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Search for the non-$D\bar{D}$ decay $\psi(3770) \to K_S^0 K_L^0$

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Abstract

Using the current world's largest data sample of $\psi(3770)$ decays, we present results of a search for the non-$D\bar{D}$ decay $\psi(3770) \to K^0_S K^0_L$. We find no signal, and obtain an upper limit of $\sigma(\psi(3770) \to K^0_S K^0_L) <$ 0.07 pb at 90% confidence level (CL). Our result tests a theoretical prediction for the upper bound on $\mathcal{B}(\psi(3770) \to K^0_S K^0_L)$ based on a charmonia-mixing model.

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The $\psi(3770)$, the lightest charmonium resonance above open-flavor-production threshold, decays dominantly into a pair of D mesons. Non-$D\bar{D}$ decays of $\psi(3770)$, which are OZI-suppressed [1], have received much attention as they were observed to constitute an unexpectedly large portion ($\approx$20%) of the total hadronic decay rate in earlier measurements summarized in [2]. Recent results [3, 4] do not confirm a discrepancy of this magnitude, but due to the experimental uncertainties, the measurements are not yet conclusive. Exclusive non-$D\bar{D}$ decays of the $\psi(3770)$ are expected as of any other charmonium state and have, in fact, been observed [5–7]. The discrepancy between the hadronic and D-pair production cross sections will be clarified by identifying other components of $\psi(3770) \to$ non-$D\bar{D}$.

This article focuses on the reaction $\psi(3770) \to K^0_S K^0_L$. This final state is particularly interesting also in the context of the perturbative QCD "12% rule" (which relates J/ψ and $\psi(2S)$ branching fractions [8]), with the help of the mixing scenario [9, 10], in which the $\psi(2S)$ and $\psi(3770)$ are considered to be mixtures of the 2^3S_1 and 1^3D_1 states of charmonium. Rosner [11] propounds a possible explanation of the "$\rho - \pi$ puzzle" using the phenomenon of charmonia mixing. In view of this, it is interesting to explore the nature and degree of mixing between the $\psi(2S)$ and $\psi(3770)$, particularly in the case of those modes which show significant deviation from the 12% rule. The pseudoscalar-pseudoscalar (PP) final state $K^0_S K^0_L$ is in this category: an average of recent results [9, 12] indicates the ratio $\mathcal{B}(\psi(2S) \to K^0_S K^0_L)/\mathcal{B}(J/\psi \to K^0_S K^0_L)$, to be as high as (29.9 ± 3.0)%, substantially enhanced compared to the prediction of 12%. In a scenario that attempts to explain this enhancement, Wang and collaborators [10] predict $(1.2\pm0.7)\times10^{-6} < \mathcal{B}(\psi(3770) \to K^0_S K^0_L) <\ (3.8\pm1.1)\times10^{-5}$. The search presented here has sufficient sensitivity to test the upper bound of this prediction.

We use data collected by the CLEO detector [14] operating at the Cornell Electron Storage Ring [13]. The sample corresponds to an integrated luminosity of 281 pb^{-1} of e^+e^- annihilations at a center-of-mass energy $\sqrt{s}$ =3773 MeV. The CLEO-c detector configuration features excellent efficiency and resolution for charged particles and photons within 93% of the solid angle. The detector components critical to this analysis, rendering the discrimination of signal events amidst background, are discussed in the following. The charged particle tracking system consists of a low mass wire inner drift chamber (ZD) suitable for low track momenta, followed by an outer drift chamber (DR). These two devices measure charged track three-momenta with excellent accuracy and achieve a momentum resolution of $\sim$0.6% at 1 GeV/c. The DR also measures energy loss that is used to identify charged tracks. The drift chamber is surrounded by a Ring Imaging Cherenkov Detector (RICH), followed by a CsI calorimeter (CC), where two regions in polar angle (measured with respect to the beam direction) are distinguished: barrel ($|\cos(\theta)| < 0.81$) and endcap ($|\cos(\theta)| \geq 0.81$). The CC allows the detection of photons with an energy resolution of 2.2% (5%) for photons with energy of 1 GeV (100 MeV) and, in combination with the tracking system, provides the basis for excellent electron identification.

The event reconstruction and final state selection criteria proceed along the lines of CLEO's $\psi(2S) \to K^0_S K^0_L$ analysis [12]. Our strategy is to reconstruct only a single K^0_S in each event and demand nothing other than an accompanying K^0_L based on the following criteria. We reconstruct the K^0_S using its decay to two charged pions, and thus require the events to have exactly two charged tracks. We have taken into account the effect of the small ($\approx$ 4 mrad) crossing angle between the e^+ and e^- beams by performing a Lorentz transformation of all the laboratory quantities to the center-of-mass frame. We impose standard track selection criteria based on the number of drift chamber hits and geometric acceptance. We use both charged particle ionization loss in the drift chamber (dE/dx) and

RICH information to identify the two tracks as pions which are used to reconstruct the K_S^0 mesons. We define the parameters $\mathrm{PID}_{1ij} = L_i - L_j$ and $\mathrm{PID}_{2ij} = \sigma_i^2 - \sigma_j^2$, where $L_{i,j}(i, j = p, K, \pi$ with $i \neq j)$ are the likelihoods given by the measured Cherenkov angles of photons in the RICH detector compared with the predicted Cherenkov angles for the $i^{\mathrm{th}}, j^{\mathrm{th}}$ particle hypothesis, and $\sigma_{i,j}(i, j = p, K, \pi, e$ with $i \neq j)$ are the ratios of the difference between the measured dE/dx and the predicted dE/dx values normalized to their standard deviations for the $i^{\mathrm{th}}, j^{\mathrm{th}}$ hypothesis. To use the RICH, we first require that the track momentum be above the RICH threshold of 0.6 GeV/c for the pion hypothesis. We then discriminate π from p, K in the following manner: (a) If the RICH information is available, we require $(\mathrm{PID}_{1\pi p}+\mathrm{PID}_{2\pi p}) < 0$ and $(\mathrm{PID}_{1\pi K}+\mathrm{PID}_{2\pi K}) < 0$. (b) If the RICH information is not available, we require $\mathrm{PID}_{2\pi p} < 0$ and $\mathrm{PID}_{2\pi K} < 0$. We further reject background from Bhabha ($e^+e^- \to e^+e^-$) and two-photon ($e^+e^- \to \gamma\gamma$) events by an electron veto of tracks that satisfy the condition for the ratio of the CC determined energy E_{CC} and the track determined momentum p as $0.92 < E_{\mathrm{CC}}/p < 1.05$ and have $|\sigma_e| < 3$.

The pair of charged pion candidates are kinematically constrained to come from a common vertex. We require that the reconstructed invariant mass of the two pions be within 10 MeV (≈ 3.2 standard deviations) of the nominal K_S^0 peak. We reject background from non-K_S^0 sources by requiring the measured flight path of the K_S^0 candidate before its decay to be greater than 5 standard deviations (≈ 5 mm) with respect to the interaction point. In addition, we require that the K_S^0 candidates originate from the e^+e^- interaction point by demanding that their distance of closest approach is within 5 standard deviations with respect to the interaction point.

Frequently, K_L^0 mesons will produce a shower in the CC. However, as this shower does not have a measured energy corresponding to the energy of the K_L^0, we do not attempt to reconstruct it, but merely allow for its existence. In order to reject contamination from anticipated background events with energy from neutral particles other than the K_L^0, we impose selection conditions as follows. We first find the K_L^0 direction by looking opposite to the K_S^0 direction, after having constrained the K_S^0 to its nominal mass and also considered the effect of the finite crossing angle. We then require the energy of the shower associated with neutrals closest to the K_L^0 direction to be less than 1.5 GeV. This cut further rejects QED background events of the type $e^+e^- \to \gamma\gamma$ (where one of the γ undergoes pair production). We also require the sum of the energy associated with neutrals outside a region around the direction of the K_L^0, defined by the angle between the position vectors of the K_L^0 and the shower in consideration ($\delta_{\mathrm{angle}} > 0.35$ radians), to be less than 300 MeV. We do not include the energy from showers which have an energy below 50 MeV, which are frequently due to electronic noise, in this summation. This cut is very efficient in eliminating hadronic background events from the following sources:

1. $K^{*0}(892)\bar{K}^0$ + charge conjugate (c.c.) produced in:
    (a) $e^+e^- \to \gamma\,\psi(2S)$, followed by the subsequent decay $\psi(2S) \to K^{*0}(892)\bar{K}^0$ + c.c.,
    (b) $e^+e^- \to K^{*0}(892)\bar{K}^0$ + c.c. via $e^+e^- \to \gamma^*$ (continuum).
2. $K_S^0K_S^0$ produced in:
    (a) $e^+e^- \to \gamma\ \psi(2S)$, followed by the subsequent radiative decay $\psi(2S) \to \gamma\chi_{c0,2}$, $\chi_{c0,2} \to K_S^0K_S^0$,
    (b) $e^+e^- \to \psi(3770) \to \gamma\ \chi_{c0,2}$, $\chi_{c0,2} \to K_S^0K_S^0$,

(c) $e^+e^- \to K_S^0 K_S^0$ via $e^+e^- \to \gamma^*$ (continuum).

We define a "good" shower as one that has an energy profile consistent with being a photon and possessing an energy above 100 MeV, and require events to have no good showers associated with neutrals outside the K_L^0 region, and at most one good shower inside this region.

Most events that contain one or more π^0 decays will be eliminated by the above cuts. However, for even better rejection, we find it useful to introduce an explicit π^0 veto with a lower photon energy requirement. To identify a π^0, we require a pair of showers not associated with charged tracks to have their energy distribution consistent with a photon even if they overlap with nearby clusters. In addition, we require each photon shower candidate to possess at least 30 MeV (50 MeV) of energy for a barrel (endcap) photon and kinematically constrain the pair to the known π^0 mass. We further require the difference between the unconstrained and fitted π^0 mass, normalized by its resolution, to be ≤ 3 and the π^0 momentum to be > 100 MeV/c. We reject all events that have any π^0 candidates meeting the above criteria. This is based upon our understanding of the basic topology of the event and our anticipated background interactions which produce π^0 mesons. Many background events will fail more than one of these cuts, but for best background rejection, all are necessary.

The above selection conditions were optimized by studying a Monte Carlo simulation of events using the EVTGEN generator [15] and a GEANT-based [16] detector modeling program. We simulated events with a $\sin^2\theta$ angular distribution, where θ is the angle between the K_S^0 and the positron beam in the center-of-mass system, as is expected for a vector resonance decaying to two pseudoscalar mesons. We also included initial state radiation effects.

We define a scaled energy variable for each event as the ratio of the K_S^0 energy to the beam energy as $E_{K_S^0}/E_{\rm beam}$. Since the K_S^0 mesons from the signal will be mono-energetic, we expect the $E_{K_S^0}/E_{\rm beam}$ distribution to peak at unity for the signal. Based upon simulations (as seen in Figure 1), we determine the signal region to be $0.98 < E_{K_S^0}/E_{\rm beam} < 1.02$.

The relevant backgrounds studied are the QED sources ($e^+e^- \to \gamma\gamma,\ l^+l^-$) and the hadronic sources: (a) $K^{*0}(892)\bar{K}^0$ + c.c. where the $K^{*0}(892)$ decays into π^0 and K^0, giving two neutral kaons in the final state, which could become a K_S^0 and a K_L^0, and (b) $K_S^0 K_S^0$ where one of the $K_S^0 \to \pi^+\pi^-$, while the other $K_S^0 \to \pi^0\pi^0$ and thus can mimic the signal. Two additional sources of background are identified and studied. One of them is $D\bar{D}$ production. Our Monte Carlo simulation study of a generic $D\bar{D}$ sample more than twice as large as the data indicates that this background is completely eliminated by our selection criteria. The second source of hadronic backgrounds taken into account is the more pervasive $K_S^0 K_L^0$ events originating from $\psi(2S)$ [12] produced at 3773 MeV in either the tail of or the radiative return to the $\psi(2S)$, the latter of which is the bigger contribution. These events peak at $E_{K_S^0}/E_{\rm beam} = 0.977$ as seen in Figure 1, which uses a simulated sample of such events analyzed in an identical manner to the data. Unfortunately, these events cannot be eliminated fully in this analysis by using the total four-momentum constraint typically used in $\psi(3770)$ studies, as in this analysis we do not reconstruct the complete event.

Figure 2 shows the $E_{K_S^0}/E_{\rm beam}$ distribution for events in data after the application of all of the above selection cuts. We observe 8 events inside the signal region, and an asymmetric background in the low sideband $E_{K_S}/E_{\rm beam} < 0.98$. Simulation studies indicate that the events in the low sideband are not from backgrounds to the K_S^0 sidebands but rather from multiple hadronic sources, dominated by contamination from $\gamma\,\psi(2S)\to\gamma\,K_S^0 K_L^0$, which may

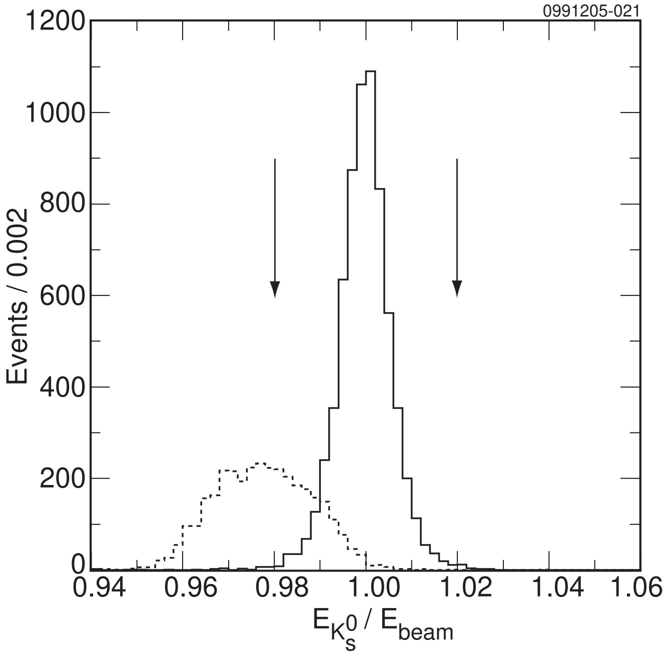

FIG. 1: The scaled K_S^0 energy ($E_{K_S^0}/E_{\mathrm{beam}}$) distribution for the $\psi(3770)$ simulation samples corresponding to the signal (solid histogram) and radiative return (dotted histogram) processes using arbitrary normalization. The arrows mark the signal region.

well extend inside the signal region. In order to account for this, we estimate the number of events expected inside our signal region originating from this radiative return background. Our estimate of the amount of this contamination, obtained using the radiative return hadronic cross section at $\sqrt{s} = 3773$ MeV [5] and $\mathcal{B}(\psi(2S) \to K_S^0 K_L^0)$ [12], is 9.5$\pm$1.6 events inside the signal region. The uncertainty on the background estimate is found to be 17.1% by taking the quadrature sum of the relevant sources which include the uncertainties on the radiative return cross section [5], the $\psi(3770)$ luminosity, the detection efficiency as obtained from simulations (the first six components listed in Table I), $\mathcal{B}(\psi(2S) \to K_S^0 K_L^0)$ [12] and $\mathcal{B}(K_S^0 \to \pi^+\pi^-)$ [17]. From such estimates, we find that the radiative return is a major part of the background, and it saturates our data in the signal region. In this analysis, we do not consider continuum subtraction from the resonance yield as this final state is forbidden to be produced via electromagnetic interactions under the SU(3) symmetry of flavor [18], as confirmed in [12].

The detection efficiency for the signal channel is calculated to be 45.8% from Monte Carlo simulations. This efficiency includes a correction due to the difference in K_L^0 detection efficiencies determined between data and Monte Carlo simulation. The study uses $e^+e^- \to \gamma\phi$, $\phi \to K_S^0 K_L^0$ events from the continuum channel in the same data sample as used in the analysis of $\psi(3770) \to K_S^0 K_L^0$. A possible momentum dependence arising from a difference in the momentum spectra of the K_L^0 mesons from the continuum and resonance channels is accounted for in the form of a systematic error component in the overall error attributed to the K_L^0 selection of 3.7%. A hardware trigger requiring that two tracks be found within 20 cm of the event vertex eliminated very long-lived K_S^0 mesons. The efficiency of this trigger for signal events was 73.6%, which is included in the calculated detection efficiency.

Based on our observed signal yield and estimated radiative return background, we find

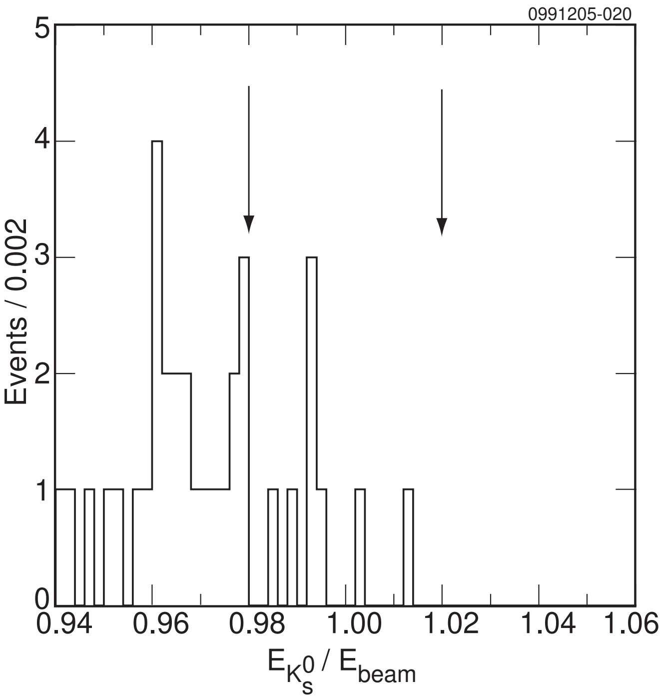

FIG. 2: The scaled K_S^0 energy ($E_{K_S^0}/E_{\rm beam}$) distribution for the $\psi(3770) \to K_S^0 K_L^0$ decay in 281 pb^{-1} of data. The arrows mark the signal region.

no evidence for a signal and calculate an upper limit on the number of signal events using the Feldman-Cousins approach [19] for an observed yield of 8 and a background estimate of 9 events which translates into an upper limit (90% CL) on the cross section of $\sigma(\psi(3770) \to K_S^0 K_L^0) < 0.06$ pb. In order to include systematic uncertainties, we first consider the systematic uncertainty on the estimated background. We take the 1σ lower value of this estimate and calculate the 90% CL upper limit on the number of signal events using the Feldman-Cousins approach. We subsequently include an overall systematic uncertainty of 5.5% from various sources listed in Table I, and measure $\sigma(\psi(3770) \to K_S^0 K_L^0) < 0.07$ pb at 90% CL.

In conclusion, using data collected by the CLEO detector at the $\psi(3770)$ resonance, we have studied the exclusive non-$D\bar{D}$ $\psi(3770)$ decay to the PP two-body mode $K_S^0 K_L^0$. We find no evidence of a signal in 281 pb^{-1} of data and report an upper limit on the production cross section, $\sigma(\psi(3770) \to K_S^0 K_L^0) < 0.07$ pb at 90% CL. This indicates that this mode is far from being able to account for any possible significant non-$D\bar{D}$ rate from the $\psi(3770)$ [2, 4]. In order to compare this result with the model prediction [10], we translate our upper limit on the cross section into an upper limit on the branching fraction using the resonance cross section of the $\psi(3770)$ reported by CLEO [4]. We obtain $\mathcal{B}(\psi(3770) \to K_S^0 K_L^0) < 1.17 \times 10^{-5}$ at 90% CL, which improves upon the current upper limit [20] of $< 2.1 \times 10^{-4}$ (90% CL) by an order of magnitude. Our measurement is below the upper bound of the model prediction presented in [10]. This may provide new insight into the nature of S- and D-wave mixing in charmonia and thereby help clarify the perturbative 12% rule.

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Source	Systematic error (%)
Trigger	2.0
Simulation statistics	0.6
K_L^0 selection	3.7
Tracking	1.4
Particle ID	0.6
K_S^0 finding	3.0
Luminosity	1.0
$\mathcal{B}(K_S^0 \to \pi^+\pi^-)$ [17]	0.1
Total	5.5

TABLE I: Summary of systematic errors.

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[1] S. Okubo, Phys. Lett. **5**, 165(1963); G. Zweig, CERN TH 401, CERN TH 412 (1964), unpublished; J. Iizuka, Progress in Theoretical Physics Supplement 37-38, 21(1966).

[2] J. L. Rosner, Annals Phys. **319**, 1 (2005), e-Print Archive: hep-ph/0411003 and references therein.

[3] Q. He *et al.* (CLEO Collaboration), Phys. Rev. Lett. **95**, 121801 (2005).

[4] D. Besson *et al.* (CLEO Collaboration), Phys. Rev. Lett. **96**, 092002 (2006).

[5] N. E. Adam *et al.* (CLEO Collaboration), Phys. Rev. Lett. **96**, 082004 (2006).

[6] T. E. Coan *et al.* (CLEO Collaboration), e-Print Archive: hep-ex/0509030 (submitted to PRL).

[7] G. S. Adams *et al.* (CLEO Collaboration), Phys. Rev. D **73**, 12002 (2006).

[8] W. S. Hou and A. Soni, Phys. Rev. Lett. **50**, 569 (1983); M. E. B. Franklin *et al.* (Mark II Collaboration), Phys. Rev. Lett. **51**, 963 (1983); W. S. Hou, Phys. Rev. D **55**, 6952 (1997); Y. F. Gu and X. H. Li, Phys. Rev. D **63**, 114019 (2001).

[9] P. Wang, X. H. Mo, and C. Z. Yuan, Phys. Rev. D **70**, 077505 (2004).

[10] P. Wang, C. Z. Yuan, and X.H. Mo, Phys. Rev. D **70**, 114014 (2004).

[11] J. L. Rosner, Phys. Rev. D **64**, 094002 (2001).

[12] S. Dobbs *et al.* (CLEO Collaboration), e-Print Archive: hep-ex/0603020 (submitted to PRL).

[13] R. A. Briere *et al.* (CESR-c and CLEO-c Taskforces, CLEO-c Collaboration), Cornell University, LEPP Report No. CLNS 01/1742 (2001), unpublished.

[14] G. Viehhauser *et al.*, Nucl. Instrum. Meth. A **462**, 146 (2001); D. Peterson *et al.*, Nucl. Instrum. Meth. Phys. Res. A **478**, 142 (2002); M. Artuso *et al.*, Nucl. Instrum. Meth. A **554**, 147 (2005).

[15] D. J. Lange, Nucl. Instrum. Meth. Phys. Res., Sect. A **462**, 152 (2001).

[16] R. Brun *et al.*, Geant 3.21, CERN Program Library Long Writeup W5013 (1993), unpublished.

[17] S. Eidelman *et al.* (Particle Data Group), Phys. Lett. B **592**, 1 (2004).

[18] H. E. Haber and J. Perrier, Phys. Rev. D **32**, 2961 (1985).
[19] G. J. Feldman, and R. D. Cousins, Phys. Rev. D **57**, 3873 (1998).
[20] M. Ablikim *et al.* (BES Collaboration), Phys. Rev. D **70**, 077101 (2004).