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C. P. Shen et al. (Belle Collaboration)

Phys. Rev. D 88, 011102 — Published 23 July 2013

DOI: 10.1103/PhysRevD.88.011102
Measurement of exclusive $\Upsilon(1S)$ and $\Upsilon(2S)$ decays into Vector-Pseudoscalar final states

(The Belle Collaboration)

1University of the Basque Country UPV/EHU, 48080 Bilbao
2Beihang University, Beijing 100191
3University of Bonn, 53115 Bonn
4Budker Institute of Nuclear Physics SB RAS and Novosibirsk State University, Novosibirsk 630090
5Faculty of Mathematics and Physics, Charles University, Prague, 121 16 Prague
6University of Cincinnati, Cincinnati, Ohio 45221
7Deutsches Elektronen-Synchrotron, 22607 Hamburg
8Justus-Liebig-Universität Gießen, 35392 Gießen
9Gifu University, Gifu 501-1193
10II. Physikalisches Institut, Georg-August-Universität Göttingen, 37073 Göttingen
11Hanyang University, Seoul 133-791
12University of Hawaii, Honolulu, Hawaii 96822
13High Energy Accelerator Research Organization (KEK), Tsukuba 305-0801
14Hiroshima Institute of Technology, Hiroshima 731-5193
15Ikerbasque, 48011 Bilbao
16Indian Institute of Technology Guwahati, Assam 781039
17Indian Institute of Technology Madras, Chennai 600036
18Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049
19Institute of High Energy Physics, Vienna 1050
20Institute for High Energy Physics, Protvino 142281
21INFN - Sezione di Torino, 10125 Torino
22Institute for Theoretical and Experimental Physics, Moscow 117218
23J. Stefan Institute, 1000 Ljubljana
24Kanagawa University, Yokohama 221-8686
25Institut für Experimentelle Kernphysik, Karlsruher Institut für Technologie, 76131 Karlsruhe
26Korea Institute of Science and Technology Information, Daejeon 305-806
27Korea University, Seoul 136-713
28Kyungpook National University, Daegu 702-701
29École Polytechnique Fédérale de Lausanne (EPFL), Lausanne 1015
30Faculty of Mathematics and Physics, University of Ljubljana, 1000 Ljubljana
31University of Maribor, 2000 Maribor
Using samples of 102 million \( \Upsilon(1S) \) and 158 million \( \Upsilon(2S) \) events collected with the Belle detector, we study exclusive hadronic decays of these two bottomonium resonances to \( K_S^0 K^+ \pi^- \) and charge-conjugate (c.c.) states, \( \pi^+ \pi^- \pi^0 \), and \( \pi^+ \pi^- \pi^0 \), and to the two-body Vector-Pseudoscalar (\( V^* (892) K^0 \) + c.c., \( V^* (892) K^+ + c.c. \), \( \omega \pi^0 \), and \( \rho \pi^0 \)) final states. For the first time, signals are observed in the modes \( \Upsilon(1S) \to K_S^0 K^+ \pi^- + c.c. \) and \( \Upsilon(2S) \to \pi^+ \pi^- \pi^0 \), and evidence is found for the modes \( \Upsilon(1S) \to \pi^+ \pi^- \pi^0, K^* (892) K^0 + c.c. \), and \( \Upsilon(2S) \to K_S^0 K^+ \pi^- + c.c. \). Branching fractions are measured for all the processes, while 90% confidence level upper limits on the branching fractions are also set for the modes with a statistical significance of less than 3\( \sigma \). The ratios of the branching fractions of \( \Upsilon(2S) \) and \( \Upsilon(1S) \) decays into the same final state are used to test a perturbative QCD prediction for OZI-suppressed bottomonium decays.

PACS numbers: 13.25.Gv, 14.40.Pq, 12.38.Qk

The \( \Upsilon(1S) \) and \( \Upsilon(2S) \) are expected to decay mainly via three gluons, with a few percent probability to two gluons and a photon [1]. The two- and three-gluon channels provide an entry to many potential final states, including states made of pure glue (glueballs), light Higgs bosons, and states made of light quarks. The study of \( \Upsilon(1S) \) and \( \Upsilon(2S) \) hadronic decays may pave the way for a more complete understanding of how gluon final states fragment into hadrons. However, little experimental information is available on exclusive decays of the \( \Upsilon \) resonances below \( B\bar{B} \) threshold. Recently, a few Vector-Tensor (VT) and Axial-vector-Pseudoscalar states from \( \Upsilon(1S) \) and \( \Upsilon(2S) \) decays were measured by the Belle Collaboration [2].

Perturbative quantum chromodynamics (pQCD) provides a relation for the ratios of the branching fractions for the OZI (Okubo-Zweig-Iizuka) [3] suppressed \( J/\psi \) and \( \psi(2S) \) decays to hadrons [4]

\[
Q_\psi = \frac{B_{\psi(2S) \to \text{hadrons}}}{B_{J/\psi \to \text{hadrons}}} = \frac{B_{\psi(2S) \to e^+ e^-}}{B_{J/\psi \to e^+ e^-}} \approx 12\%,
\]
which is referred to as the “12% rule” and is expected to apply with reasonable accuracy to both inclusive and exclusive decays. However, substantial deviations are seen for \( \rho \pi \) and other Vector-Pseudoscalar (VP) final states such as \( K^*(892)K \), as well as for VT final states [5]. This is the so-called “\( \rho \pi \) puzzle.” None of the many existing theoretical explanations that have been proposed have been able to accommodate all of the measurements reported to date [6].

A similar rule can be derived for OZI-suppressed bottomonium decays, where we expect

\[
Q_T = \frac{B_{\Omega(2S)\to \pi^+ \pi^-}}{B_{\Omega(1S)\to \pi^+ \pi^-}} = 0.77 \pm 0.07.
\]

This rule should hold better than the 12% rule for charmonium decay since the bottomonium states have higher mass and pQCD and the potential models have better predictive power, as has been demonstrated in calculations of the \( b\bar{b} \) meson spectrum. For the \( \pi^+ \pi^- \pi^0 \) and \( \rho \pi \) modes, upper limits of \( 1.84 \times 10^{-5} \) and \( 2 \times 10^{-4} \) have been published [7] for the decays \( \Upsilon(1S) \to \pi^+ \pi^- \pi^0 \) and \( \Upsilon(1S) \to \rho \pi \), respectively.

If violation of the pQCD rules is observed in the bottomonium system, a comparison with the charmonium system may help to develop a theoretical explanation of the \( \rho \pi \) puzzle. For \( K^*(892)K \), there is a large isospin-violating difference between the branching fractions for the charged and neutral \( \psi(2S) \to K^*(892)K \) decays; this is not seen in \( J/\psi \) decays [1]. This pattern can be probed in \( \Upsilon(1S) \) and \( \Upsilon(2S) \) decays.

In this paper, we report studies of exclusive hadronic decays of the \( \Upsilon(1S) \) and \( \Upsilon(2S) \) resonances to the \( K^0_S K^+ \pi^- \) [8], \( \pi^+ \pi^- \pi^0 \pi^0 \), and \( \pi^+ \pi^- \pi^0 \), and two-body VP \( (K^*(892)^0 K^0, K^*(892)^- K^+, \omega \pi^0, \text{ and } \rho \pi) \) final states. The data are collected with the Belle detector [9] operating at the KEKB asymmetric-energy \( e^+e^- \) collider [10]. This analysis is based on a 5.7 fb\(^{-1} \) \( \Upsilon(1S) \) data sample (102 million \( \Upsilon(1S) \) events), a 24.7 fb\(^{-1} \) \( \Upsilon(2S) \) data sample (158 million \( \Upsilon(2S) \) events) [11], and a 89.4 fb\(^{-1} \) continuum data sample collected at \( \sqrt{s} = 10.52 \text{ GeV} \). Here, \( \sqrt{s} \) is the center-of-mass (C.M.) energy of the colliding \( e^+e^- \) system. The numbers of the \( \Upsilon(1S) \) and \( \Upsilon(2S) \) events are determined by counting the hadronic events in the data taken at the \( \Upsilon(1S) \) and \( \Upsilon(2S) \) peaks after subtracting the appropriately scaled continuum background from the data sample collected at \( \sqrt{s} = 9.43 \text{ GeV} \) and 9.993 GeV, respectively. The selection criteria for hadronic events are validated with the off-resonance data by comparing the measured \( R \) value \( (R = \frac{\sigma(e^+e^- \to \pi^+ \pi^- \pi^0 \pi^0)}{\sigma(e^+e^- \to \pi^+ \pi^- \pi^0 \pi^0)}) \) with CLEO’s result [12].

The EVTGEN [13] generator is used to simulate Monte Carlo (MC) events. For two-body decays, the angular distributions are generated using the formulae in Ref. [14]. Inclusive \( \Upsilon(1S) \) and \( \Upsilon(2S) \) MC events, produced using PYTHIA [15] with four times the luminosity of the real data, are used to identify possible peaking backgrounds from \( \Upsilon(1S) \) and \( \Upsilon(2S) \) decays.

The Belle detector is described in detail elsewhere [9]. It 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 superconducting solenoid coil that provides a 1.5 T magnetic field. An iron flux return located outside of the coil is instrumented to detect \( K^0_L \) mesons and to identify muons (KLM).

For each charged track other than those from \( K^0_L \) decays, the impact parameters perpendicular to and along the beam direction with respect to the interaction point are required to be less than 0.5 cm and 4 cm, respectively, and the transverse momentum must exceed 0.1 GeV/c in the laboratory frame. Well-measured charged tracks are selected and the number of good charged tracks must equal four for the \( K^0_S K^+ \pi^- \) final state or two for the \( \pi^+ \pi^- \pi^0 \pi^0 \) and \( \pi^+ \pi^- \pi^0 \) final states. For each charged track, a likelihood \( L_X \) is formed from several detector subsystems for particle hypothesis \( X \in \{e, \mu, \pi, K, p\} \). A track with a likelihood ratio \( R_K = \frac{L_K}{L_{K^*}} > 0.6 \) is identified as a kaon, while a track with \( R_K < 0.4 \) is treated as a pion [16]. With this selection, the kaon (pion) identification efficiency is about 85% (89%), while 6% (9%) of kaons (pions) are misidentified as pions (kaons). Similar likelihood ratios \( R_e \) and \( R_\mu \) are defined to identify electrons and muons, respectively [17, 18].

Except for the \( \pi^+ \pi^- \pi^0 \) pair from \( K^0_S \) decay, all charged tracks are required to be positively identified as pions or kaons. The requirements \( R_\mu < 0.95 \) and \( R_e < 0.95 \) for the charged tracks remove 9.3% (79%) of the backgrounds for \( K^0_S K^+ \pi^- (\pi^+ \pi^- \pi^0) \) with no loss in efficiency.

For \( K^0_S \) candidates decaying into \( \pi^+ \pi^- \) in the \( K^0_S K^+ \pi^- \) mode, we require that the invariant mass of the \( \pi^+ \pi^- \) pair lies within a \( \pm 8 \text{ MeV}/c^2 \) interval around the \( K^0_S \) nominal mass (which contains about 95% of the signal according to MC simulation) and that the pair has a displaced vertex and flight direction consistent with a \( K^0_S \) originating from the interaction point [19].

To be identified as a photon candidate, a cluster in the electromagnetic calorimeter should not match the extrapolated position of any charged track and should have energy exceeding 100 (200) MeV in the \( \pi^+ \pi^- \pi^0 \pi^0 \) (\( \pi^+ \pi^- \pi^0 \)) mode. A \( \pi^0 \) candidate is reconstructed from a pair of photons. We perform a mass-constrained fit to the selected \( \pi^0 \) candidate and require \( \chi^2 < 15 \).

To remove additional backgrounds in the \( \pi^+ \pi^- \pi^0 \) final state, we require a matching ECL cluster for each charged track, with \( E^\text{ECL}_{\pi^0}/P_{\pi} > 0.02 \). Here, \( E^\text{ECL}_{\pi^0} \) and \( P_{\pi} \) represent the energy deposited in the ECL and the momentum in the laboratory frame, respectively, for the pion candidate. To suppress the background events from the initial-state-radiation (ISR) process \( e^+e^- \to \rho^0 \to \pi^+ \pi^- \) where the charged tracks are combined with a \( \pi^0 \) candidate, we require \( |(E_1 - E_2)/(E_1 + E_2)| < 0.65 \), where
$E_1$ and $E_2$ are the $\pi^0$ daughter-photon energies in the laboratory frame. To suppress background from the ISR process $e^+e^- \rightarrow \omega \rightarrow \pi^+\pi^-\pi^0$, the same requirement is imposed for the higher-momentum $\pi^0$ in the $\omega\pi^0$ mode.

We define an energy conservation variable $X_T = \Sigma h E_h/\sqrt{s}$, where $E_h$ is the energy of the final-state particle $h$ in the $e^+e^-$ C.M. frame. For signal candidates, $X_T$ should be around 1. Figure 1 shows the $X_T$ distributions for $\Upsilon(1S)$ and $\Upsilon(2S)$ decays to $K_S^0K^+\pi^-, \pi^+\pi^-\pi^0\pi^0$, and $\pi^+\pi^-\pi^0$ after applying all selection criteria. Solid points with error bars are from data at the indicated $\Upsilon$ resonance.

The continuum background contribution is measured by extrapolating the data at $\sqrt{s} = 10.52$ GeV to the $\Upsilon(1S)$ and $\Upsilon(2S)$ resonances. For the extrapolation, we use the scale factor, $f_{\text{scale}} = \sigma \text{cont}/\sigma_{\text{cont}}$, where $\sigma_{\text{cont}}$ and $\sigma_{\text{cont}}$ are the ratios of luminosity, cross sections and efficiencies, respectively, at the bottomonium masses and continuum energy points. For nominal results, the $s$ dependence of the cross section is assumed to be $1/s^2$ and the corresponding scale factor is about 0.12 for the $\Upsilon(1S)$ and 0.37 for the $\Upsilon(2S)$. The dependence of the cross section on the beam energy could vary from $1/s^3$ to $1/s^4$ [20, 21]; this range is included as a systematic uncertainty.

Besides the continuum background contribution, we search for possible backgrounds from $\Upsilon(1S)$ and $\Upsilon(2S)$ decays. No peaking backgrounds from the $\Upsilon(1S)$ and $\Upsilon(2S)$ inclusive MC samples are found in the $X_T$ signal regions. Potential backgrounds due to particle misidentification — for example, from $2(\pi^+\pi^-)$ and $K^+K^-\pi^-\pi^-$ for $K^0_SK^+\pi^-$ — are estimated and found to be negligible. In the lower $X_T$ region, backgrounds arise from decays with additional $\pi^0$s: from are $K^0_SK^+\pi^-\pi^0$ for $K^0_SK^+\pi^-\pi^-\pi^0\pi^0$, and $\pi^+\pi^-\pi^0\pi^0$ for $\pi^+\pi^-\pi^0\pi^0$. There are also some backgrounds from $\pi^-\pi^- \rightarrow \pi^+\pi^-\pi^0\pi^0\pi^0$, with $n \geq 2$ for $\pi^+\pi^-\pi^0\pi^0$, and $n \geq 1$ for $\pi^+\pi^-\pi^0\pi^0$. The $X_T$ distributions from the above backgrounds are checked with MC simulations and found to be featureless.

We find that these backgrounds from $\Upsilon(1S)$ and $\Upsilon(2S)$ decays together with the normalized contribution from continuum production can describe the data in the $X_T < 0.975$ region very well. For $\pi^+\pi^-\pi^0\pi^0$, the fraction of events with multiple combinations is 2.1% (1.7%) due to multiple $\pi^0$ candidates; this is consistent with the MC simulation and is taken into account in the efficiency determination.

An unbinned simultaneous maximum likelihood fit to the $X_T$ distributions is performed to extract the signal and background yields in the $\Upsilon(1S)$ and continuum data samples, and in the $\Upsilon(2S)$ and continuum data samples. The signal shapes are obtained from MC simulated signal samples directly, where for $K^0_SK^+\pi^-$ the signal shape is smeared with a Gaussian function to account for an 18% difference in the resolution between data and MC samples. In this fit, an exponential background shape is used for the $\Upsilon(1S)/\Upsilon(2S)$ decay backgrounds in addition to the normalized continuum contribution. The fit ranges and results for the $X_T$ distributions from $K^0_SK^+\pi^-$, $\pi^+\pi^-\pi^0\pi^0$, and $\pi^+\pi^-\pi^0$ candidate events are shown in Fig. 1, and the fit results are summarized in Table I.

![FIG. 1: The fits to the scaled total energy $X_T$ distributions from $\Upsilon(1S)$ and $\Upsilon(2S)$ decays to $K^0_SK^+\pi^-$, $\pi^+\pi^-\pi^0\pi^0$, and $\pi^+\pi^-\pi^0$. Solid points with error bars are from resonance data. The solid histograms show the best fits, dashed curves are the total background estimates, and shaded histograms are the normalized continuum background contributions.](image-url)
There are several sources of systematic errors in the branching fraction measurements. The uncertainty in the branching fraction measurement for tracks with angles and momenta is about 0.3%, per track and listed in Table 1. To improve the branching fraction estimate for tracks with angles and momenta, except for a first-order Chebyshev polynomial fit described above for $\pi^0$ distributions, there is no indication of signal in any other final state. The expected mass regions for $\Psi(1S)$ decays is for the continuum data without normalization in the lower left-hand panel, while the upper left-hand panel is for the continuum data without normalization in the laboratory system, respectively.

![Diagram](image-url)

**TABLE I:** Results for the $\Upsilon(1S)$ and $\Upsilon(2S)$ decays, where $N_{\text{sig}}$ is the number of signal events from the fits, $N_{\text{UL}}^{\text{UL}}$ is the upper limit on the number of signal events, $\epsilon$ is the efficiency ($\%$), $\Sigma$ is the statistical significance ($\sigma$), $B$ is the branching fraction (in units of $10^{-6}$), $B^{\text{UL}}$ is the 90% C.L. upper limit on the branching fraction, $Q_T$ is the ratio of the $\Upsilon(1S)$ to $\Upsilon(1S)$ branching fractions, and $Q_T^{\text{UL}}$ is the upper limit on the value of $Q_T$. The first error in $B$ and $Q_T$ is statistical, and the second systematic. Here $B(K_0^* \to \pi^+ \pi^-)$ has been included in the efficiency for the $K_0^* K^\pi$ final states. In order to set conservative upper limits on these branching fractions, the efficiencies are lowered by a factor of $1 - \sigma_{\text{sys}}$ in the calculation, where $\sigma_{\text{sys}}$ is the total systematic error.

<table>
<thead>
<tr>
<th>Channel</th>
<th>$N_{\text{sig}}$</th>
<th>$N_{\text{UL}}^{\text{UL}}$</th>
<th>$\epsilon$</th>
<th>$\Sigma$</th>
<th>$B$</th>
<th>$B^{\text{UL}}$</th>
<th>$Q_T$</th>
<th>$Q_T^{\text{UL}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_0^* K^\pi^-$</td>
<td>37.2 ± 7.6</td>
<td>22.96</td>
<td>6.2</td>
<td>1.59</td>
<td>0.33</td>
<td>0.18</td>
<td>39.5</td>
<td>10.3</td>
</tr>
<tr>
<td>$\pi^+ \pi^- \pi^0$</td>
<td>143.2 ± 22.4</td>
<td>11.20</td>
<td>7.1</td>
<td>12.8</td>
<td>2.01</td>
<td>2.27</td>
<td>260.7</td>
<td>37.2</td>
</tr>
<tr>
<td>$\pi^+ \pi^- \pi^0$</td>
<td>25.5 ± 8.6</td>
<td>11.86</td>
<td>3.4</td>
<td>2.14</td>
<td>0.72</td>
<td>0.34</td>
<td>-21.1</td>
<td>9.5</td>
</tr>
<tr>
<td>$K^*(892)^+ K^\pi^-$</td>
<td>16.1 ± 4.7</td>
<td>16.23</td>
<td>4.4</td>
<td>2.92</td>
<td>0.85</td>
<td>0.37</td>
<td>14.7</td>
<td>6.0</td>
</tr>
<tr>
<td>$K^*(892)^- K^\pi^+$</td>
<td>2.0 ± 1.9</td>
<td>6.3</td>
<td>18.92</td>
<td>1.3</td>
<td>0.31</td>
<td>0.30</td>
<td>1.11</td>
<td>5.7</td>
</tr>
<tr>
<td>$\omega \pi^0$</td>
<td>2.5 ± 2.1</td>
<td>6.8</td>
<td>2.11</td>
<td>1.6</td>
<td>1.32</td>
<td>0.11</td>
<td>3.90</td>
<td>0.4</td>
</tr>
<tr>
<td>$\rho \pi$</td>
<td>11.3 ± 5.9</td>
<td>22</td>
<td>6.41</td>
<td>2.2</td>
<td>1.75</td>
<td>0.91</td>
<td>0.28</td>
<td>3.68</td>
</tr>
</tbody>
</table>
mesons. In the $K_S^0 K^+ \pi^-$ mode, the $K_S^0$ reconstruction and the systematic error is verified by comparing the ratio of $D^+ \to K_S^0 \pi^+$ and $D^+ \to K^- \pi^+ \pi^0$ yields with the MC expectations; the difference between data and MC simulation is less than 4.9\% [23]. The efficiency of the requirement $E_{\text{CUT}}^{\text{ISR}}/P_x > 0.02$ is 97.4\% in $\pi^+ \pi^- \pi^0$ and the uncertainty can be neglected according to a check of the results with and without this requirement. Errors on the branching fractions of the intermediate states are taken from the PDG listings [1]. For the $\pi^+ \pi^- \pi^0$ final state, the trigger efficiency is verified using the pure ISR control sample $e^+e^- \to \omega \to \pi^+ \pi^- \pi^0$. According to MC simulation, for the $\pi^+ \pi^- \pi^0$ ($\rho\pi$) mode, the trigger efficiency is 97\% (94\%), with an uncertainty that is smaller than 1.5\% (3\%); for the other modes, the trigger efficiency is greater than 99\% and the corresponding uncertainty is neglected. The trigger efficiency in $\rho \pi$ is somewhat lower due to high momentum $\pi^0$ in $\rho^0 \pi^0$. We estimate the systematic errors associated with the fitting procedure by changing the order of the background polynomial, the range of the fit and introducing an extra Gaussian function to describe the possible excess around $X_T \sim 0.96$ in $X_T$ fits and take the differences in the results of the fits, which are 1.5\%-11\% depending on the final state particles, as systematic errors. To investigate the effect of possible intermediate resonances for the $\Upsilon(1S)/\Upsilon(2S) \to K_S^0 K^+ \pi^-$, $\pi^+ \pi^- \pi^0 \pi^0$ and $\pi^+ \pi^- \pi^0$ decays, the efficiencies are estimated by using sampled phase space MC signal events according to the Dalitz plot or scatter plot that are shown in Fig. 2. The difference is 7.3\%/3.3\% for $\Upsilon(1S)/\Upsilon(2S) \to K_S^0 K^+ \pi^-$, 5.6%/4.4\% for $\Upsilon(1S)/\Upsilon(2S) \to \pi^+ \pi^- \pi^0 \pi^0$, 11%/7.8\% for $\Upsilon(1S)/\Upsilon(2S) \to \pi^+ \pi^- \pi^0$; these values are assigned as a systematic uncertainty due to this source. For the $K^*(892)K$ and $\rho \pi$ modes, we estimate the systematic errors associated with the resonance parameters by changing the values of the masses and widths of the resonances by $\pm 1\sigma$. The $K^*(892)$ and $\rho$ line shapes are replaced by a relativistic Breit-Wigner function and the Gounaris-Sakurai parametrization [24], respectively. The total differences of 2.6\%-11\% in the fitted results are taken as systematic errors. For the central values of the branching fractions, the difference between alternative C.M. energy dependences of the cross section is included as a systematic error due to the uncertainty of the continuum contribution, which is in the range of 4.7\% to 22\%. The uncertainty due to limited MC statistics is at most 2.6\%. Finally, the uncertainties on the total numbers of $\Upsilon(1S)$ and $\Upsilon(2S)$ events are 2.2\% and 2.3\%, respectively, which are mainly due to imperfect simulations of the charged multiplicity distributions from inclusive hadronic MC events. Assuming that all of these systematic error sources are independent, the total systematic error is 11\%-26\% depending on the final state, as shown in Table II.

Table I shows the results for the branching fractions including the upper limits at 90\% C.L. for the channels with a statistical significance of less than 3$\sigma$. In order to set conservative upper limits on these branching fractions, the efficiencies are lowered by a factor of $1 - \sigma_{\text{sys}}$ in the calculation, where $\sigma_{\text{sys}}$ is the total systematic error. The corresponding ratio of the branching fractions of $\Upsilon(2S)$ and $\Upsilon(1S)$ decay ($Q_{\Upsilon}$) is calculated; in some cases, the systematic errors cancel. A Bayesian upper limit on the ratio at the 90\% C.L. ($Q_{\Upsilon}^{UL}$) is obtained by performing toy MC experiments. We sample $B_{\Upsilon(1S)}$ and $B_{\Upsilon(2S)}$ by assuming they follow Gaussian distributions, where the mean values and standard deviations of the Gaussian functions are set to be the central value and total error (with a common error removed) of the branching fraction, respectively. For the sampled distribution of the ratio of the branching fractions greater than zero, we obtain $Q_{\Upsilon}^{UL}$, where $Q_{\Upsilon}^{UL}$ corresponds to the number of experiments with $Q_{\Upsilon} < Q_{\Upsilon}^{UL}$ in less than 90\% of the total number of toy experiments. At present, all the results on the branching fractions, including upper limits reported in this letter, are the first measurements or the
In summary, we have measured Υ(1S) and Υ(2S) exclusive hadronic decays to $K^0_K K^+\pi^-$, $\pi^+\pi^-\pi^0\pi^0$, and $\pi^+\pi^-\pi^0\pi^0$, as well as the two-body VP ($K^*(892)^0 K^0$, $K^*(892)^- K^+$, $\omega\pi^0$, and $\rho\pi$) states. Signals are observed for the first time in the $\Upsilon(1S) \rightarrow K^0_K K^+\pi^-$, $\pi^+\pi^-\pi^0\pi^0\pi^0$ and $\Upsilon(2S) \rightarrow \pi^+\pi^-\pi^0\pi^0$ decay modes. Although many $\Upsilon(1S)$ and $\Upsilon(2S)$ exclusive decay modes were previously measured using CLEO data [25], only the $K^0_K K^+\pi^-$ mode overlaps with our measurement and upper limits at 90% C.L. were presented there. Our results for the $K^0_K K^+\pi^-$ mode are well below the upper bounds reported in Ref. [25]. There is an indication for large isospin-violation between the branching fractions for the charged and neutral $K^*(892)K$ for both $\Upsilon(1S)$ and $\Upsilon(2S)$ decays, as in $\psi(2S)$ decays, which indicates that the electromagnetic process plays an important role in these decays [26]. We find that, for the processes $K^0_K K^+\pi^-$ and $\pi^+\pi^-\pi^0\pi^0$, the $Q_\Upsilon$ ratios are consistent with the expected value; for $\pi^+\pi^-\pi^0$, the $Q_\Upsilon$ ratio is a little lower than the pQCD prediction. The results for the other modes are inconclusive due to low statistical significance. These results may supply useful guidance for interpreting violations of the 12% rule for OZI-suppressed decays in the charmonium sector.

We thank the KEKB group for excellent operation of the accelerator; the KEK cryogenics group for efficient solenoid operations; and the KEK computer group, the NII, and PNNL/EMSL for valuable computing and SINET4 network support. We acknowledge support from MEXT, JSPS and Nagoya's TLPRC (Japan); ARC and DIISR (Australia); FWF (Austria); NSFC (China); MSMT (Czechia); CZF, DFG, and VS (Germany); DST (India); INFN (Italy); MEST, NRF, GSDC of KISTI, and WCU (Korea); MNISW and NCN (Poland); MES and RFAAE (Russia); ARRS (Slovenia); IKERBASQUE and UPV/EHU (Spain); SNSF (Switzerland); NSC and MOE (Taiwan); and DOE and NSF (USA).
[22] The ππ invariant mass includes π^+π^−, π^+π^0 and π^-π^0 invariant masses.
[26] The ratio of cross sections between neutral and charged K*(892)K is larger than 4.6 at 90% C.L. in continuum data sample at $\sqrt{s} = 10.52$ GeV, which is not very different from the expected value of 4 with the assumption of SU(3) symmetry [27].