PROCEEDINGS OF SCIENCE

B_s^0 decays at Belle

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We report a measurement of the branching fraction of the decays $B_s^0 \to J/\psi\,\phi(1020)$, $B_s^0 \to J/\psi\, f_2'(1525)$, and the determination of the $B_s^0 \to J/\psi K^+K^-$ branching fraction, where the latter includes both resonant and non-resonant contributions to the K^+K^- channel. We also determine the S-wave contribution within the $\phi(1020)$ mass region.
Furthermore we present the first evidence of the baryonic B_s^0 decay $\bar{B}_s^0 \to \Lambda_c^+\pi^-\bar{\Lambda}$.
All results are based on a $121\,\mathrm{fb}^{-1}$ data sample collected with the Belle detector at the KEK-B asymmetric e^+e^- collider at the $\Upsilon(5S)$ resonance.

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1. Introduction

During its operation, the Belle detector collected over 700 fb^{-1} of data at the $\Upsilon(4S)$ resonance and 121 fb^{-1} at the $\Upsilon(5S)$ resonance. This second data sample is unique at B factories and provides the opportunity to study decays of $\mathrm{B_S^0}$ mesons.
To extract the $\mathrm{B_S^0}$ signal, two nearly independent kinematic variables, the energy difference $\Delta\mathrm{E}$ and the beam-energy constrained mass $\mathrm{M_{bc}}$, are used:

$$\Delta\mathrm{E} = \mathrm{E_B^*} - \mathrm{E_{beam}^*} \qquad \text{and} \qquad \mathrm{M_{bc}} = \sqrt{\left(\mathrm{E_{beam}^*}\right)^2 - \left(\mathrm{p_B^*}\right)^2} \tag{1.1}$$

where $\mathrm{E_{beam}^*}$ is the beam energy in the center of mass frame and $\mathrm{E_B^*}$ and $\mathrm{p_B^*}$ denote the energy and the momentum of the reconstructed $\mathrm{B_S^0}$ meson, respectively, given in the center of mass system.
In the presented analyses, the $\mathrm{B_S^0}$ meson is fully reconstructed. However, the photon from the decay $\mathrm{B_S^*} \to \mathrm{B_S}\,\gamma$ is not included. As the energy information from this photon is lost, the signal region plotted in the $\mathrm{M_{bc}}$-$\Delta\mathrm{E}$ plane splits up into three clusters, depending on the number of $\mathrm{B_S^*}$ mesons in the initial state. As these areas are not overlapping in $\mathrm{M_{bc}}$, they can easily be separated during the analysis by choosing a certain range in $\mathrm{M_{bc}}$ (fig. 1(b)).
The Belle detector (fig. 1(a)), located at the asymmetric $\mathrm{e^+e^-}$ collider KEK-B [1] in Tsukuba Japan, is a large-solid-angle magnetic spectrometer that consists of a silicon vertex detector (SVD), a 50-layer 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 comprised of CsI(Tl) crystals (ECL) located inside a super-conducting solenoid coil that provides a 1.5 T magnetic field. An iron flux-return located outside of the coil is instrumented to detect K_L^0 mesons and to identify muons (KLM). The detector is described in detail elsewhere [2].

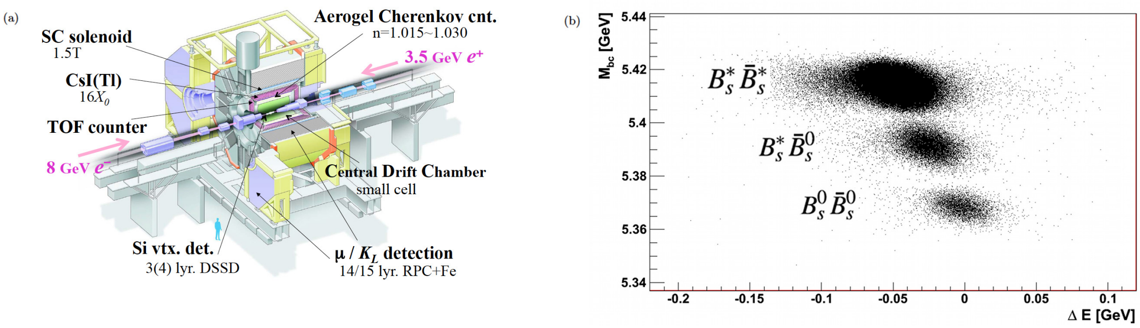

Figure 1: (a) Schematic view of the Belle detector. (b) Signal regions (from MC data) shown as a scatter plot in the $\mathrm{M_{bc}} - \Delta\mathrm{E}$ plane.

2. Measurement of branching ratios for $\mathrm{B_S^0} \to J/\psi\,\phi(1020)$, $\mathrm{B_S^0} \to J/\psi\, f_2'(1525)$ and $\mathrm{B_S^0} \to J/\psi\,\mathrm{K^+K^-}$ as well as the S-wave contribution in the $\phi\,(1020)$ mass range.

The decay $\mathrm{B_S^0} \to \mathrm{J}/\Psi\ \phi$ is an important mode for measuring the CP violating phase ϕ_S in $\mathrm{B_S\overline{B}_S}$ mixing, which is of particular interest as it is expected to be sensitive to physics beyond the Standard Model [3]. In this context an advanced understanding of decay modes $B_s^0 \to J/\psi K^+K^-$ apart from $\mathrm{B_S^0} \to \mathrm{J}/\psi\,\phi(1020)$ is crucial. Recently the LHCb [4, 5], CDF [6, 7, 8] and DØ[9] experiments have published their results concerning the branching fractions for $\mathrm{B_S^0} \to \mathrm{J}/\psi\,\phi(1020)$, $\mathrm{B_S^0} \to \mathrm{J}/\psi\, f_2'(1525)$ and the entire $\mathrm{B_S^0} \to \mathrm{J}/\psi\,\mathrm{K^+K^-}$ component which includes resonant and non-resonant contributions.

However, hadron collider experiments can only provide relative measurements of the branching ratio. The Belle experiment has the advantage that the number of produced $\mathrm{B_S^{(*)}}$ mesons is known. This means that we can determine the absolute branching ratio by normalizing to the absolute number of $\mathrm{B_S^0}$ mesons rather than using a reference decay channel and thus provide results which are based on different methods and systematic effects than previous results.

Candidate events are selected as follows: First, the decay $\mathrm{J}/\psi \to \ell^+\ell^-$ is reconstructed by identifying two oppositely charged leptons (electrons or muons) with invariant mass close to the nominal J/ψ mass. A correction for energy loss through bremsstrahlung emission is applied. The J/ψ candidate is combined with two oppositely charged identified kaons. In case of the invariant kaon mass, only a lower cut of $\mathrm{M(K^+K^-)} \geq 0.95\,\mathrm{GeV}$ is applied, which corresponds to the lower end of the $\mathrm{M(K^+K^-)}$ phasespace, so that the full $\mathrm{m(K^+K^-)}$ distribution can be investigated.

To extract the $\mathrm{B_S^0}$ meson signal only events with $\mathrm{M_{bc}} > 5.4\,\mathrm{GeV}$ are selected, which means only the dominant $\mathrm{B_S^*\overline{B}_S^*}$ signal region is investigated as this provides the best signal to background ratio. To extract the signal yields a two dimensional unbinned likelihood fit in $\Delta\mathrm{E}$ and $\mathrm{m(K^+K^-)}$ is performed, where the $\Delta\mathrm{E}$ distribution is modeled with a sum of a Gaussian and a Crystal Ball [10] function (a sum of two Gaussian functions) for the $\mathrm{J}/\psi \to \mathrm{e^+e^-}$ ($\mathrm{J}/\psi \to \mu^+\mu^-$) data sample. The corresponding pdf parameters are adjusted by using the real data control sample from the decay $\mathrm{B^0} \to \mathrm{J}/\psi\,\mathrm{K}^*(892)$, as its final state is very similar to the final state of the investigated decays, except that one kaon is replaced by a pion.

The probability density functions (PDFs) for the $\mathrm{m(K^+K^-)}$ distribution are determined by investigating generic Monte Carlo (MC) data, which basically includes all known contributions that can be found in the PDG and additionally the decay $\mathrm{B_S^0} \to \mathrm{J}/\psi\,\mathrm{f}_2'(1525)$. The $\phi(1020)$ and the $\mathrm{f}_2'(1525)$ resonance are both described by a nonrelativistic Breit-Wigner function, while the non-resonant decay $\mathrm{B_S^0} \to \mathrm{J}/\psi\,\mathrm{K^+K^-}$ is parameterized by an Argus function [11].

The combinatorial background is modeled with a first order polynom in $\Delta\mathrm{E}$ and an Argus function in $\mathrm{M(K^+K^-)}$. The parameters for these PDFs are determined from a data sideband in the region of $5.25\,\mathrm{GeV} \leq \mathrm{M_{bc}} \leq 5.35\,\mathrm{GeV}$.

Figures 2 and 3 present the fit projection in $\Delta\mathrm{E}$ and $\mathrm{M(K^+K^-)}$, respectively, and illustrate a good agreement between the applied fit model and the data.

The corresponding absolute branching fractions calculated through the fitted yields are:

$$\mathscr{B}\left(\mathrm{B_S^0} \to \mathrm{J}/\psi\;\phi\right) = (1.25 \pm 0.07\,(\mathrm{stat}) \pm 0.08\,(\mathrm{syst}) \pm 0.22\,(f_s)) \times 10^{-3} \tag{2.1}$$

$$\mathscr{B}(\mathrm{B_S^0} \to \mathrm{J}/\psi\,\mathrm{f}_2'(1525)) = (0.26 \pm 0.06\,(\mathrm{stat}) \pm 0.02\,(\mathrm{syst}) \pm 0.05\,(f_s)) \times 10^{-3} \tag{2.2}$$

$$\mathscr{B}\left(\mathrm{B_S^0} \to \mathrm{J}/\psi\;\mathrm{K^+K^-}\right) = (1.01 \pm 0.09\,(\mathrm{stat}) \pm 0.10\,(\mathrm{syst}) \pm 0.18\,(f_s)) \times 10^{-3} \tag{2.3}$$

The dominant systematic error in this calculation is the uncertainty in parameter f_s which denotes the percentage of $\mathrm{B_S}$ events within all $b\bar{b}$ states. All determined branching fractions are in agreement with recent measurements from hadron collider experiments.

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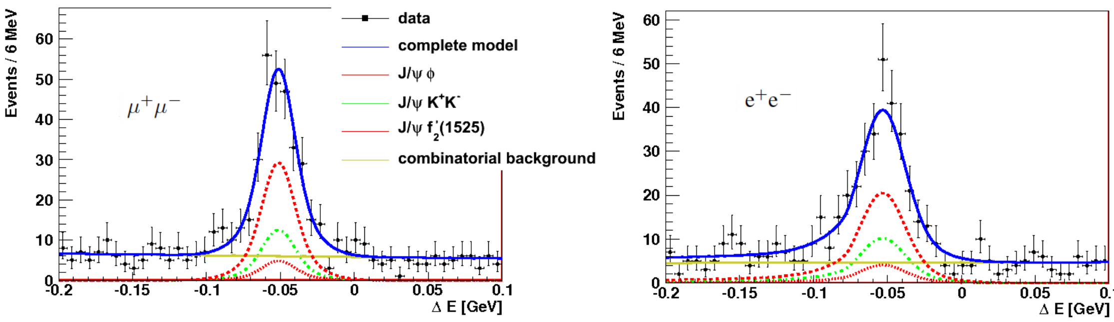

Figure 2: Fitted ΔE distribution for the $\mu^+\mu^-$ and the $\mathrm{e^+e^-}$ channel on $121\,\mathrm{fb}^{-1}$.

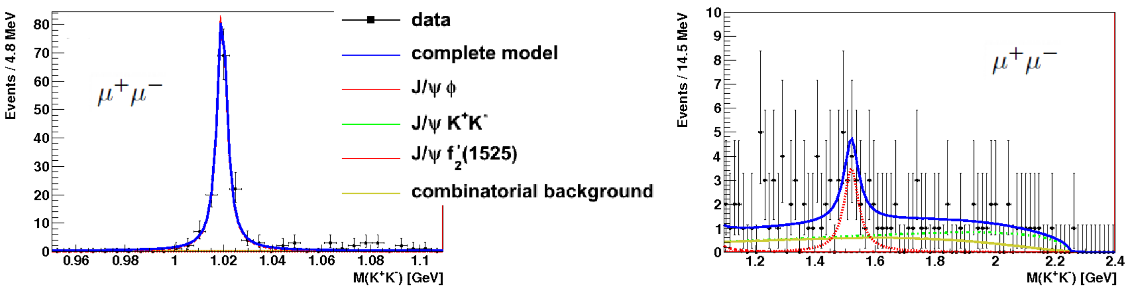

Figure 3: Fitted $\mathrm{M(K^+K^-)}$ distribution for the $\mu^+\mu^-$ channel on $121\,\mathrm{fb}^{-1}$. The selection $-0.07\,\mathrm{GeV} \leq \Delta\mathrm{E} \leq -0.03\,\mathrm{GeV}$ is applied.

The branching ration for $\mathrm{B_S^0} \to \mathrm{J}/\psi\ \mathrm{f}_2'(1525)$, relative to the branching fraction for $\mathrm{B_S^0} \to \mathrm{J}/\psi\ \phi$, is determined to be

$$\frac{\mathscr{B}\left(\mathrm{B_S^0} \to \mathrm{J}/\psi\ \mathrm{f}_2'(1525)\right)}{\mathscr{B}\left(\mathrm{B_S^0} \to \mathrm{J}/\psi\ \phi\right)} = (21.5 \pm 4.9\,(\mathrm{stat}) \pm 2.6\,(\mathrm{syst}))\% \tag{2.4}$$

This result is compared with the values reported by LHCb abd DØwhich are $(26.4 \pm 2.7\,(\mathrm{stat}) \pm 2.4\,(\mathrm{syst}))\%$ [4] and $(19 \pm 5\,(\mathrm{stat}) \pm 4\,(\mathrm{syst}))\%$ by DØ [9], respectively. All three results are in good agreement within their errors.

In this analysis we also determine the S-wave contribution within the ϕ mass region. Instead of performing a full angular analysis as it is done in hadron collider experiments, we distinguish the S- and P-wave components via the $\mathrm{M(K^+K^-}$ distribution. It is assumed that the P-wave fully originates from the decay $\mathrm{B_S^0} \to \mathrm{J}/\psi\ \phi$, while the S-wave component originates from the nonresonant decay $\mathrm{B_S^0} \to \mathrm{J}/\psi\ \mathrm{K^+K^-}$. These assumptions are verified through investigation of the helicity angular distributions of these decay modes.

The obtained results for the S-wave contribution in two different mass regions around the ϕ peak are presented in Table 1. The first quoted error is statistical, which arises through the uncertainty in the fitted yields for $\mathrm{B_S^0} \to \mathrm{J}/\psi\ \phi$ and $\mathrm{B_S^0} \to \mathrm{J}/\psi\ \mathrm{K^+K^-}$. The second error is systmatic and includes the uncertainties in the PDF parameters and the PDF model. The third error is the uncertainty due to a possible $\mathrm{B_S^0} \to \mathrm{J}/\psi \mathrm{f_0}(980)$ contribution as it was seen by LHCb, and was estimated by taking

Mass range	1.009 GeV − 1.028 GeV
CDF [12]	$(0.8 \pm 0.2)\%$
This analysis	$(0.47 \pm 0.07 \pm 0.22^{+2.2}_{-0})\%$
Mass range	1.007 GeV − 1.031 GeV
LHCb [5]	$(1.1 \pm 0.1^{+0.2}_{-0.1})\%$
This analysis	$(0.57 \pm 0.09 \pm 0.26^{+2.0}_{-0})\%$

Table 1: The *S*-wave contribution in different mass regions around the $\phi(1020)$ resonance. The first error is statistical, the second systematic and the third error is the uncertainty due to a possible $B_s^0 \to J/\psi f_0(980)$ contribution.

into account the difference between our PDF model and the applied LHCb PDF model.
The central values for the S-wave contriubtion obtained in this analysis are smaller than the results from hadron collider experiments, but in agreement with the CDF and LHCb results when including the systematic error due to a possible $\mathrm{B_S^0} \to \mathrm{J}/\psi \mathrm{f_0}(980)$ contribution.
Further details on the presented study can be found in [13].

3. First evidence of $\bar{\mathrm{B}}_\mathrm{s}^0 \to \Lambda_\mathrm{c}^+ \pi^- \bar{\Lambda}$

Different baryonic B meson decays with 2-, 3-, 4- and even 5-body final states have been observed so far. The measured branching fractions show a hierarchy structre, as low multiplicity final states have smaller branching ratios compared to high multiplicity decays. Furthermore, a near threshold peak has been seen in the invariant baryon-antibaryon mass distribution for three-body final states. In this analysis we present the first evidence for a baryonic $\mathrm{B_S^0}$ decay. The branching fraction of the decay $\bar{\mathrm{B}}_\mathrm{S}^0 \to \Lambda_\mathrm{c}^+ \pi^- \bar{\Lambda}$ is measured and a search for a near threshold enhancement in the baryon-antibaryon mass distribution is performed.
The Λ_c^+ baryon is reconstructed in the three final states $\Lambda_\mathrm{c}^+ \to p\mathrm{K}^-\pi^+$, $p\mathrm{K_S^0}$ and $\Lambda\pi^+$. The reconstructed mass of all particles ($\mathrm{K_S^0}$, Λ, and Λ_c^+) is required to lie within a $\pm 3\,\sigma$ interval around the nominal mass.
The fit projections for all three Λ_c^+ decay channels are presented in Figure 4. With a signal yield of 20.3 events, the mode $\Lambda_\mathrm{c}^+ \to p\mathrm{K}^-\pi^+$ gives the most dominant contribution. Summarizing all three channels the absolute branching fraction is calculated to be

$$\mathscr{B}(\bar{\mathrm{B}}_\mathrm{S}^0 \to \Lambda_\mathrm{c}^+ \pi^- \bar{\Lambda}) = (3.6 \pm 1.1(\mathrm{stat})^{+0.3}_{-0.5}(\mathrm{sys}) \pm 0.9(\Lambda_\mathrm{c}^+) \pm 0.7(\mathrm{N}_{\bar{\mathrm{B}}_\mathrm{S}^0})) \times 10^{-4} \tag{3.1}$$

with a significance of $4.4\,\sigma$, where the systematic error is already included. The obtained branching ratio is comparable with the branching fraction of the $\mathrm{B_u}$ decay $\mathrm{B}^- \to \Lambda_\mathrm{c}^+ \bar{p}\pi^-$ which is $2.8 \pm 0.8 \cdot 10^{-4}$.
To investigate a possible near threshold enhancement, we extracted the signal yield in bins of the baryon-antibaryon mass, applied an efficiency correction and calculated the differential branching fractions. Even though a hint of the threshold enhancement was seen, the underlying statistic is too low to observe the effect.
Further details on the presented analysis can be found in [14].

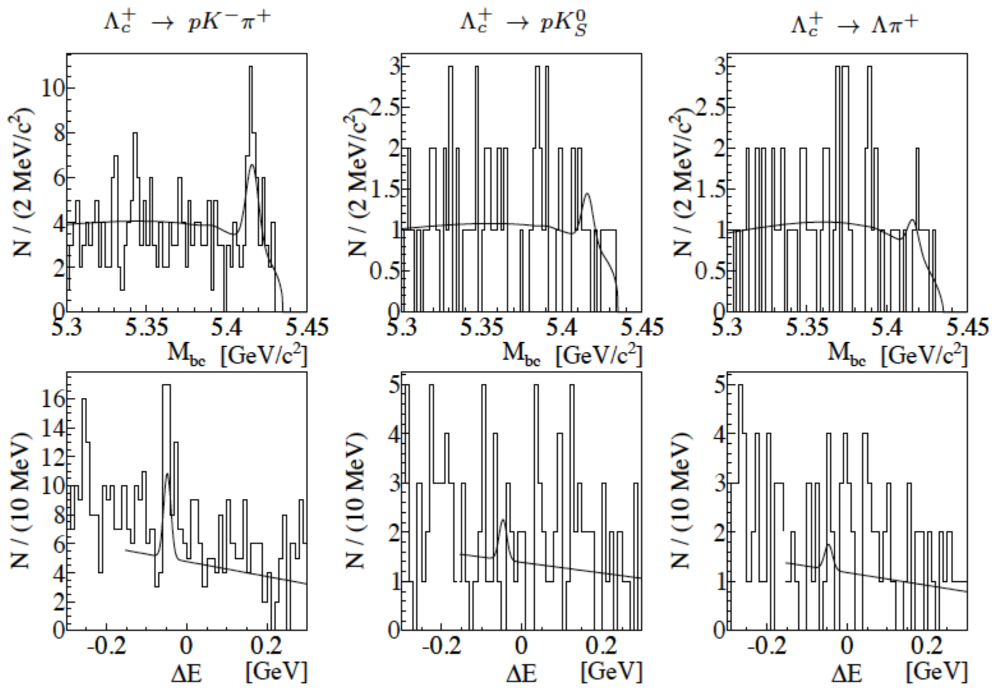

Figure 4: Fit projections for the different Λ_c^+ decay channels for $-71\,\text{MeV} < \Delta E < -23\,\text{MeV}$ and $5.405\,\text{GeV}/c^2 < M_{bc} < 5.427\,\text{GeV}/c^2$.

4. Summary

We performed a measurement of the absolute branching fraction for $B_S^0 \to J/\psi\ \phi$, for $B_S^0 \to J/\psi\ f_2'(1525)$ and for the entire $B_S^0 \to J/\psi\ K^+K^-$ decay, which includes resonant and nonresonant contributions. All obtained results are in agreement with the results from hadron collider experiments. The determined S-wave contribution within the ϕ mass region is smaller than the reported values from CDF and LHCb, but still in agreement with their results when we take into account a possible $B_S^0 \to J/\psi f_0(980)$ contribution.
Furthermore, we report the first evidence for the baryonic decay $\bar{B}_S^0 \to \Lambda_c^+\pi^-\bar{\Lambda}$. Due to the low statistic, a near threshold enhancement in the invariant baryon-antibaryon mass could not be observed.

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