meas} is the directly measured result of $B(B_s \to D_s X)$, and B_{semi} is the branching ratio of B_s semi-leptonic decay $B(B_s \to D_s l \nu X)$ = $(16.2 \pm 2.6)\% \quad (l = e, \mu)$ [7].

3. Event Selection

The charged tracks, except those from K_S decay, are required to originate from the interaction point (IP) and have the point of closest approach to the IP within 2.0 cm along the beam axis and 0.5 cm in the plane transverse to the beam. Additionally, all tracks should have at least one associated hit in the plane transverse to the beam and two hits along the beam axis within the SVD detector. Kaon and pion hypotheses are assigned to the tracks based on the likelihood combining the information from Belle sub-detectors. The leptons should have a minimum momentum of 1.0 GeV in the center of mass frame. The standard Belle lepton identification requirements are used to further select lepton candidates.

The neutral intermediate particles, ϕ, K_S^0 or K^{*0}, are reconstructed with the selected charged tracks. For ϕ reconstruction, any two oppositely charged kaons with invariant mass within $\pm$ 15 MeV of the ϕ nominal mass are considered as a ϕ candidate. For K^{*0}, the candidate tracks are oppositely charged K and π, and the invariant mass window is $\pm$ 20 MeV. The K_S^0 candidates are selected with a standard method in Belle and the invariant mass cut of $\pm$ 50 MeV is applied.

The D_s meson is reconstructed by using the reconstructed intermediate particles, ϕ, K^{*0} and K_S^0, and one π meson for ϕ, or one K meson for K^{*0} or K_S^0. The reconstructed D_s should pass the vertex fit and the invariant mass should be within $\pm$ 50 MeV which corresponds to 7.5 σ. The momentum of the reconstructed D_s in the center of mass system $P^*_{D_s}$ is required to be within the 0.5 GeV/c – 3.0 GeV/c range. For $\phi\pi$ and $K^{*0}K$ decay modes, a vertex fit is performed for the four tracks used to reconstruct the D_s meson and the χ^2 of the fit output should be less than 100.

To suppress combinatorial background, the helicity angle for $D_s \to \phi(K^+K^-)\pi$ and $D_s \to K^{*0}(K\pi)K$ is required as $|\cos\theta_{hel}| > 0.5$. The thrust angle, which is defined as the angle between the thrust axis of the selected tag side D_s and lepton and another thrust axis of the remaining tracks in the event, is required as $|\cos\theta_{thrust}| < 0.8$ in this analysis. To further suppress continuum background, we require that the event shape variable R_2, which is the ratio of second to zeroth Fox-Wolfram moments [10], satisfy $R_2 < 0.4$.

After the previous D_s and lepton reconstruction, sometimes there are more than one possible D_s and lepton combinations. To select one candidate per event, we perform a vertex fit on the tracks forming the D_s candidate and choose the one giving the smallest χ^2 as the D_s tag.

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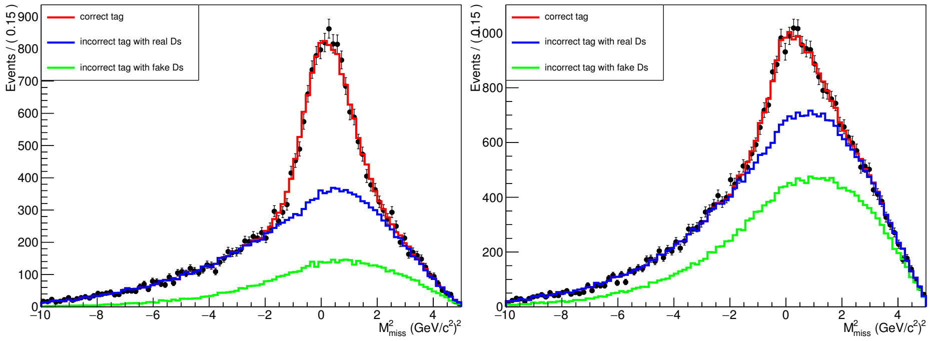

Figure 1: Fitting results of the missing mass square for $\phi\pi$ tag mode (left) and $K^0_S K$ tag mode (right). The red lines for real tag. The blue lines are fake tag with real D_s. The green lines are fake tag with fake D_s.

After tagging, we reconstruct an additional D_s from the remainder of the event. The selection criteria are the same as with the tag side D_s. To increase statistics, one more D_s decay channel, $D_s \to K^{*0}K, K^{*0} \to K\pi$, is used. We allow none of the tracks of the B_s tag candidate, the tagging D_s and charged lepton, to be used to reconstruct the D_s signal candidate.

The signal side D_s reconstruction efficiency ε_{rec} is defined as the the number of reconstructed D_s, N_{rec}, over the total number of D_s in the signal side, N_{tot}. This efficiency is obtained from signal MC sample and it varies only slightly over the tag side D_s momentum range of 0.5 GeV/c to 3.0 GeV/c.

4. Tagging and Fitting

After the tag side D_s and lepton candidate has been selected, the number of tags events can be extracted by fitting the missing mass square distribution. The tag side missing mass square is defined in 2.1. The selected candidates can be grouped into three categories: real tag events in which the D_s is correctly reconstructed and combined with the correct lepton; fake tag events with correct D_s in which the D_s is correctly reconstructed but combined with the wrong lepton and fake tag events with wrong D_s in which the D_s is wrongly reconstructed, which is combinatorial background.

The shapes of the missing mass square distributions for these three categories are obtained from the generic MC samples. By fitting the missing mass square distributions, we can extract the number of tagged events in $\Upsilon(5S)$ data taken by Belle, as shown in Figure 1.

We can extract the number of signal D_s in $D_s l$ tag candidate events with a 3D fit. The three fitting variables are: the invariant mass of signal side D_s; the invariant mass of tag side D_s and the missing mass calculated by using tag side D_s and lepton (μ or e). The mass of the signal D_s distribution has two contributions: the corrected reconstructed D_s and the incorrectly reconstructed D_s.

For both the tag and signal side D_s mass, we model the distributions with double Gaussians with a common mean. The widths for each Gaussian and their relative areas are obtained from the signal MC. For incorrectly reconstructed D_s signal, their invariant mass distribution is modeled as first order linear polynomial. The missing mass distributions for the three tag side categories are

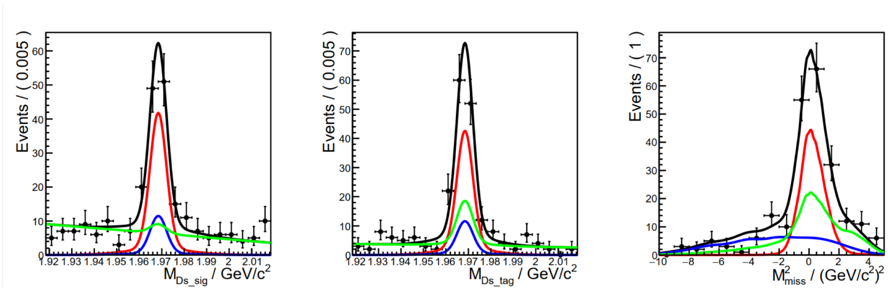

Figure 2: 1D projections of results from 3D signal fitting, all D_s modes combined: data (points with error bars), signal (red), cross-feed (green), background (blue), and total PDF(black).

obtained from signal and generic MC. There are three contributions to the tag side distribution and two the signal side distribution which lead to six distinct contributions to the 3D PDF distribution.

In the fitting procedure, the cross feed events are considered as signal to increase the statistics. The cross feed events are defined as both tag side and signal side D_s are correctly reconstructed but the tag side lepton is associated with the wrong D_s. But if we swap the two D_s by combining lepton with signal side D_s, the event can be considered as signal event, because signal side D_s and lepton are decaying from the same B_s in this case. The relative ratio of the cross feed events respect to the signal events is obtained from the MC samples and can be used in the fitting. The results of signal fitting is shown in Figure 2.

5. Results and Conclusions

Applying previous selection rules and fitting procedures to 6 streams of Belle generic MC samples for $\Upsilon(5S)$ decays, we can get the branching fraction of $B_s \to D_s X$ as (78.5 ± 2.5) %. After the correction defined in Eq. 2.3, the corrected branching fraction is (80.2 ± 2.5) %, which is consistent with the truth value in the MC sample (81.36 ± 0.01) %. The analyis with full $\Upsilon(5S)$ data taken by Belle is still on-going.

References

[1] A. F. Falk and A. A. Petrov, Phys. Rev. Lett. 85, 252(2000).

[2] S. Petrak, SLAC Report No. 2001-041, 2001.

[3] D. Atwood and A. Soni, Phys. Lett. B 533, 37 (2002).

[4] D. Buskulic et al. Z.Phys., C69:585–596, 1996.

[5] P.D. Acton et al. Phys.Lett., B295:357–370, 1992.

[6] A. Drutskoy et al. Phys.Rev.Lett., 98:052001, 2007.

[7] M. Tanabashi et al. (Particle Data Group), Phys. Rev. D 98, 030001 (2018)

[8] A. Abashian et al, (Belle Collaboration), Nulc. Instrum. Methods Phys. Res., Sect. A 479, 117 (2002)

[9] S. Kurokawa and E. Kikutani, Nucl. Instrum. Methods Phys. Res., Sect. A 499, 1 (2003).

[10] G.C. Fox and S. Wolfram, Phys. Rev. Lett. 41, 1581 (1978).