Observation of the $D_{sJ}(2317)$ and $D_{sJ}(2457)$ in $B$ decays

P. Krokovny,1 K. Abe,7 K. Abe,38 T. Abe,7 I. Adachi,7 H. Aihara,40 K. Akai,7 M. Akatsu,20 M. Akemoto,7 Y. Asano,45 T. Aso,44 T. Aushhev,11 A. M. Bakich,35 I. Bedny,1 P. K. Behera,46 I. Bizjak,12 A. Bondar,1 M. Bračko,18,12 T. E. Browder,6 B. C. K. Casey,6 Y. Chao,24 B. G. Cheon,34 R. Chistov,11 S.-K. Choi,5 Y. Choi,34 Y. K. Choi,34 A. Chuvikov,30 L. Y. Dong,9 J. Dragic,19 S. Eidelman,1 V. Eiges,11 Y. Enari,20 J. Flanagan,7 N. Gabyshev,7 A. Garmash,1,7 T. Gershon,7 B. Golosh,17,12 R. Guo,22 C. Hagner,47 F. Handa,39 N. C. Hastings,7 H. Hayashii,21 M. Hazumi,7,15 L. Hinz,16 T. Hokune,20 Y. Hoshi,38 W.-S. Hou,24 H.-C. Huang,24 Y. Igarashi,7 H. Ikeda,7 A. Ishikawa,20 R. Itoh,7 H. Iwasaki,7 M. Iwasaki,40 K. H. Jiang,33 T. Kamitani,7 J. H. Kang,49 N. Katayama,7 H. Kawai,2 T. Kawasaki,37 H. Kichimi,7 E. Kikutani,7 D. W. Kim,34 H. J. Kim,49 Hyunwoo Kim,14 J. H. Kim,34 K. Kinoshita,3 H. Koiso,7 P. Koppenburg,7 S. Korpar,18,12 P. Križan,17,12 A. Kuzmin,1 Y.-J. Kwon,49 J. S. Lange,4,31 S. H. Lee,33 T. Lesiak,25 A. Limosani,19 S.-W. Lin,24 J. MacNaughton,10 G. Majumder,36 F. Mandl,10 M. Masuzawa,7 T. Matsumoto,42 S. Michizono,7 Y. Mikami,39 W. Mitaroff,10 H. Miyata,27 D. Mohapatra,47 G. R. Moloney,19 T. Nagamine,39 Y. Nagasaka,8 T. Nakadaira,40 T. T. Nakamura,7 E. Nakano,28 M. Nakao,7 H. Nakazawa,7 J. W. Nam,44 Z. Natkaniec,8 O. Nitoh,43 T. Nozaki,7 S. Ogawa,37 Y. Ogawa,7 Y. Ohnishi,7 T. Ohshima,20 N. Ohuchi,7 K. Oide,7 T. Okabe,20 S. Okuno,13 S. L. Olsen,6 W. Ostrowicz,25 H. Ozaki,7 P. Pakhlov,11 H. Palka,25 C. W. Park,14 H. Park,15 K. S. Park,34 N. Parslow,35 L. E. Piilonen,47 N. Root,1 M. Rozanska,29 H. Sagawa,7 S. Saitoh,7 Y. Sakai,7 T. R. Sarangi,46 A. Satpathy,7,8 O. Schneider,16 C. Schwanda,7,10 A. J. Schwartz,3 S. Semenov,11 M. E. Sevior,19 H. Shibuya,47 T. Shidara,7 V. Sidorov,1 J. B. Singh,29 N. Soni,29 S. Stanič,45,46 A. Sugi,20 K. Sumisawa,7 T. Suniyoshi,42 S. Suzuki,48 F. Takasaka,7 K. Tamai,7 N. Tamura,27 J. Tanaka,40 M. Tanaka,7 M. Tawada,7 Y. Teramoto,28 T. Tomura,40 K. Trabelsi,6 T. Tsuboyama,7 T. Tsukamoto,7 S. Uehara,7 K. E. Varvell,35 C. H. Wang,24 Y. Watanabe,41 E. Won,14 B. D. Yabsley,47 Y. Yamada,7 A. Yamaguchi,39 N. Yamamoto,7 Y. Yamashita,26 M. Yamauchi,7 H. Yanai,27 Y. Yuan,9 C. C. Zhang,9 Z. P. Zhang,32 V. Zhilich,1 and D. Zonta,17,12

(The Belle Collaboration)

1Budker Institute of Nuclear Physics, Novosibirsk
2Chiba University, Chiba
3University of Cincinnati, Cincinnati, Ohio 45221
4University of Frankfurt, Frankfurt
5Gyeongsang National University, Chinju
6University of Hawaii, Honolulu, Hawaii 96822
7High Energy Accelerator Research Organization (KEK), Tsukuba
8Hiroshima Institute of Technology, Hiroshima
9Institute of High Energy Physics, Chinese Academy of Sciences, Beijing
10Institute of High Energy Physics, Vienna
11Institute for Theoretical and Experimental Physics, Moscow
12J. Stefan Institute, Ljubljana
13Kanagawa University, Yokohama
14Korea University, Seoul
15Kyungpook National University, Taegu
16Institut de Physique des Hautes Énergies, Université de Lausanne, Lausanne
17University of Ljubljana, Ljubljana
18University of Maribor, Maribor
19University of Melbourne, Victoria
20Nagoya University, Nagoya
21Nara Women’s University, Nara
22National Kaohsiung Normal University, Kaohsiung
23National Lien-Ho Institute of Technology, Miaoli
24Department of Physics, National Taiwan University, Taipei
25H. Niewodniczanski Institute of Nuclear Physics, Krakow
26Nihon Dental College, Niigata
27Niigata University, Niigata
28Osaka City University, Osaka
29Panjab University, Chandigarh
30Princeton University, Princeton, New Jersey 08545
31RIKEN BNL Research Center, Upton, New York 11973
32University of Science and Technology of China, Hefei
We report the first observation of the $B \rightarrow D\bar{D}_{sJ}(2317)$ and $B \rightarrow D\bar{D}_{sJ}(2457)$ decays based on 123.8×10^6 $B\bar{B}$ events collected with the Belle detector at KEKB. We observe the $D_{sJ}(2317)$ decay to $D_s\pi^0$ and $D_{sJ}(2457)$ decay to the $D_s^*\pi^0$ and $D_s\gamma$ final states. We also set 90% CL upper limits for the decays $D_{sJ}(2317) \rightarrow D_s^*\gamma$, $D_{sJ}(2457) \rightarrow D_s^*\gamma$, $D_{sJ}(2457) \rightarrow D_s\pi^0$ and $D_{sJ}(2457) \rightarrow D_s\pi^+\pi^-$. 

PACS numbers: 13.25.Hw, 14.40.Lb

Recently a new $D_s\pi^0$ resonance with a mass of 2317 MeV/c^2 and a very narrow width was observed by the BaBar collaboration (1). A natural interpretation is that this is a $P$-wave $c\bar{s}$ quark state that is below the $DK$ threshold, which accounts for the small width (2). This interpretation is supported by the observation of a $D_s^*\pi^0$ resonance (3) by the CLEO collaboration (4) and Belle collaboration (5). All groups observe these states in inclusive $e^+e^-$ processes. The mass difference between the two observed states is consistent with the expected hyperfine splitting of the $P$-wave $D_s$ meson doublet with total light-quark angular momentum $j = 1/2$ (2). However, the masses of these states are considerably below potential model expectations (3), and are nearly the same as those of the corresponding $cu$ states recently measured by Belle (5). The low mass values have caused speculation that these states may be more exotic than a simple $q\bar{q}$ meson system (3, 4, 10, 11, 12, 13). To clarify the nature of these states, it is necessary to determine their quantum numbers and decay branching fractions, particularly those for radiative decays. In this context it is useful to search for these states, which we refer to as $D_{sJ}$, in exclusive $B$ meson decay processes.

We search for decays of the type $B \rightarrow D\bar{D}_{sJ}$, which are expected to be the dominant exclusive $D_{sJ}$ production mechanism in $B$ decays. Because of the known properties of the parent $B$ meson, angular analyses of these decays can unambiguously determine the $D_{sJ}$ quantum numbers. Moreover, since QCD sum rules in HQET predict that $P$-wave mesons with $j = 1/2$ should be more readily produced in $B$ decays than mesons with $j = 3/2$ (14), the observation of $B \rightarrow D\bar{D}_{sJ}$ would provide additional support for the $P$-wave nature of these states as well as serving as a check of these predictions.

In this Letter we report on a search for the $B \rightarrow D\bar{D}_{sJ}(2317)$ and $B \rightarrow D\bar{D}_{sJ}(2457)$ decays based on a sample of 123.8×10^6 $B\bar{B}$ pairs produced at the KEKB asymmetric energy $e^+e^-$ collider (15). The inclusion of charge conjugate states is implicit throughout this report.

The Belle detector has been described elsewhere (16). Charged tracks are selected with a set of requirements based on the average hit residual and impact parameter relative to the interaction point (IP). The transverse momentum of at least 0.05 GeV/c is required for each track in order to reduce the combinatorial background.

For charged particle identification (PID), the combined information from specific ionization in the central drift chamber ($dE/dx$), time-of-flight scintillation counters and aerogel Čerenkov counters is used. Charged kaons are selected with PID criteria that have an efficiency of 88%, a pion misidentification probability of 8%, and negligible contamination from protons. All charged tracks with PID responses consistent with a pion hypothesis that are not positively identified as electrons are considered as pion candidates.

Neutral kaons are reconstructed via the decay $K^0_S \rightarrow \pi^+\pi^-$ with no PID requirements for the daughter pions. The two-pion invariant mass is required to be within 9 MeV/c^2 ($\sim 3\sigma$) of the $K^0_S$ mass and the displacement of the $\pi^+\pi^-$ vertex from the IP in the transverse ($r - \varphi$) plane is required to be between 0.2 cm and 20 cm. The direction in the $r - \varphi$ plane from the IP to the $\pi^+\pi^-$ vertex is required to agree within 0.2 radians with the combined momentum of the two pions.

Photon candidates are selected from calorimeter showers not associated with charged tracks. An energy de-
position of at least 30 MeV and a photon-like shape are required for each candidate. A pair of photons with an invariant mass within 12 MeV/c² (~2.5σ) of the π₀ mass is considered as a π₀ candidate.

We reconstruct \( \bar{D}^0(D^-) \) mesons in the \( K^+\pi^- \), \( K^+\pi^-\pi^+ \) and \( K^+\pi^0\pi^0 \) (\( K^+\pi^-\pi^- \)) decay channels and require the invariant mass to be within 12 MeV/c² (1.5σ for \( K^+\pi^-\pi^0 \) and 2.5σ for other modes) of the \( \bar{D}^0(D^-) \) mass. For the \( \pi^0 \) from the \( \bar{D}^0 \) → \( K^+\pi^-\pi^- \) decay, we require that the \( \pi^0 \) momentum in the \( Y(4S) \) center-of-mass (CM) frame be greater than 0.4 GeV/c in order to reduce combinatorial backgrounds. We reconstruct \( D^+_s \) mesons in the \( \phi\pi^+ \), \( K^0\phi \) and \( K^0\phi \) decay channels. \( K^0 \) mesons are reconstructed from \( K^+K^- \) pairs with an invariant mass within 10 MeV/c² (2.5σ) of the \( K^- \) mass. \( K^0 \) mesons are reconstructed from \( K^-\pi^+ \) pairs with an invariant mass within 75 MeV/c² (1.5σ) of the \( K^0 \) mass. After calculating the invariant mass of the corresponding set of particles, we define the \( D^+_s \) signal region as being within 12 MeV/c² (~2.5σ) of the \( D_s \) mass. \( D^+_s \) mesons are reconstructed in the \( D^+_s \rightarrow D_s\gamma \) decay channel. The mass difference between \( D^+_s \) and \( D_s \) candidates is required to be within 8 MeV/c² of its nominal value (~2.5σ). The \( D_{sJ} \) candidates are reconstructed from \( D^0 \) mesons and a \( \pi^0 \), \( \gamma \), or \( \pi^+\pi^- \) pair. The mass difference \( M(D_{sJ}) - M(D^0) \) is used to select \( D_{sJ} \) candidates. We use central mass values of 2317 MeV/c² and 2400 MeV/c² for \( D_{sJ}(2317) \) and \( D_{sJ}(2457) \) respectively and define signal regions within 12 MeV/c² for the corresponding mass difference.

We combine \( \bar{D} \) and \( D_{sJ} \) candidates to form \( B \) mesons. Candidate events are identified by their CM energy difference, \( \Delta E = (\sum p_i - E_{beam}) \), and the beam constrained mass, \( M_{bc} = \sqrt{E_{beam}^2 - (\sum p_i^2)} \), where \( E_{beam} \) is the beam energy and \( p_i^2 \) are the momenta and energies of the decay products of the \( B \) meson in the CM frame. We select events with 5.272 GeV/c² < \( M_{bc} < 5.288 \) GeV/c² and \( |\Delta E| < 0.2 \) GeV, and define a \( B \) signal region of \( |\Delta E| < 0.03 \) GeV. In cases with more than one candidate in an event, the one with \( D \) and \( D^+_s \) masses closest to the nominal values is chosen. We use a Monte Carlo (MC) simulation to model the response of the detector and determine the efficiency.

Variables that characterize the event topology are used to suppress background from the two-jet-like \( e^+e^- \rightarrow q\bar{q} \) continuum process. We require that \( \cos \theta_{thr} < 0.80 \), where \( \theta_{thr} \) is the angle between the thrust axis of the \( B \) candidate and that of the rest of the event; this eliminates 77% of the continuum background while retaining 78% of the signal events. To suppress combinatorial background we apply a restriction on the invariant mass of the \( D \) meson and the \( \pi^0 \) or \( \gamma \) from \( D_{sJ} \) decay: \( M(D\pi^0) > 2.3 \) GeV/c², \( M(D\gamma) > 2.2 \) GeV/c².

The \( \Delta E \) and \( D_{sJ} \) candidate’s invariant mass (\( M(D_{sJ}) \)) distributions for \( B \rightarrow \bar{D}D_{sJ} \) candidates are presented in Fig. 1 where all \( \bar{D}^0 \) and \( D^- \) decay modes are combined. Each distribution is the projection of the signal region of the other parameter; distributions for events in the \( M(D_{sJ}) \) and \( \Delta E \) sidebands are shown as crosshatched histograms. Clear signals are observed for the \( D_{sJ}(2317)[D_\pi^0\pi^0] \) and \( D_{sJ}(2457)[D^0_\pi^0\pi^0, D^*_\pi^0\gamma] \) final states. The measured masses for the \( D_{sJ}(2317) \) and \( D_{sJ}(2457) \) are \( (2319.8 \pm 2.1 \pm 2.0) \) MeV/c² and \( (2459.2 \pm 1.6 \pm 2.0) \) MeV/c² respectively. The fitted widths are consistent with those expected for \( D_s \) mesons of zero intrinsic width. The systematic error in the \( D_{sJ} \) mass is expected to come from the photon energy scale.

We also study the helicity distribution for the \( D_{sJ}(2457) \) → \( D_s\gamma \) decay. The helicity angle \( \theta_{D_s\gamma} \) is defined as the angle between the \( D_{sJ}(2457) \) momentum in the \( B \) meson rest frame and the \( D_s \) momentum in the \( D_{sJ}(2457) \) rest frame. The \( \theta_{D_s\gamma} \) distribution in the data (Fig. 2) is consistent with MC expectations for the \( J = 1 \) hypothesis for the \( D_{sJ}(2457) \) (\( \chi^2/n.d.f. = 5/6 \)), and contradicts the \( J = 2 \) hypothesis (\( \chi^2/n.d.f. = 44/6 \)). The \( J = 0 \) hypothesis is already ruled out by the conservation of angular momentum and parity in \( D_{sJ}(2457) \rightarrow D_s\gamma \).

For each decay channel, the \( \Delta E \) distribution is fitted with a Gaussian signal and a linear background function. The Gaussian mean value and width are fixed to the values from a MC simulation of signal events. The region \( \Delta E < -0.07 \) GeV is excluded from the fit to avoid contributions from other \( B \) decays of the type \( B \rightarrow \bar{D}D_{sJ}X \) where \( X \) denotes an additional particle that is not reconstructed. The \( M(D_{sJ}) \) distribution is fitted by the sum of a Gaussian for the signal, and a linear function for the background. The Gaussian width is fixed to the value found in the MC (6–7 GeV/c² depending on the decay mode). The fit results are given in Table 1 where the listed efficiencies include intermediate branching fractions. We use the \( \Delta E \) distribution to calculate the branching fractions. The statistical significance of the signal quoted in Table 1 is defined as \( \sqrt{-2\ln(L_0/L_{max})} \), where \( L_{max} \) and \( L_0 \) denote the maximum likelihood with the nominal and with zero signal yield, respectively.

The results of combined fits of \( B^+ \rightarrow \bar{D}^0D^0_{sJ} \) and \( B^0 \rightarrow D^-D^+_{sJ} \) modes assuming isospin invariance are shown in Table 1. The normalization of the background in each sub-mode is allowed to float while the signal yields are required to satisfy the constraint \( N_t = N_{BB}\cdot B(B \rightarrow \bar{D}D_{sJ}) \cdot \varepsilon_i \), where the branching fraction \( B(B \rightarrow \bar{D}D_{sJ}) \) is a fit parameter; \( N_{BB} \) is the number of \( BB \) pairs and \( \varepsilon_i \) is the efficiency, which includes all intermediate branching fractions. From the two \( B \rightarrow \bar{D}D_{sJ}(2457) \) branching fraction measurements, we determine the ratio \( B(D_{sJ}(2457) \rightarrow D_s\gamma)/B(D_{sJ}(2457) \rightarrow D^*_\pi^0\gamma) \) = 0.38 ± 0.11 ± 0.04.

The signals for the \( B \rightarrow \bar{D}D_{sJ}(2317)[D_\pi^0\pi^0] \) and \( B \rightarrow \bar{D}D_{sJ}(2457)[D^0_\pi^0\pi^0, D^*_\pi^0\gamma] \) channels have greater than 5σ statistical significance. Figure 3 shows the \( \Delta E \) distributions for the other channels, where significant signals are
similar final states: we apply a similar procedure to decay chains with the sample. No peaking background is found. As a check, B sample of generic B decay modes using MC. We also analyze a MC sH (2457) [sH 0](2317) J/ψ, sH(2457) [sH 0](2317) J/ψ. Points with errors represent the experimental data, crosshatched histograms show the sidebands and curves are the results of the fits.

FIG. 1: ∆E (left) and M(D_{sJ}) (right) distributions for the B → D_{sJ} candidates: (a) D_{sJ}(2317) → D_{π^0}, (b) D_{sJ}(2457) → D_{π^0} and (c) D_{sJ}(2457) → D_{π^0}, D_{γ}. Points with errors represent the experimental data, crosshatched histograms show the sidebands and curves are the results of the fits.

TABLE I: Product branching fractions for B → DD_{sJ} decays.

| Decay channel | ∆E yield | M(D_{sJ}) yield | Efficiency, 10^{-4} | B, 10^{-4} | Significance |
|---------------|-----------|-----------------|---------------------|-----------|--------------|
| B^+ → D^0D^+_s(J/ψ)(2317) | 13.7$$^{+3.4}_{-4.5}$$ | 13.4$$^{+6.2}_{-5.4}$$ | 1.36 | 8.1$$^{+1.0}_{-2.3}$$ ± 2.4 | 5.0σ |
| B^0 → D^0D^+_s(J/ψ)(2317) | 10.3$$^{+3.9}_{-3.1}$$ | 10.8$$^{+4.2}_{-3.6}$$ | 0.97 | 8.6$$^{+3.3}_{-2.6}$$ ± 2.6 | 6.1σ |
| B^+ → D^0D^+_s(J/ψ)(2317) | 3.4$$^{+2.8}_{-2.2}$$ | 2.1$$^{+4.1}_{-3.4}$$ | 1.08 | 2.5$$^{+2.1}_{-1.5}$$ (< 7.6) | — |
| B^0 → D^0D^+_s(J/ψ)(2317) | 2.3$$^{+2.5}_{-1.9}$$ | 1.6$$^{+2.4}_{-1.9}$$ | 0.69 | 2.7$$^{+2.9}_{-2.2}$$ (< 9.5) | — |
| B^+ → D^0D^+_s(J/ψ)(2317) | 7.2$$^{+3.7}_{-3.0}$$ | 8.9$$^{+4.0}_{-3.3}$$ | 0.49 | 11.9$$^{+6.1}_{-4.9}$$ ± 3.6 | 2.9σ |
| B^0 → D^0D^+_s(J/ψ)(2317) | 11.8$$^{+3.8}_{-3.2}$$ | 14.9$$^{+4.4}_{-3.9}$$ | 0.42 | 22.7$$^{+7.3}_{-6.8}$$ ± 6.8 | 6.5σ |
| B^+ → D^0D^+_s(J/ψ)(2317) | 19.1$$^{+5.0}_{-6.9}$$ | 20.2$$^{+7.2}_{-6.9}$$ | 2.75 | 5.6$$^{+1.6}_{-1.9}$$ ± 1.7 | 5.0σ |
| B^0 → D^0D^+_s(J/ψ)(2317) | 18.5$$^{+5.0}_{-4.9}$$ | 19.6$$^{+5.6}_{-5.0}$$ | 1.83 | 8.2$$^{+2.2}_{-2.3}$$ ± 2.5 | 6.5σ |
| B^+ → D^0D^+_s(J/ψ)(2317) | 4.4$$^{+3.8}_{-3.3}$$ | 8.2$$^{+4.0}_{-3.4}$$ | 1.15 | 3.1$$^{+2.7}_{-2.3}$$ (< 9.8) | — |
| B^0 → D^0D^+_s(J/ψ)(2317) | 1.1$$^{+1.8}_{-1.2}$$ | 0.2$$^{+1.8}_{-1.2}$$ | 0.71 | 1.3$$^{+2.0}_{-1.4}$$ (< 6.0) | — |
| B^+ → D^0D^+_s(J/ψ)(2317) | < 4.0 | < 2.2 | < 2.2 | — |
| B^0 → D^0D^+_s(J/ψ)(2317) | < 2.5 | < 2.0 | < 2.0 | — |
| B^+ → D^0D^+_s(J/ψ)(2317) | < 2.4 | < 2.0 | < 2.0 | — |
| B^0 → D^0D^+_s(J/ψ)(2317) | < 2.4 | < 2.0 | < 2.0 | — |

The following sources of systematic errors are considered: tracking efficiency (1-2% per track), kaon identification efficiency (1%), π^0 efficiency (6%), K^0 S reconstruction efficiency (6%), D branching fraction uncertainties (2%-6%), signal and background shape parameterization (4%) and MC statistics (3%). The uncertainty in the tracking efficiency is estimated using partially reconstructed D^{π^+} → D^0[K_S^0π^0π^-]π^+ decays. The kaon identification uncertainty is determined from D^{π^+} → D^0[K^-π^+]π^+ decays. The π^0 reconstruction is seen. We set 90% confidence level (CL) upper limits for these modes.

We study the possible feed-in between all studied D_{sJ} decay modes using MC. We also analyze a MC sample of generic B̅B events corresponding to our data sample. No peaking background is found. As a check, we apply a similar procedure to decay chains with the similar final states: B → D^(*) D_{sJ}^(*) . For each mode, we measure branching fractions that are consistent with the world average values [18].
TABLE II: Combined fit results.

| Decay channel | $B, 10^{-4}$ | Significance |
|---------------|--------------|--------------|
| $B \to D_{sJ}(2317) [D_s^0\pi^0]$ | $8.5^{+1.0}_{-0.9} \pm 2.6$ | $6.1\sigma$ |
| $B \to D_{sJ}(2317) [D_s^0\pi^0]$ | $2.5^{+1.0}_{-0.9} \pm 7.5$ | $1.8\sigma$ |
| $B \to D_{sJ}(2457) [D_s^0\pi^0]$ | $17.8^{+5.9}_{-3.9} \pm 5.3$ | $6.4\sigma$ |
| $B \to \bar{D}D_{sJ}(2457) [\bar{D}_s^0\gamma]$ | $6.7^{+1.5}_{-1.2} \pm 2.0$ | $7.4\sigma$ |
| $B \to \bar{D}D_{sJ}(2457) [\bar{D}_s^0\pi^0]$ | $2.7^{+1.5}_{-1.2} \pm 7.3$ | $2.1\sigma$ |
| $B \to D_{sJ}(2457) [D_s^0\pi^-\pi^+]$ | $< 1.6$ | $-$ |
| $B \to \bar{D}D_{sJ}(2457) [\bar{D}_s^0\pi^0]$ | $< 1.8$ | $-$ |

FIG. 2: The $D_{sJ}(2457) \to D_s \gamma$ helicity distribution. The points with error bars are the results of fits to the $\Delta E$ spectra for experimental events. Solid and dashed curves are MC predictions for the $J = 1$ and $J = 2$ hypotheses, respectively. The highest bin has no events because of the cut on the $D_s \gamma$ invariant mass.

knowledge support from the Ministry of Education, Culture, Sports, Science, and Technology of Japan and the Japan Society for the Promotion of Science; the Australian Research Council and the Australian Department of Education, Science and Training; the National Science Foundation of China under contract No. 10175071; the Department of Science and Technology of India; the BK21 program of the Ministry of Education of Korea and the CHEP SRC program of the Korea Science and Engineering Foundation; the Polish State Committee for Scientific Research under contract No. 2P03B 01324; the Ministry of Science and Technology of the Russian Federation; the Ministry of Education, Science and Sport of the Republic of Slovenia; the National Science Council and the Ministry of Education of Taiwan; and the U.S. Department of Energy.

* on leave from Nova Gorica Polytechnic, Nova Gorica
[1] BaBar Collaboration, B. Aubert et al., Phys. Rev. Lett. 90, 242001 (2003).
[2] W. Bardeen, E. Eichten and C. Hill, Phys. Rev. D 68, 054024 (2003).
[3] In the heavy $c$-quark mass limit, one expects two doublets of $c\bar{s}$ states with quantum numbers $J^P = 0^+$, $1^+$ and $1^-, 2^-$. The second one has been observed in $D(1370)K$ decays.
[4] CLEO Collaboration, D. Besson et al., Phys. Rev. D 68, 032002 (2003).
[5] Belle Collaboration, K. Abe et al., EPS contribution paper, BELLE-CONF-0340, hep-ex/0307052.
[6] J. Bartelt and S. Shukla, Ann. Rev. Nucl. Part. Sci. 45, 133 (1995).

[7] Belle Collaboration, K. Abe et al., hep-ex/0307021, submitted to Phys. Rev. D.

[8] R. Cahn and D. Jackson, Phys. Rev. D 68, 037502 (2003).

[9] T. Barnes, F. Close and H. Lipkin, Phys. Rev. D 68, 054006 (2003).

[10] E. Beveren and G. Rupp, Phys. Rev. Lett. 91, 012003 (2003).

[11] H. Cheng and W. Hou, Phys. Lett. B 566, 193 (2003).

[12] P. Colangelo and F. Fazio, Phys. Lett. B 570, 180 (2003).

[13] S. Godfrey, Phys. Lett. B 568, 254 (2003).

[14] A. Yaouanc et al., Phys. Lett. B 520, 59 (2001).

[15] S. Kurokawa and E. Kikutani, Nucl. Instr. and Meth. A 499, 1 (2003).

[16] Belle Collaboration, A. Abashian et al., Nucl. Inst. and Meth. A 479, 117 (2002).

[17] R. Brun et al., GEANT 3.21, CERN DD/EE/84-1, 1984.

[18] K. Hagiwara et al. (Particle Data Group), Phys. Rev. D 66, 010001 (2002).