

Search for $B^- \rightarrow J/\psi \Lambda \bar{p}$ decay

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We report the results of a search for $B^- \rightarrow J/\psi \Lambda \bar{p}$ based on a data set of 78 fb^{-1} data collected at the $Y(4S)$ resonance with the Belle detector at the KEKB asymmetric e^+e^- collider. No substantial signal is found, and we set the branching fraction upper limit $\mathcal{B}(B^- \rightarrow J/\psi \Lambda \bar{p}) < 4.1 \times 10^{-5}$ at 90% confidence level.

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The inclusive decay of $B \rightarrow J/\psi + X$ has been studied by CLEO [1], Belle [2], and BaBar [3]. The J/ψ momentum spectrum in the e^+e^- center of mass frame is consistent with the distribution predicted by nonrelativistic QCD calculations [4], except for an excess in the low momentum region which has been observed by all of the above experiments. The excess below $0.8 \text{ GeV}/c$ corresponds to a branching fraction of $4 \times 10^{-4} - 6 \times 10^{-4}$.

In order to explain this excess, several theoretical hypotheses have been proposed [5–7]. One of them is that the excess arises from $B \rightarrow J/\psi \Lambda \bar{p}$ decays [5]; this possibility can also be inferred from the rather large branching fraction of $B \rightarrow \Lambda \bar{p} X$, $(2.3 \pm 0.4)\%$ [8]. At the quark level, $B^- \rightarrow J/\psi \Lambda \bar{p}$ can be described as $(ud\bar{u}\bar{d})$ produced by gluon emission from the Cabibbo favored $b \rightarrow c\bar{c}s$ diagram. The decay rate could be enhanced by an intermediate exotic state such as a bound state of Λ and \bar{p} , J/ψ and Λ , or J/ψ and \bar{p} . In this case, the momentum distributions of the daughter particles will exhibit some characteristic enhancements. Thus, searching for $B^- \rightarrow J/\psi \Lambda \bar{p}$ helps to understand the source of the excess at low J/ψ momentum and to find intermediate states. The BaBar Collaboration has recently reported results of a similar search [9].

In this paper we report on the study of $B^- \rightarrow J/\psi \Lambda \bar{p}$. The analysis is based on a data sample of 78 fb^{-1} accumulated at the $Y(4S)$ resonance with the Belle detector at the KEKB 8 GeV e^- and 3.5 GeV e^+ asymmetric collider [10].

The Belle detector consists of a three-layer silicon vertex detector (SVD), a 50-layer central drift chamber (CDC), an array of aerogel threshold Čerenkov counters (ACC), time-

of-flight scintillation counters (TOF), a CsI(Tl) crystal electromagnetic calorimeter (ECL), a 1.5 T superconducting solenoid coil and an instrumented iron-flux return for muon and K_L detection (KLM). The detector is described in detail elsewhere [11].

In this analysis, we use the decay chain: $B^- \rightarrow J/\psi \Lambda \bar{p}$, $J/\psi \rightarrow l^+ l^-$ ($l = e, \mu$), and $\Lambda \rightarrow p \pi^-$. Inclusion of charge conjugate states is implied throughout this paper. To suppress continuum backgrounds we require the ratio of the second to zeroth Fox-Wolfgram moments [12] to be less than 0.5.

To remove charged tracks that are badly measured or do not come from the interaction region, we require leptons from J/ψ to originate from within 5 cm of the interaction point along the beam direction. Both lepton tracks are required to be well identified as leptons. Electrons are identified using a combination of specific ionization measurements (dE/dx) from the CDC, the ACC response, and electromagnetic shower position, shape and energy from the ECL [13]. Muons are identified with KLM hit positions and penetration depth [14]. In order to recover dielectron events where one or both electrons have radiated a photon (final state radiation or bremsstrahlung), we include the four-momentum of every photon detected within 0.05 radians of the original e^+ or e^- direction in the invariant mass calculation. The invariant mass of the candidate $J/\psi \rightarrow \mu^+ \mu^-$ ($e^+ e^-$) is required to be between -60 (-150) MeV/c^2 and $+36$ ($+36$) MeV/c^2 of the known J/ψ mass. The asymmetric mass requirements are due to radiative tails. The selection criteria for J/ψ are identical to those used in Ref. [15].

Particle identification information from the ACC, TOF and dE/dx information from the CDC is used to construct likelihoods L_i for each hadron type i ($i = \pi, K$, and p). We require $L_p/(L_p + L_K) > 0.6$ and $L_\pi/(L_\pi + L_K) > 0.6$ to select protons and pions, respectively. For the prompt \bar{p} candidates, tracks that are positively identified as muons or electrons are rejected.

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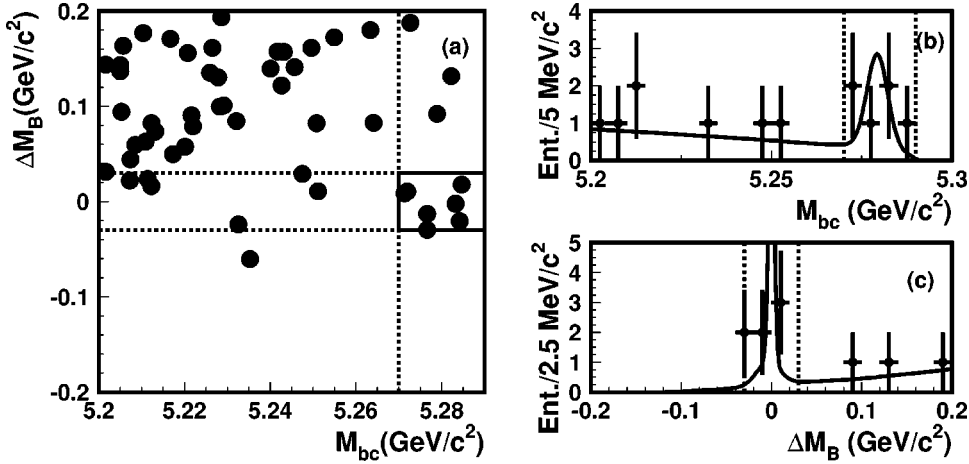


FIG. 1. (a) $(\Delta M_B, M_{bc})$ distribution of $B^- \rightarrow J/\psi \Lambda \bar{p}$ candidates, and its projections onto (b) M_{bc} and (c) ΔM_B . The dashed lines indicate the bands used for the projections. The curves illustrate the result of the fit described in the text.

Λ candidates are reconstructed via the $p\pi^-$ decay channel. We require that the transverse impact parameters of both Λ daughter tracks with respect to the nominal beam axis be greater than 0.03 cm, the z distance between the daughter tracks before constraining the Λ vertex be less than 12 cm, and the vertex fitting χ^2 be smaller than 100 (with one degree of freedom). The invariant mass of the Λ candidate is required to be within ± 6 MeV/ c^2 of the nominal Λ mass. These criteria are determined to maximize $S/\sqrt{S+B}$, where S is the number of expected signal events in the signal region defined below obtained from Monte Carlo (MC) simulations, and B is the number of expected background events obtained from sideband data. For the calculation of S , we assume the branching fraction of $B^- \rightarrow J/\psi \Lambda \bar{p}$ to be 1.0×10^{-5} which is consistent with our final result. We apply vertex and mass constrained fits for J/ψ and Λ candidates to improve the momentum resolution.

We identify $B^- \rightarrow J/\psi \Lambda \bar{p}$ candidates using two kinematic variables calculated in the center of mass frame: the beam-energy constrained mass, $M_{bc} \equiv \sqrt{E_{\text{beam}}^2 - \vec{p}_B^2}$, and the mass difference, $\Delta M_B \equiv M_B - m_{B^-}$, where E_{beam} is the beam energy, \vec{p}_B and M_B are the reconstructed momentum and mass of the B candidate, and m_{B^-} is the nominal B^- mass. Candidates with $|\Delta M_B| < 0.20$ GeV/ c^2 and $M_{bc} > 5.20$ GeV/ c^2 are selected for the final analysis. The signal region is defined to be 5.27 GeV/ $c^2 < M_{bc} < 5.29$ GeV/ c^2 and $|\Delta M_B| < 0.03$ GeV/ c^2 , which corresponds to three standard deviations based on the MC simulation. We also define a ΔM_B sideband region as 0.06 GeV/ $c^2 < \Delta M_B < 0.20$ GeV/ c^2 .

In this analysis, we do not use the widely used $\Delta E \equiv E_B - E_{\text{beam}}$, where E_B is the energy of the reconstructed B . For the $J/\psi \Lambda \bar{p}$ events, the kinematic limit of ΔE can be expressed as $\Delta E = \sqrt{M_{\text{tot}}^2 + E_{\text{beam}}^2} - M_{bc} - E_{\text{beam}}$, where M_{tot} is the sum of the masses of J/ψ , Λ and \bar{p} . This kinematic limit is close to the signal region and depends on M_{bc} , which introduces a distortion in the $M_{bc} - \Delta E$ phase space. Consequently, events outside the $M_{bc} / \Delta E$ signal region cannot be used to model the $\Delta E / M_{bc}$ distributions for the background. Furthermore, we find a large negative correlation between ΔE and M_{bc} for signal events. On the contrary, ΔM_B and M_{bc} are uncorrelated, which is confirmed using Monte Carlo

simulations. Therefore, we use ΔM_B and M_{bc} to identify signal candidates in this analysis [16].

Around 15% of the selected events have more than one B candidate. We select the best candidate by first choosing the Λ candidate with the smallest total χ^2 of the vertex and mass constrained fit. If multiple B candidates with the same Λ remain, we select the one with the smallest χ^2 of the $J/\psi \bar{p}$ vertex.

Figure 1 shows a scatter plot of ΔM_B versus M_{bc} and their projections for candidates after all selection criteria are applied. The $\Delta M_B(M_{bc})$ projection is shown for candidates in the $M_{bc}(\Delta M_B)$ signal region. There are six events in the $(M_{bc}, \Delta M_B)$ signal region. We obtain the signal yield by fitting the M_{bc} distribution, since this variable has a better agreement between data and MC simulations than ΔM_B . The background is described by an ARGUS function [17] and the signal PDF is modeled by a sum of two Gaussians plus a Crystal Ball line function [18] to account for the small tail, with parameters obtained from MC simulations. In the fitting, E_{beam} and the width of the main Gaussian are fixed as 5.289 GeV and 2.62 MeV/ c^2 respectively, based on a control sample of $B^- \rightarrow D^0 \pi^-$. We simultaneously fit the signal and sideband regions, where the PDF in the sideband region is given by an ARGUS function with the same parameters as used in the signal region, except for the normalization, which is allowed to float. The M_{bc} fit gives 3.5 ± 2.3 signal events and 0.92 ± 0.34 background events in the signal box. The statistical significance of the signal, defined as

TABLE I. Summary of uncertainties in the reconstruction efficiency.

Source	Relative systematic error
Tracking	$\pm 8.5\%$
PID (proton and pion)	$\pm 8\%$ (3% per p , 2% per π)
Lepton identification	$\pm 4\%$ (2% per lepton)
Λ reconstruction	$\pm 6\%$
Simulation modeling	+41.3% / -34.1%
MC statistics	$\pm 1.8\%$
Total	+43.6% / -36.8%

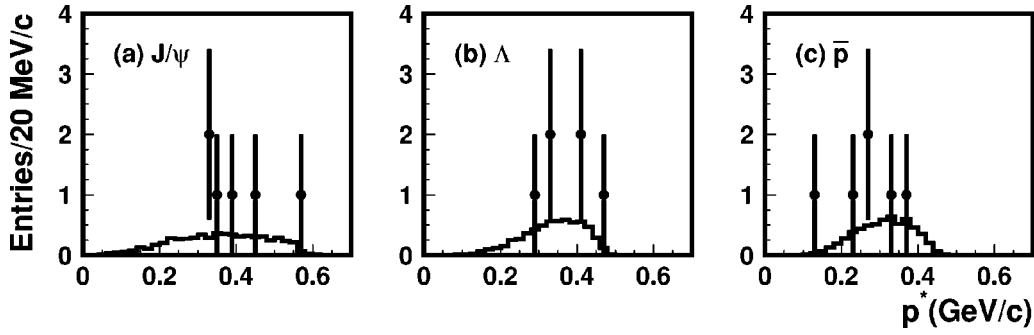


FIG. 2. Momentum distributions of (a) J/ψ , (b) Λ and (c) \bar{p} in the rest frame of the reconstructed B for the six $B^- \rightarrow J/\psi \Lambda \bar{p}$ candidates. The histograms are phase space distributions from signal MC simulations normalized to six events.

$\sqrt{-2 \ln(L_0/L_{\max})}$, is 2.3, where L_{\max} and L_0 denote the maximum likelihood with the fitted signal yield and with the yield fixed at zero, respectively. We examine the contribution of other decay modes including J/ψ and baryons, such as $B^- \rightarrow J/\psi \Sigma^0 \bar{p}$, which may also peak in the M_{bc} signal region. Using MC simulations, we find them to be negligible with an assumption that their branching fractions are comparable to $B^- \rightarrow J/\psi \Lambda \bar{p}$. As a cross check we also fit the ΔM_B distributions; the obtained signal yield is 4.7 ± 2.7 , with a statistical significance of 2.8, while the background yield is 0.55 ± 0.31 . These results are consistent with the results of the M_{bc} fit. Since the signal yield is not substantial, we give an upper limit of the branching fraction as the main result of this analysis.

The reconstruction efficiency (ϵ) is estimated using signal MC simulations where a three-body phase-space model is employed. We obtain $\epsilon = (6.3^{+2.7}_{-2.3})\%$. The sources and amounts of systematic uncertainties are summarized in Table I. The uncertainty of the tracking efficiency is estimated by adding the momentum dependent single track systematic error. The uncertainty is $\sim 1\%$ for leptons from J/ψ , $\sim 3.5\%$ and $\sim 1.6\%$ for low momentum pions and protons from Λ , and $\sim 1.4\%$ for prompt protons from B . The uncertainty of the Λ reconstruction is determined by comparing the proper time distributions for data and MC simulation. For the uncertainty due to modeling three-body decays in the phase space, we conservatively assign the maximum variation of the efficiencies among the slices of $M(J/\psi, \Lambda)$, $M(J/\psi, \bar{p})$, and $M(\Lambda, \bar{p})$.

We use the method of Feldman and Cousins [19], including the uncertainties of the background and efficiency estimations [20], to obtain a 90% confidence interval for the branching fraction given by $N_S / [\epsilon \times N_{B\bar{B}} \times \mathcal{B}(J/\psi \rightarrow l^+ l^-) \times \mathcal{B}(\Lambda \rightarrow p \pi^-)]$, where N_S is the signal yield, $N_{B\bar{B}}$ is the number of $B\bar{B}$ pairs, $(85.0 \pm 0.5) \times 10^6$, and the decay branching fractions $\mathcal{B}(J/\psi \rightarrow l^+ l^-)$ and $\mathcal{B}(\Lambda \rightarrow p \pi^-)$ are taken from the world averages [8]. The fractions of neutral and charged B mesons produced in $Y(4S)$ decays are as-

sumed to be equal. With six observed candidates, 0.92 ± 0.34 background events, and the uncertainties in ϵ , $N_{B\bar{B}}$, and secondary branching fractions mentioned above, we obtain an upper bound of the interval from this procedure of $\mathcal{B}(B^- \rightarrow J/\psi \Lambda \bar{p}) < 4.1 \times 10^{-5}$, which we interpret as a conservative estimate of the 90% confidence upper limit of the branching fraction [21].

Figure 2 shows the momentum distributions for J/ψ , Λ , and prompt \bar{p} of the six candidates in the B rest frame. We do not observe any significant enhancement above the phase space distribution, such as would be expected by an intermediate resonance [5].

In summary, we have searched for the decay of $B^- \rightarrow J/\psi \Lambda \bar{p}$ at Belle with 78 fb^{-1} data collected at the $Y(4S)$ resonance. No statistically significant signals are found. We set an upper limit of $\mathcal{B}(B^- \rightarrow J/\psi \Lambda \bar{p}) < 4.1 \times 10^{-5}$ at 90% confidence level. This result is consistent with the BaBar result [9]. This mode does not account for a significant fraction of the observed excess in the low momentum region of $B \rightarrow J/\psi X$.

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- [21] The 90% confidence interval obtained is $[3.5 \times 10^{-6}, 41 \times 10^{-6}]$. The central value of the branching fraction is $(8.7_{-6.5}^{+6.9}) \times 10^{-6}$, where the uncertainty includes both statistical and systematic components.