PHYSICAL REVIEW D **78,** 051104(R) (2008)

Observation of $B^{\pm} \to \psi(2S)\pi^{\pm}$ and search for direct CP violation

V. Bhardwaj,[35] R. Kumar,[35] J. B. Singh,[35] I. Adachi,[10] H. Aihara,[44] K. Arinstein,[1] T. Aushev,[20,15] T. Aziz,[41] S. Bahinipati,[3] A. M. Bakich,[40] V. Balagura,[15] E. Barberio,[23] A. Bay,[20] K. Belous,[14] U. Bitenc,[16] A. Bondar,[1] A. Bozek,[29] M. Bračko,[22,16] J. Brodzicka,[10] T. E. Browder,[9] M.-C. Chang,[4] P. Chang,[28] A. Chen,[26] B. G. Cheon,[8] R. Chistov,[15] I.-S. Cho,[49] S.-K. Choi,[7] Y. Choi,[39] J. Dalseno,[10] M. Dash,[48] A. Drutskoy,[3] S. Eidelman,[1] P. Goldenzweig,[3] B. Golob,[21,16] H. Ha,[18] T. Hara,[34] K. Hayasaka,[24] H. Hayashii,[25] M. Hazumi,[10] Y. Hoshi,[43] W.-S. Hou,[28] Y. B. Hsiung,[28] H. J. Hyun,[19] T. Iijima,[24] K. Inami,[24] A. Ishikawa,[36] H. Ishino,[45] R. Itoh,[10] M. Iwasaki,[44] Y. Iwasaki,[10] N. J. Joshi,[41] D. H. Kah,[19] J. H. Kang,[49] N. Katayama,[10] H. Kawai,[2] T. Kawasaki,[31] H. Kichimi,[10] H. O. Kim,[19] S. K. Kim,[38] Y. I. Kim,[19] Y. J. Kim,[6] K. Kinoshita,[3] S. Korpar,[22,16] P. Križan,[21,16] P. Krokovny,[10] A. Kuzmin,[1] Y.-J. Kwon,[49] S.-H. Kyeong,[49] J. S. Lange,[5] J. S. Lee,[39] S.-W. Lin,[28] C. Liu,[37] Y. Liu,[6] D. Liventsev,[15] F. Mandl,[13] A. Matyja,[29] S. McOnie,[40] T. Medvedeva,[15] K. Miyabayashi,[25] H. Miyata,[31] Y. Miyazaki,[24] R. Mizuk,[15] G. R. Moloney,[23] Y. Nagasaka,[11] M. Nakao,[10] Z. Natkaniec,[29] S. Nishida,[10] O. Nitoh,[47] S. Ogawa,[42] T. Ohshima,[24] S. Okuno,[17] S. L. Olsen,[9,12] H. Ozaki,[10] P. Pakhlov,[15] G. Pakhlova,[15] C. W. Park,[39] H. Park,[19] H. K. Park,[19] L. S. Peak,[40] R. Pestotnik,[16] L. E. Piilonen,[48] H. Sahoo,[9] Y. Sakai,[10] O. Schneider,[20] J. Schümann,[10] C. Schwanda,[13] A. J. Schwartz,[3] K. Senyo,[24] M. E. Sevior,[23] M. Shapkin,[14] C. P. Shen,[12] J.-G. Shiu,[28] B. Shwartz,[1] A. Somov,[3] S. Stanič,[32] M. Starič,[16] T. Sumiyoshi,[46] S. Suzuki,[36] N. Tamura,[31] M. Tanaka,[10] G. N. Taylor,[23] Y. Teramoto,[33] K. Trabelsi,[10] S. Uehara,[10] T. Uglov,[15] Y. Unno,[8] S. Uno,[10] P. Urquijo,[23] G. Varner,[9] K. E. Varvell,[40] K. Vervink,[20] C. C. Wang,[28] C. H. Wang,[27] M.-Z. Wang,[28] P. Wang,[12] X. L. Wang,[12] Y. Watanabe,[17] E. Won,[18] Y. Yamashita,[30] M. Yamauchi,[10] C. C. Zhang,[12] V. Zhulanov,[1] T. Zivko,[16] A. Zupanc,[16] and O. Zyukova[1]

(The Belle Collaboration)

[1]*Budker Institute of Nuclear Physics, Novosibirsk*
[2]*Chiba University, Chiba*
[3]*University of Cincinnati, Cincinnati, Ohio 45221*
[4]*Department of Physics, Fu Jen Catholic University, Taipei*
[5]*Justus-Liebig-Universität Gießen, Gießen*
[6]*The Graduate University for Advanced Studies, Hayama*
[7]*Gyeongsang National University, Chinju*
[8]*Hanyang University, Seoul*
[9]*University of Hawaii, Honolulu, Hawaii 96822*
[10]*High Energy Accelerator Research Organization (KEK), Tsukuba*
[11]*Hiroshima Institute of Technology, Hiroshima*
[12]*Institute of High Energy Physics, Chinese Academy of Sciences, Beijing*
[13]*Institute of High Energy Physics, Vienna*
[14]*Institute of High Energy Physics, Protvino*
[15]*Institute for Theoretical and Experimental Physics, Moscow*
[16]*J. Stefan Institute, Ljubljana*
[17]*Kanagawa University, Yokohama*
[18]*Korea University, Seoul*
[19]*Kyungpook National University, Taegu*
[20]*École Polytechnique Fédérale de Lausanne (EPFL), Lausanne*
[21]*Faculty of Mathematics and Physics, University of Ljubljana, Ljubljana*
[22]*University of Maribor, Maribor*
[23]*University of Melbourne, School of Physics, Victoria 3010*
[24]*Nagoya University, Nagoya*
[25]*Nara Women's University, Nara*
[26]*National Central University, Chung-li*
[27]*National United University, Miao Li*
[28]*Department of Physics, National Taiwan University, Taipei*
[29]*H. Niewodniczanski Institute of Nuclear Physics, Krakow*
[30]*Nippon Dental University, Niigata*
[31]*Niigata University, Niigata*
[32]*University of Nova Gorica, Nova Gorica*
[33]*Osaka City University, Osaka*
[34]*Osaka University, Osaka*
[35]*Panjab University, Chandigarh*

[36]*Saga University, Saga*
[37]*University of Science and Technology of China, Hefei*
[38]*Seoul National University, Seoul*
[39]*Sungkyunkwan University, Suwon*
[40]*University of Sydney, Sydney, New South Wales*
[41]*Tata Institute of Fundamental Research, Mumbai*
[42]*Toho University, Funabashi*
[43]*Tohoku Gakuin University, Tagajo*
[44]*Department of Physics, University of Tokyo, Tokyo*
[45]*Tokyo Institute of Technology, Tokyo*
[46]*Tokyo Metropolitan University, Tokyo*
[47]*Tokyo University of Agriculture and Technology, Tokyo*
[48]*Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061*
[49]*Yonsei University, Seoul*

(Received 15 July 2008; published 25 September 2008)

We report the first observation of $B^{\pm} \to \psi(2S)\pi^{\pm}$, a Cabibbo- and color-suppressed decay. This analysis is based on 657×10^6 $B\bar{B}$ events collected at the $\Upsilon(4S)$ resonance with the Belle detector at the KEKB energy-asymmetric e^+e^- collider. The measured branching fraction is $(2.44 \pm 0.22 \pm 0.20) \times 10^{-5}$ and the charge asymmetry is $\mathcal{A} = 0.022 \pm 0.085 \pm 0.016$. The ratio of the branching fractions $\mathcal{B}(B^{\pm} \to \psi(2S)\pi^{\pm})/\mathcal{B}(B^{\pm} \to \psi(2S)K^{\pm}) = (3.99 \pm 0.36 \pm 0.17)\%$ is also determined.

DOI: 10.1103/PhysRevD.78.051104 PACS numbers: 11.30.Er, 12.15.Hh, 13.25.Hw, 14.40.Gx

The study of exclusive B meson decays to charmonium has played an important role in exploring CP-violation [1]. Among these, Cabibbo-suppressed charmonium decays provide an opportunity to understand nonleptonic B decays [2–9] and can be studied at the B factories which, due to their high integrated luminosities, overcome the suppression factor. At quark level, the decay $B^- \to \psi(2S)\pi^-$ [10] proceeds primarily via a $b \to c\bar{c}d$ transition; the leading contribution to this decay comes from the Cabibbo- and color-suppressed tree diagram shown in Fig. 1. The measurement of the branching fraction for the decay $B^- \to \psi(2S)\pi^-$, which has not been observed so far, is important for detailed studies of the $b \to c\bar{c}d$ transition.

Assuming tree dominance and factorization, the branching fraction $\mathcal{B}(B^- \to \psi(2S)\pi^-)$ is expected to be about 5% of that of the Cabibbo- favored mode $B^- \to \psi(2S)K^-$ [11]. Under this assumption, the charge asymmetries for the $B^- \to \psi(2S)\pi^-$ and $B^- \to \psi(2S)K^-$ decays are expected to be negligibly small in the standard model. However, the penguin amplitude in the $b \to c\bar{c}d$ transition contains a complex phase due to one of the Kobayashi-Maskawa matrix elements [12], V_{td}, and therefore, if penguin or new physics contributions are substantial, direct CP violation may occur in $B^- \to \psi(2S)\pi^-$ [13,14].

In this paper, we report the first observation of the $B^- \to \psi(2S)\pi^-$ decay, along with a measurement of the branching fractions $\mathcal{B}(B^- \to \psi(2S)\pi^-)$ and the ratio $\mathcal{B}(B^- \to \psi(2S)\pi^-)/\mathcal{B}(B^- \to \psi(2S)K^-)$. A search for direct CP-violation in $B^- \to \psi(2S)\pi^-$ decays is also presented. These measurements are based on a data sample that contains $657 \times 10^6 B\bar{B}$ events, collected with the Belle detector [15] at the KEKB [16] energy-asymmetric e^+e^- collider operating at the $\Upsilon(4S)$ resonance.

The Belle detector is a large solid-angle magnetic spectrometer that consists of a silicon vertex detector (SVD) surrounded by a 50-layer central drift chamber (CDC), an array of aerogel threshold Cherenkov counters (ACC), a barrel-like arrangement of time-of-flight (TOF) scintillation counters, and an electromagnetic calorimeter (ECL) comprised of CsI(Tl) crystals. All these subdetectors are located inside a superconducting solenoid coil that provides a 1.5 T magnetic field. An iron flux-return yoke located outside the coil is instrumented to detect K_L^0 mesons and to identify the muons (KLM). The data sample used in this analysis is collected with two different detector configurations. The first sample of $152 \times 10^6 B\bar{B}$ events is collected with a 2.0 cm radius beam-pipe and a 3-layer SVD, while the remaining $505 \times 10^6 B\bar{B}$ events are collected with a 1.5 cm radius beam-pipe, a 4-layer SVD and a smaller-cell inner drift chamber [17]. The detector is described in detail elsewhere [15]. A GEANT-based Monte Carlo (MC) simulation is used to model the response of the detector and determine the efficiency of the signal reconstruction [18,19].

The reconstruction of the $\psi(2S)$ meson is performed using the $\ell^+\ell^-$ ($\ell = e$ or μ) and $J/\psi\pi^+\pi^-$ decay channels. The J/ψ mesons are reconstructed in the $\ell^+\ell^-$ decay

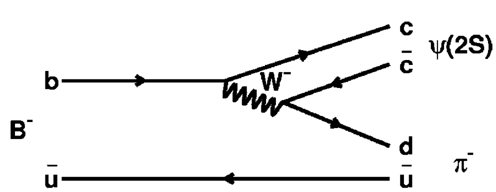

FIG. 1. Leading-order tree level diagram for the decays under study.

channel. Both daughter tracks of $J/\psi \to \ell^+\ell^-$ or $\psi(2S) \to \ell^+\ell^-$ decays are required to be positively identified as leptons. From the selected charged tracks, e^+ and e^- candidates are identified by combining information from the CDC (dE/dx), E/p (E is the energy deposited in the ECL and p is the momentum measured by the SVD and the CDC), and shower shape in the ECL. In addition, ACC information and position matching between electron track candidates and ECL clusters are used in the identification of electron candidates. Identification of μ candidates is based on the track penetration depth and hit pattern in the KLM system.

In $J/\psi \to e^+e^-$ and $\psi(2S) \to e^+e^-$ decays, the four-momenta of all photons within 50 mrad of each of the original e^+ or e^- tracks are included in the invariant mass calculation [hereafter denoted as $M_{e^+e^-(\gamma)}$], in order to reduce the radiative tail. The reconstructed invariant mass of the J/ψ candidates is required to satisfy $-0.150\ \mathrm{GeV}/c^2 < M_{e^+e^-(\gamma)} - m_{J/\psi} < 0.036\ \mathrm{GeV}/c^2$ or $-0.060\ \mathrm{GeV}/c^2 < M_{\mu^+\mu^-} - m_{J/\psi} < 0.036\ \mathrm{GeV}/c^2$, where $m_{J/\psi}$ denotes the nominal world-average J/ψ mass [20]. These intervals are asymmetric in order to include part of the radiative tails. In $\psi(2S)$ reconstruction, the invariant mass is required to satisfy $3.55\ \mathrm{GeV}/c^2 < M_{e^+e^-(\gamma)} < 3.75\ \mathrm{GeV}/c^2$ or $3.65\ \mathrm{GeV}/c^2 < M_{\mu^+\mu^-} < 3.75\ \mathrm{GeV}/c^2$. For the $\psi(2S) \to J/\psi\pi^+\pi^-$ candidates, $\Delta M = M_{\ell^+\ell^-\pi^+\pi^-} - M_{\ell^+\ell^-}$ should satisfy the condition $0.578\ \mathrm{GeV}/c^2 < \Delta M < 0.598\ \mathrm{GeV}/c^2$. In order to reduce the combinatorial background from low-momentum pions, $M_{\pi^+\pi^-}$ [invariant mass of the two pions coming from the $\psi(2S)$ decay] is required to be greater than $0.40\ \mathrm{GeV}/c^2$. In order to veto peaking background coming from K_S^0 ($B^- \to J/\psi K^{*-}(K_S^0\pi^-)$), all pairs of pions with mass $0.4856\ \mathrm{GeV}/c^2 < M_{\pi^+\pi^-} < 0.5096\ \mathrm{GeV}/c^2$ are rejected in the $\psi(2S) \to J/\psi\pi^+\pi^-$ reconstruction of the $B^- \to \psi(2S)\pi^-$ mode. A mass- and vertex-constrained fit is performed to all the selected $\psi(2S)$ and J/ψ candidates in order to improve the momentum resolution.

We combine $\psi(2S)$ and π^- (K^-) mesons to form B meson candidates. The combined information from the CDC (dE/dx), TOF, and ACC is used to identify π^- (K^-) on the basis of the $\pi - K$ likelihood ratio, $\mathcal{R}_{\pi(K)} = \mathcal{L}_{\pi(K)}/(\mathcal{L}_\pi + \mathcal{L}_K)$, where $\mathcal{L}_\pi(\mathcal{L}_K)$ is the likelihood of a pion (kaon) hypothesis. Charged tracks with $\mathcal{R}_\pi > 0.85$ ($\mathcal{R}_K > 0.85$) are identified as π^- (K^-). This requirement is 88.0% (82.6%) efficient for π (K) with a K (π) fake rate of 6.0% (3.7%).

To discriminate the signal from background, we use two kinematic variables: the beam-constrained mass, $M_{\rm bc} \equiv \sqrt{E_{\rm beam}^{*2} - p_B^{*2}}$ and the energy difference, $\Delta E \equiv E_B^* - E_{\rm beam}^*$ to discriminate the signal from the background, where $E_{\rm beam}^*$ is the run-dependent beam energy, and E_B^* and p_B^* are the reconstructed energy and momentum, respectively, of the B meson candidates in the center-of-mass (CM) frame. We retain B candidates with $5.27\ \mathrm{GeV}/c^2 < M_{\rm bc} < 5.29\ \mathrm{GeV}/c^2$ and $-0.15\ \mathrm{GeV} < \Delta E < 0.2\ \mathrm{GeV}$. After all selection requirements, 2.3% of the events for $\psi(2S)(\ell^+\ell^-)\pi^-$ and 7.1% for $\psi(2S) \times (J/\psi\pi^+\pi^-)\pi^-$ contain more than one B candidate. For these events, we choose the B candidate whose $M_{\rm bc}$ is closest to the nominal B meson mass.

To suppress continuum background, events having a ratio of the second to zeroth Fox-Wolfram moments [21] $R_2 > 0.5$ are rejected. Large $B \to (J/\psi, \psi(2S))X$ MC samples corresponding to 3.86×10^{10} generic $B\bar{B}$ events are used for the background study, because backgrounds predominantly come from B decays into final states having $J/\psi \to \ell^+\ell^-$ or $\psi(2S) \to \ell^+\ell^-$. We find that the dominant background comes from $B^- \to \psi(2S)K^-$ where the kaon is misidentified as a pion. This decay mode makes a peak at $\Delta E \sim -0.07$ GeV. Other backgrounds originate from random combinations of $\psi(2S)$ and π^- candidates (combinatorial background) and do not form any peaking structure in the ΔE projection of the MC sample. Studies of ΔM and $\ell^+\ell^-$ invariant mass data sidebands support this assumption.

We extract the signal yield by performing an unbinned extended maximum-likelihood fit to the ΔE distribution of the selected B candidates. The extended likelihood function used is

$$\mathcal{L}(N_S, N_{BK}, N_C) = \frac{e^{-(N_S+N_{BK}+N_C)}}{N!} \prod_{i=1}^{N} [N_S P_S(\Delta E_i) + N_{BK} P_{BK}(\Delta E_i) + N_C P_C(\Delta E_i)], \tag{1}$$

where N is the total number of candidate events; N_S, N_{BK}, and N_C denote the number of signal, background from $B^- \to \psi(2S)K^-$, and combinatorial background events, respectively. The modeling PDF's include a sum of two Gaussians for the signal ($P_S(\Delta E_i)$), a sum of two bifurcated Gaussians for the $B^- \to \psi(2S)K^-$ background ($P_{BK}(\Delta E_i)$) and a second-order polynomial for other backgrounds ($P_C(\Delta E_i)$). In this study the $B^- \to \psi(2S)K^-$ decay mode is used as a control sample, as well as the denominator of the relative branching fraction ratio $\mathcal{B}(B^- \to \psi(2S)\pi^-)/\mathcal{B}(B^- \to \psi(2S)K^-)$. The $B^- \to \psi(2S)\pi^-$ signal shape is fixed to that obtained from the $B^- \to \psi(2S)K^-$ control sample. The $B^- \to \psi(2S)K^-$ background shape is determined from the MC sample after applying a correction for the difference between data and MC. For the smooth combinatorial background, parameters of the second-order polynomial are floated in the fit.

We perform a simultaneous fit to all the considered $\psi(2S)$ decay modes to obtain a common branching fraction, taking into account different detection efficiencies for each subdecay mode and detector configuration. The efficiencies are determined from signal MC samples after

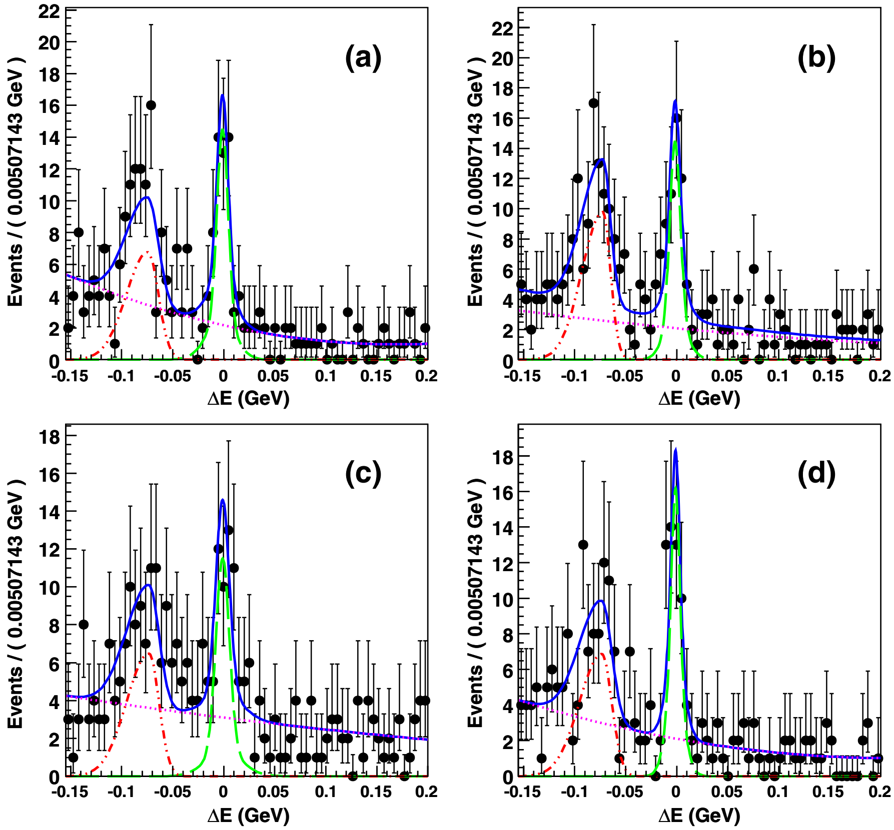

FIG. 2 (color online). ΔE distributions of the $B^- \to \psi(2S)\pi^-$ candidates, reconstructed in the following four submodes: (a) $B^- \to \psi(2S)(J/\psi(ee)\pi^+\pi^-)\pi^-$, (b) $B^- \to \psi(2S)(J/\psi(\mu\mu)\pi^+\pi^-)\pi^-$, (c) $B^- \to \psi(2S)(ee)\pi^-$, and (d) $B^- \to \psi(2S)(\mu\mu)\pi^-$. The curves show the signal (green dashed) and the background components (red dotted-dashed for $B^- \to \psi(2S)K^-$, magenta dotted for combinatorial background) as well as the overall fit (blue solid).

applying the correction factors taking into account the data and MC differences as described later. In the fit, the yield of $B^- \to \psi(2S)K^-$ (background) and the yield and polynomial parameters of the combinatorial backgrounds are floated for each decay mode separately. The fit gives a branching fraction of $(2.44 \pm 0.22 \pm 0.20) \times 10^{-5}$, where the first error is statistical and the second is systematic. Equal production of neutral and charged B meson pairs in the $\Upsilon(4S)$ decay is assumed. We use the $J/\psi \to e^+e^-$, $J/\psi \to \mu^+\mu^-$, $\psi(2S) \to J/\psi\pi^+\pi^-$, $\psi(2S) \to e^+e^-$, and $\psi(2S) \to \mu^+\mu^-$ intermediate branching fractions from Ref. [20]. Separate fits to the four submodes are also performed. The results are shown in Fig. 2 and summarized in Table I. The yields are calculated from the obtained branching fractions and efficiencies. The efficiencies listed in Table I are weighted averages of the two separate data sets. For all submodes, we observe signals with more than 5σ statistical significance and the branching fractions agree well with one another. The statistical significance is defined as $\sqrt{-2\ln(\mathcal{L}_0/\mathcal{L}_{\max})}$ where $\mathcal{L}_{\max}$ ($\mathcal{L}_0$) denotes the likelihood value at the maximum (with the signal yield fixed to zero).

A correction for small differences in the signal detection efficiency calculated from signal MC and data has been applied for the pion identification requirement, muon identification, and ΔM. Uncertainties on these corrections are included in the systematic error. The $J/\psi \to \ell^+\ell^-$ and $e^+e^- \to e^+e^-\ell^+\ell^-$ samples are used to estimate the lep-

TABLE I. Summary of the results.

Decay mode	Efficiency (%)	Signal yield	Branching fraction (10^{-5})	Statistical significance
$B^- \to \psi(2S)(J/\psi(e^+e^-)\pi^+\pi^-)\pi^-$	15.1	48.9 ± 8.3	2.57 ± 0.44	9.5σ
$B^- \to \psi(2S)(J/\psi(\mu^+\mu^-)\pi^+\pi^-)\pi^-$	16.8	44.0 ± 8.1	2.08 ± 0.38	8.4σ
$B^- \to \psi(2S)(e^+e^-)\pi^-$	32.2	44.0 ± 9.0	2.80 ± 0.57	7.3σ
$B^- \to \psi(2S)(\mu^+\mu^-)\pi^-$	35.7	43.5 ± 7.7	2.50 ± 0.44	9.0σ
$B^- \to \psi(2S)\pi^-$ (combined)			$2.44 \pm 0.22 \pm 0.20$	

ton identification correction and uncertainty whereas the pion (kaon) identification correction and uncertainty are determined from a $D^{*+} \to D^0(K^-\pi^+)\pi^+$ sample. A correction factor for the ΔM requirement is determined from the $B^- \to \psi(2S)K^-$ sample and is estimated by taking the ratio of yields from data and MC for tight ($0.578\ \mathrm{GeV}/c^2 < \Delta M < 0.598\ \mathrm{GeV}/c^2$) and loose ($0.570\ \mathrm{GeV}/c^2 < \Delta M < 0.610\ \mathrm{GeV}/c^2$) selection cuts. The fitting procedure is checked using signal and $B \to (J/\psi, \psi(2S))X$ MC samples and no significant bias is found. The signal yield systematic uncertainty is calculated by varying each fixed parameter in the fit by $\pm 1\sigma$, and then taking the sum in quadrature of the deviations of the signal yield from the nominal value. The total systematic uncertainty assigned to the yield estimation is 3.5%. The uncertainties due to the daughter branching fractions amount to 3.4%. The uncertainty on the tracking efficiency is estimated to be 1.2% per track and 5.0% in total. Systematic errors have been estimated by taking into account whether the particular error is correlated or uncorrelated and then combining them with the proper weights. All the systematic uncertainties are summarized in Table II. The total systematic error of 8.4% is the sum in quadrature of all the uncertainties.

The CP-violating charge asymmetry $\mathcal{A}$ is defined as

$$\mathcal{A} = \frac{\mathcal{B}(B^- \to \psi(2S)\pi^-) - \mathcal{B}(B^+ \to \psi(2S)\pi^+)}{\mathcal{B}(B^- \to \psi(2S)\pi^-) + \mathcal{B}(B^+ \to \psi(2S)\pi^+)}. \quad (2)$$

We extract branching fractions for B^+ and B^- samples separately using the same procedure as described above, except the polynomial background shape is fixed to that obtained in the previous fit to the total $B^{\pm} \to \psi(2S)\pi^{\pm}$ yield. We obtain

$$\mathcal{A} = 0.022 \pm 0.085 \pm 0.016 \quad (3)$$

with corresponding signal yields of 89 ± 11 and 93 ± 11 for B^+ and B^-, respectively. Here the systematic error includes contributions from the uncertainty on the yield extraction method, charge asymmetry in the pion identification efficiency as well as a possible detector bias and a possible difference between B^+ and B^- signal shape parameters. Among all these uncertainties, the only non-negligible one is a possible detector bias: it is estimated to be 0.016 from a study of $B^- \to J/\psi K^-$.

TABLE II. Summary of systematic errors on the $B^- \to \psi(2S)\pi^-$ branching fraction.

Source	Uncertainty (%)
Uncertainty in yield	3.5
Tracking error	5.0
Lepton identification	4.2
Pion identification	1.6
MC statistics	0.3
Number of $B\bar{B}$ pairs	1.4
Daughter branching fractions	3.4
ΔM requirement	0.5
Total	8.4

We also measure the ratio of $\mathcal{B}(B^- \to \psi(2S)\pi^-)$ and $\mathcal{B}(B^- \to \psi(2S)K^-)$. In a study using large $B \to (J/\psi, \psi(2S))X$ MC samples, the amount of background for $B^- \to \psi(2S)(\ell^+\ell^-)K^-$ is found to be negligible. On the other hand, in the case of $B^- \to \psi(2S)(J/\psi\pi^+\pi^-)K^-$, the decay mode $B^- \to J/\psi K_1(1270)^-$ as well as $B^- \to J/\psi\pi^+\pi^-K^-$ appear as peaking backgrounds since they have the same final state as the signal. The background estimation is performed using the ΔM data sideband defined as $0.51\ \mathrm{GeV}/c^2 < \Delta M < 0.57\ \mathrm{GeV}/c^2$ and $0.61\ \mathrm{GeV}/c^2 < \Delta M < 0.67\ \mathrm{GeV}/c^2$. We obtain 7.2 ± 2.7 events for $B^- \to \psi(2S)(J/\psi(ee)\pi\pi)K^-$ and 9.4 ± 2.7 events for $B^- \to \psi(2S)(J/\psi(\mu\mu)\pi\pi)K^-$ when scaled to the signal region. These backgrounds are subtracted from the appropriate signal yields. A simultaneous unbinned extended maximum-likelihood fit gives a branching fraction of $(6.12 \pm 0.09) \times 10^{-4}$ and corresponding signal yield of 4720 ± 69, where the error is statistical only. The resulting fit is shown in Fig. 3. The branching fraction is in good agreement with our previous measurement [4] and the world-average [20].

We obtain the ratio of $\mathcal{B}(B^- \to \psi(2S)\pi^-)$ and $\mathcal{B}(B^- \to \psi(2S)K^-)$ to be

$$\frac{\mathcal{B}(B^- \to \psi(2S)\pi^-)}{\mathcal{B}(B^- \to \psi(2S)K^-)} = (3.99 \pm 0.36 \pm 0.17)\%, \quad (4)$$

which is consistent with the expectations of the factorization hypothesis. Many sources of systematic errors cancel in the ratio of the branching fractions. Contributions to the systematic error come from the uncertainty in pion identification, signal extraction method, MC statistics from $B^- \to \psi(2S)\pi^-(K^-)$ decay, kaon identification, and uncertainty on the background estimation from $B^- \to \psi(2S)K^-$ decay. The total uncertainty is 4.2%.

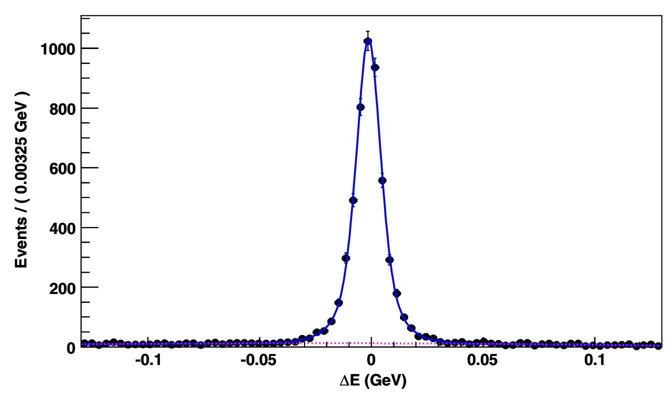

FIG. 3 (color online). ΔE distribution of the $B^- \to \psi(2S)K^-$ candidates. The curves show the overall fit and the background component (magenta dotted for combinatorial background).

In summary, we report the first observation of the decay $B^- \to \psi(2S)\pi^-$ using 657×10^6 $B\bar{B}$ events. The measured branching fraction is $\mathcal{B}(B^- \to \psi(2S)\pi^-) = (2.44 \pm 0.22 \pm 0.20) \times 10^{-5}$. No significant direct CP-violating charge asymmetry is observed in $B^- \to \psi(2S)\pi^-$. The ratio of branching fractions is $(3.99 \pm 0.36 \pm 0.17)\%$ which is consistent with the theoretical prediction based on factorization [11].

We thank the KEKB group for excellent operation of the accelerator, the KEK cryogenics group for efficient solenoid operations, and the KEK computer group and the NII for valuable computing and SINET3 network support. We acknowledge support from MEXT and JSPS (Japan); ARC and DEST (Australia); NSFC (China); DST (India); MOEHRD, KOSEF and KRF (Korea); KBN (Poland); MES and RFAAE (Russia); ARRS (Slovenia); SNSF (Switzerland); NSC and MOE (Taiwan); and DOE (USA).

[1] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. Lett. **87**, 091801 (2001); K. Abe *et al.* (Belle Collaboration), Phys. Rev. Lett. **87**, 091802 (2001).
[2] P. Avery *et al.* (CLEO Collaboration), Phys. Rev. D **62**, 051101 (2000).
[3] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. D **65**, 032001 (2002).
[4] K. Abe *et al.* (Belle Collaboration), Phys. Rev. D **67**, 032003 (2003).
[5] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. Lett. **91**, 061802 (2003).
[6] S. U. Kataoka *et al.* (Belle Collaboration), Phys. Rev. Lett. **93**, 261801 (2004); S. E. Lee *et al.* (Belle Collaboration), Phys. Rev. D **77**, 071101 (2008).
[7] B. Aubert *et al.* (*BABAR* Collaboration), Phys. Rev. D **74**, 011101(R)(2006).
[8] R. Kumar *et al.* (Belle Collaboration), Phys. Rev. D **74**, 051103 (R)(2006).
[9] M.-C. Chang *et al.* (Belle Collaboration), Phys. Rev. Lett. **98**, 131803 (2007).
[10] Hereafter charge-conjugate modes are included throughout the paper unless stated otherwise.
[11] M. Neubert and B. Stech, in *Heavy Flavours II*, edited by A. J. Buras and M. Linder (World Scientific, Singapore, 1988), pp. 345.
[12] N. Cabibbo, Phys. Rev. Lett. **10**, 531 (1963); M. Kobayashi and T. Maskawa, Prog. Theor. Phys. **49**, 652 (1973).
[13] M. Gronau, Phys. Rev. Lett. **63**, 1451 (1989).
[14] I. Dunietz, Phys. Lett. B **316**, 561 (1993).
[15] A. Abashian *et al.* (Belle Collaboration), Nucl. Instrum. Methods Phys. Res., Sect. A **479**, 117 (2002).
[16] S. Kurokawa and E. Kikutani, Nucl. Instrum. Methods Phys. Res., Sect. A **499**, 1 (2003) and other papers included in this volume.
[17] Z. Natkaniec (Belle SVD2 Group), Nucl. Instrum. Methods Phys. Res., Sect. A **560**, 1 (2006).
[18] We use the EvtGen *B* meson decay generator developed by the CLEO and *BABAR* Collaborations, see: http://www.slac.stanford.edu/~lange/EvtGen/.
[19] The detector response is simulated with a program based on GEANT-3, CERN program library long writeup W5013, CERN (1993).
[20] W.-M. Yao *et al.* (Particle Data Group), J. Phys. G **33**, 1 (2006) and 2007 partial update for 2008.
[21] G. Fox and S. Wolfram, Phys. Rev. Lett. **41**, 1581 (1978).