SLAC – PUB – 4302
DESY 87 – 038
April 1987
(T/E)

Experimental Upper Limits for the Hadronic Transitions $\Upsilon(2S) \rightarrow \eta\ \Upsilon(1S)$ and $\Upsilon(2S) \rightarrow \pi^\circ\ \Upsilon(1S)$ *

B. Lurz, D. Antreasyan, D. Besset, J.K. Bienlein, E.D. Bloom, I. Brock, R. Cabenda, A. Cartacci, M. Cavalli-Sforza[1)], R. Clare, G. Conforto, S. Cooper[2)], R. Cowan, D. Coyne[1)], C. Edwards, A. Engler, G. Folger, A. Fridman[3)], J. Gaiser, D. Gelphman, G. Godfrey, F.H. Heimlich, R. Hofstadter, J. Irion, Z. Jakubowski, S. Keh, H. Kilian, I. Kirkbride, T. Kloiber, W. Koch, A.C. König, K. Königsmann, R.W. Kraemer, R. Lee, S. Leffler, R. Lekebusch, A.M. Litke, W. Lockman, S. Lowe, D. Marlow, W. Maschmann, T. Matsui, F. Messing, W.J. Metzger, B. Monteleoni, R. Nernst, B. Niczyporuk, G. Nowak, C. Peck, P.G. Pelfer, B. Pollock, F.C. Porter, D. Prindle, P. Ratoff, B. Renger, C. Rippich, M. Scheer, P. Schmitt, J. Schotanus, A. Schwarz, D. Sievers, T. Skwarnicki, K. Strauch, U. Strohbusch, J. Tompkins, H.J. Trost, R.T. Van de Walle, H. Vogel, U. Volland, K. Wacker, W. Walk, H. Wegener, D. Williams, P. Zschorsch

THE CRYSTAL BALL COLLABORATION

California Institute of Technology, Pasadena, CA 91125, USA
Carnegie-Mellon University, Pittsburgh, PA 15213, USA
Cracow Institute of Nuclear Physics, Cracow, Poland
Deutsches Elektronen Synchrotron DESY, Hamburg, Germany
Universität Erlangen-Nürnberg, Erlangen, Germany
INFN and University of Firenze, Italy
Universität Hamburg, I. Institut für Experimentalphysik, Hamburg, Germany
Harvard University, Cambridge, MA 02138, USA
University of Nijmegen and NIKHEF-Nijmegen, The Netherlands
Princeton University, Princeton, NJ 08544, USA
Department of Physics, HEPL, and Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94305, USA
Universität Würzburg, Würzburg, Germany

Abstract

Using the Crystal Ball detector at the e^+e^- storage ring DORIS-II, we have searched for the hadronic transitions $\Upsilon(2S) \rightarrow \eta\ \Upsilon(1S)$ and $\Upsilon(2S) \rightarrow \pi^\circ\ \Upsilon(1S)$ in exclusive decays, where the $\Upsilon(1S)$ decays into an e^+e^- or a $\mu^+\mu^-$ pair and the η and π° are detected by their decay modes $\eta \rightarrow \gamma\gamma$, $\eta \rightarrow 3\pi^\circ \rightarrow 6\gamma$ and $\pi^\circ \rightarrow \gamma\gamma$. From the number of observed events we derive, after consideration of possible background sources, upper limits on the branching ratios $B(\Upsilon(2S) \rightarrow \eta\ \Upsilon(1S)) < 0.7\%$ and $B(\Upsilon(2S) \rightarrow \pi^\circ\ \Upsilon(1S)) < 0.8\%$ at the 90% confidence level.

Submitted to *Zeitschrift für Physik*

---

* This work was supported in part by the Department of Energy, contracts DE-AC03-81ER40050 (CIT), DE-AC02-76ER03066 (CMU), DE-AC02-76ER03064 (Harvard), DE-AC02-76ER03072 (Princeton), DE-AC03-76SF00515 (SLAC), DE-AC03-76SF00326 (Stanford), and by the National Science Foundation, grants PHY75-22980 (CIT), PHY81-07396 (HEPL), PHY82-08761 (Princeton).

1) Present Address: Inst. for Particle Physics, University of California, Santa Cruz, CA 95064, USA
2) Present Address: Massachusetts Institute of Technology, Cambridge, MA 02139, USA
3) Permanent Address: DPHPE, Centre d'Etudes Nucléaires de Saclay, Gif sur Yvette, France

INTRODUCTION

In heavy quarkonium systems, like charmonium and bottonium, the OZI-rule forbidden hadronic transitions play an important role. For instance the transitions $\psi(3685) \rightarrow \pi\pi\ J/\psi$ and $\Upsilon(2S) \rightarrow \pi\pi\ \Upsilon(1S)$ are among the dominant decay modes of the $\psi(3685)$ and $\Upsilon(2S)$ states. Although their absolute decay rates are not yet calculable from first principles, a general formalism [1-5] has been developed which describes hadronic transitions in terms of a multipole expansion of the gluonic field. In this formalism transition rates in the bottonium system are related by simple scaling laws to analogous transitions in the charmonium system. The experimental verification of such predictions for the $\pi\pi$ transitions [6-10] was one of the cornerstones of the applicability of this formalism. Further tests of this model could be provided by other hadronic transitions, which are however more difficult to observe experimentally.

We have used our $\Upsilon(2S)$ data sample, accumulated with the Crystal Ball detector at the e^+e^- storage ring DORIS-II, to search for the hadronic transitions $\Upsilon(2S) \rightarrow \eta\ \Upsilon(1S)$ and $\Upsilon(2S) \rightarrow \pi^\circ\ \Upsilon(1S)$. Our results are compared with the measured branching ratios of the analogous transitions in the charmonium system and with theoretical predictions.

DETECTOR AND DATA SAMPLE

The Crystal Ball detector has been described in detail elsewhere [11]. It is a non-magnetic calorimetric detector especially designed for measuring electromagnetically showering particles with good angular and energy resolution. The main component of the detector is a highly segmented spherical array of 672 optically isolated NaI(Tl) crystals. Each crystal has a truncated pyramidal shape and is 16 radiation lengths long. The angular coverage of the NaI(Tl) shell amounts to 93% of the full solid angle and is extended to 98% by NaI(Tl) endcaps. The calorimeter provides an energy measurement for electromagnetically showering particles – electrons, positrons and photons – with an energy resolution of $\sigma/E = (2.7 \pm 0.2)\% \ / \ \sqrt[4]{E/\mathrm{GeV}}$.

Directions of photons and electrons are determined from their lateral energy distributions with an angular resolution of 1 to 2 degrees, slightly dependent on energy. The fine segmentation of the calorimeter allows an efficient discrimination between electromagnetically showering and minimum ionizing particles by means of pattern recognition techniques. The energy deposit of non-interacting minimum ionizing particles, e.g. muons, in the active material follows a distribution sharply peaked at 210 MeV. This energy is deposited in only a few – usually less than three – crystals. Electrons and photons are identified by their characteristic shower profile with an energy distribution typically spread over 13 adjacent crystals. Tagging and measurement of directions of charged particles was originally performed by three double layers and, after an upgrade, by four double layers of cylindrical proportional tube chambers with charge division readout.

The data sample used for this analysis consists of $(193 \pm 15) \cdot 10^3$ produced $\Upsilon(2S)$ resonance decays corresponding to an integrated luminosity of 52 pb^{-1}.

ANALYSIS

We searched for the hadronic transitions $\Upsilon(2S) \to \pi^\circ\ \Upsilon(1S)$ and $\Upsilon(2S) \to \eta\ \Upsilon(1S)$ using those decay modes where the $\Upsilon(1S)$ resonance decays into a lepton pair $\ell^+\ell^-$ (ℓ = e or μ), the π° decays into two photons, and the η decays either $\eta \to \gamma\gamma$ or $\eta \to 3\pi^\circ \to 6\gamma$. The criteria for selecting events of the above types are very similar to those used in our analysis of the cascade decays $\Upsilon(2S) \to \gamma\chi_b \to \gamma\gamma\ \Upsilon(1S) \to \gamma\gamma\ell^+\ell^-$ [12]. The criteria are based on the characteristic event topology of two almost back-to-back leptons and 2 or 6 photons with an energy sum close to the mass difference between the $\Upsilon(1S)$ and $\Upsilon(2S)$ state.

With loose cuts on the total observed energy, the number of particles, the opening angle of the lepton pair and the energy sum of the photon candidates we preselected about 10^5 events from our total trigger sample of about ten million events. These events were further subjected to sets of cuts tailored to the different decay channels considered. In the following we outline the criteria used for the $\gamma\gamma\ell^+\ell^-$ final state. The criteria for the selection of the $(6\gamma)\ell\ell$ final state are based on straightforward multiplicity generalizations.

For a candidate event we require exactly four particles, each well separated in angle from detector regions close to the beam axis. A particle is defined as a contiguous group of crystals having an energy sum greater than 50 MeV. The event must have two lepton candidates. For an e^+e^- pair each must have an energy deposition between 3.0 GeV and 6.0 GeV; for a $\mu^+\mu^-$ pair the range is 150 MeV to 330 MeV. The opening angle of the two lepton candidates has to exceed 154° for an e^+e^- pair and 162° for a $\mu^+\mu^-$ pair, respectively. Each of the two remaining particles must have an energy in the range from 50 MeV to 550 MeV and a shower profile consistent with a photon signature. The energy sum of the photons is required to be greater than 350 MeV. This cut eliminates most of the QED background but not the events we are looking for. To achieve good energy measurement of the photon candidates a cut on the opening angle between each pair of particles was applied. Photon candidates must be separated from the leptons by more than 37°, whereas for a photon pair a cut at 28° was imposed, corresponding to the smallest kinematically allowed opening angle for the two photons originating from $\Upsilon(2S) \rightarrow \pi^\circ\ \Upsilon(1S) \rightarrow \gamma\gamma\ell\ell$. In addition we require that at least one of the two photon candidates be identified by the tube chambers as a neutral particle. To eliminate background we reject events with additional energy not correlated with any of the particles. The maximum allowed uncorrelated energy is 80 MeV in the endcaps for $\gamma\gamma ee$ events and 80 MeV in the full calorimeter for $\gamma\gamma\mu\mu$ events.

These cuts reduce the preselected data sample to 135 events of the type $\gamma\gamma ee$ and 105 events of the type $\gamma\gamma\mu\mu$. This sample consists mainly of events from the radiative cascade transitions $\Upsilon(2S) \rightarrow \gamma\chi_b \rightarrow \gamma\gamma\ \Upsilon(1S)$. The major contribution to the background is due to the hadronic transition $\Upsilon(2S) \rightarrow \pi^\circ\pi^\circ\ \Upsilon(1S)$, where two of the four photons from the $\pi^\circ \rightarrow \gamma\gamma$ decays escape detection. To further suppress background contributions we kinematically fit the selected events to the hypothesis $\Upsilon(2S) \rightarrow \gamma\gamma\Upsilon(1S)$. Besides energy and momentum conservation we use the additional constraint that the mass recoiling against the two photons agrees with the $\Upsilon(1S)$ mass. The energies of the leptons are treated in the fit as unmeasured quantities, resulting in a 3C fit. A cut on the confidence level of the kinematic fit at 5% passes 57 $\gamma\gamma ee$ events and 35 $\gamma\gamma\mu\mu$ events. The efficiency of this cut is 92% as determined by Monte Carlo calculations. The Monte Carlo is an accurate representation of the data including the non-gaussian tails of the energy and angular resolution for photons and leptons.

The events satisfying the above requirements are shown in the Dalitz plots (fig. 1a, b) for the $\gamma\gamma ee$ and $\gamma\gamma\mu\mu$ final states, respectively. Each event creates two entries corresponding to the two possible mass combinations for $M^2(\Upsilon(1S), \gamma)$. The solid lines represent the kinematic boundaries for events of the type $\Upsilon(2S) \rightarrow \gamma\gamma\Upsilon(1S)$ after taking into account our cuts on energies and opening angles of the photons. Vertical dot-dashed lines indicate the kinematic regions populated by the radiative transitions $\Upsilon(2S) \rightarrow \gamma\chi_b \rightarrow \gamma\gamma\ \Upsilon(1S)$ [13]. The horizontal lines at low and high di-photon mass values mark the π° and η bands which would correspond to the hadronic transitions $\Upsilon(2S) \rightarrow \pi^\circ\ \Upsilon(1S)$ and $\Upsilon(2S) \rightarrow \eta\ \Upsilon(1S)$, respectively. The width of each band corresponds to $\pm 3\sigma$ of our di-photon mass resolution for the π° (σ = 10 MeV) and the η (σ = 6 MeV) transition. These mass resolutions were determined with Monte Carlo calculations simulating the complete decay chain and include the response of our detector to the final state particles.

Excluding the kinematic regions of the cascade transitions we find 1 $\gamma\gamma ee$ event and 2 $\gamma\gamma\mu\mu$ events inside the π° band. Within the η band we observe 4 $\gamma\gamma ee$ events and 1 $\gamma\gamma\mu\mu$ event. The Dalitz plots show a clear separation of the kinematic regions for $\Upsilon(2S) \rightarrow \eta\ \Upsilon(1S)$ and $\Upsilon(2S) \rightarrow \gamma\chi_b \rightarrow \gamma\gamma\ \Upsilon(1S)$ transitions. Therefore the cascade transitions cannot feed the population of the η band. For the $\gamma\gamma ee$ final state a comparable number of entries is found in the sideband below the η signal region, indicating the presence of background.

In table 1 we list the number of observed events for the decay channels considered. Also given are the detection efficiencies of the individual decay channels as determined from Monte Carlo simulations. The systematic errors on the efficiencies reflect the effect of variations in the lower bound on the photon energy, in the limit on the uncorrelated energy and in the confidence level of the kinematic fit.

Table 1 also includes the results of the analysis of the hadronic transition $\Upsilon(2S) \rightarrow \eta\ \Upsilon(1S)$, $\eta \rightarrow 3\pi^\circ \rightarrow 6\gamma$. The selection criteria used for the search of the $(6\gamma)\ell\ell$ final state are similar to those described above with modifications to take into account the higher multiplicity. However, because of lower expected background we applied milder cuts on the opening angles between any two particles and used a lower bound of 20 MeV for the photon energies. For this decay mode we observe no events in either the ee or the $\mu\mu$ final state.

Background Studies

Before converting the results of table 1 into branching ratios or upper limits we consider possible background sources.

The background contamination arising from the hadronic transition $\Upsilon(2S) \rightarrow \pi^\circ\pi^\circ\ \Upsilon(1S)$ and $\Upsilon(2S) \rightarrow \pi^+\pi^-\ \Upsilon(1S)$ was studied by Monte Carlo simulations. The first reaction can lead to background events when two of the four photons from the $\pi^\circ \rightarrow \gamma\gamma$ decays escape detection. The second transition can fake $\gamma\gamma\ell\ell$ events when the charged pions are misidentified as photons. The $\pi\pi$ background was studied with a Monte Carlo simulation of ten times the number of $\Upsilon(2S) \rightarrow \pi\pi\ \Upsilon(1S)$ decays as found in our real $\Upsilon(2S)$ data. After scaling, we obtain a background contribution of zero events in the π° band and of 0.2 events in the η band.

To estimate background from the double radiative QED process $e^+e^- \rightarrow \gamma\gamma e^+e^-$ as well as from other possible nonresonant processes we used a $\Upsilon(1S)$ and $\Upsilon(4S)$ data sample, which is twice the integrated luminosity of our $\Upsilon(2S)$ data sample, and subjected it to the selection criteria stated above. The selected $\gamma\gamma\ell\ell$ events were kinematically fitted to the hypothesis $\Upsilon(2S) \rightarrow \gamma\gamma\Upsilon(1S)$ with the same constraints as used in our analysis of the $\Upsilon(2S)$ resonance data. The fact that the events were taken at different center of mass energies does not influence the results, as we do not use the measured lepton energies in the fit. In fig.2 the surviving events of the background sample are plotted in the same manner as the $\Upsilon(2S)$ data in fig.1.

After scaling, we find 1.5 $\gamma\gamma ee$ events and 0.5 $\gamma\gamma\mu\mu$ events with di-photon mass values consistent with the nominal π° mass value. Thus we conclude that the observed 1 $\gamma\gamma ee$ event and the two $\gamma\gamma\mu\mu$ events in the π° band of our $\Upsilon(2S)$ sample are consistent with being due to background processes.

The contamination in the η band is harder to estimate. The η band region of the background plot (fig.2) contains 1 $\gamma\gamma\mu\mu$ and 1 $\gamma\gamma ee$ event. A further inspection of fig.2 reveals that in general the background is more prominent in the $\gamma\gamma ee$ final state than in the $\gamma\gamma\mu\mu$ final state. However, simply scaling the results of the background study does not quantitatively explain the four observed $\gamma\gamma ee$ events. Furthermore, as mentioned in the previous section, the cascade events are kinematically excluded from feeding the η band. Nevertheless two features make it very likely that these events are caused by background processes: a) The observed excess of $\gamma\gamma ee$ over $\gamma\gamma\mu\mu$ events is present in both the $\Upsilon(2S)$ and the background sample. b) All five events have their low energy photon in the range 221 MeV to 241 MeV, whereas one expects a flat distribution over the kinematically allowed range from 221 MeV to 281 MeV for $\gamma\gamma\ell\ell$ events originating from $\Upsilon(2S) \to \eta\ \Upsilon(1S)$. The observed clustering of five events in one third of the kinematically allowed range has a probability of only $(1/3)^4 \approx 0.01$.

Results and Discussion

The above considerations imply that most of the observed events come from background processes. However, since our background studies do not quantitatively reproduce the number of observed events, we prefer not to subtract any background. Instead we derive conservative upper limits for the branching ratios of the transitions $\Upsilon(2S) \to \eta\ \Upsilon(1S)$ and $\Upsilon(2S) \to \pi^\circ\ \Upsilon(1S)$ from the uncorrected numbers of 5 and 3 events, respectively. To include the systematic and statistical uncertainties of the efficiencies (tab. 1) and of the number of $\Upsilon(2S)$ resonance decays in the upper limit calculation, we assume that these quantities are Gaussianly distributed. The upper limits for the branching ratios are then derived from the probability density functions, which are obtained by folding the Poisson distribution for n observed events with a Gaussian distribution. The latter depends on the decay mode considered and takes into account the errors on the corresponding efficiencies, on the number of $\Upsilon(2S)$ decays and on the branching ratios for the decays $\pi^\circ \to \gamma\gamma$, $\eta \to \gamma\gamma$, $\eta \to 3\pi^\circ$ and $\Upsilon(1S) \to \ell\ell$ [14]. For the two hadronic transitions we obtain the following upper limits on the branching ratios

$$B(\Upsilon(2S) \to \eta\ \Upsilon(1S)) < 0.7\% \quad (90\%\ CL)\ , \tag{1}$$

$$B(\Upsilon(2S) \to \pi^\circ\ \Upsilon(1S)) < 0.8\% \quad (90\%\ CL)\ . \tag{2}$$

Using $\Gamma_{tot}(\Upsilon(2S))= (30 \pm 7)$ keV [14] the above results correspond to upper limits on the partial rates of

$$\Gamma(\Upsilon(2S) \to \eta\ \Upsilon(1S)) \ < \ 0.2 \text{ keV} , \tag{3}$$

$$\Gamma(\Upsilon(2S) \to \pi^\circ\ \Upsilon(1S)) \ < \ 0.3 \text{ keV} . \tag{4}$$

Ours is the first result on the π° transition. The η transition has also been studied by ARGUS, CLEO and CUSB. The ARGUS limit [15] on $\Upsilon(2S) \to \eta\ \Upsilon(1S)$ is 0.5% and the CLEO limit [7] is 1%. CUSB [8], with a slightly smaller data sample than ours ($184 \cdot 10^3$ vs. $193 \cdot 10^3$ $\Upsilon(2S)$ decays) and a lower total acceptance of (58% vs. 74%) found no events consistent with the η mass, resulting in an upper limit of 0.2%. The difference between the CUSB upper limit and our result may be due to a background fluctuation.

All experimental upper limits obtained thus far are an order of magnitude larger than the theoretical predictions. Kuang and Yan [16] have estimated a partial width of $\Gamma(\Upsilon(2S) \to \eta\ \Upsilon(1S))= 0.01$ keV within the framework of the multipole expansion. Voloshin and Zakharov [17] have calculated the ratio of $\Gamma(\Upsilon(2S) \to \eta\ \Upsilon(1S))$ to the width of the process $\Upsilon(2S) \to \pi^+\pi^-\ \Upsilon(1S)$, where the evaluation of the matrix elements for the gluon conversion into the light hadrons makes use of triangle anomalies in the axial-vector current and the trace of the energy-momentum tensor. With $\Gamma(\Upsilon(2S) \to \pi^+\pi^-\ \Upsilon(1S))= (5.6 \pm 1.3)$ keV [14] the prediction by these authors corresponds to about 0.03 keV. These absolute rate predictions suffer from the limited understanding of how the soft gluons emitted by the heavy quarkonium systems hadronize into an η or a $\pi\pi$ system. In this respect, ratios of rates between similar transitions in the charmonium and bottonium system are more reliable. Under the assumption that the hadronic transition involving an η meson is dominated by the multipole operators of lowest order, Yan [4] obtains

$$\frac{\Gamma(\Upsilon(2S) \to \eta\ \Upsilon(1S))}{\Gamma(\psi(3685) \to \eta\ J/\psi)} \simeq \left[\frac{m_c}{m_b}\right]^4 \cdot \left[\frac{p(\Upsilon)}{p(J/\psi)}\right]^3 \simeq \frac{1}{275} , \tag{5}$$

where $m_b = 5.2$ GeV and $m_c = 1.8$ GeV are the quark masses and $p(\Upsilon)$ and $p(J/\psi)$ are the η decay momenta. The momentum dependent phase space factor alone would only yield a reduction by a factor of four. Using $B(\psi(3685) \to \eta\ J/\psi)= (2.7 \pm 0.4)\%$ and $\Gamma_{tot}(\psi(3685))= (215 \pm 40)$ keV [14] and our upper limit on $\Gamma(\Upsilon(2S) \to \eta\ \Upsilon(1S))$ we find

$$\frac{\Gamma(\Upsilon(2S) \to \eta\ \Upsilon(1S))}{\Gamma(\psi(3685) \to \eta\ J/\psi)} < \frac{1}{25} . \tag{6}$$

This observed suppression is about a factor six larger than the reduction expected from phase space alone and therefore supports the validity of the multipole expansion formalism.

The hadronic transition $\Upsilon(2S) \rightarrow \pi^\circ\ \Upsilon(1S)$ is isospin violating. Therefore its rate is expected to be much lower than the rate for $\Upsilon(2S) \rightarrow \eta\ \Upsilon(1S)$. However in the charmonium system the analogous transition $\psi(3685) \rightarrow \pi^\circ\ J/\psi$ is observed with a surprisingly large branching ratio $B(\psi(3685) \rightarrow \pi^\circ\ J/\psi) = (0.10 \pm 0.03)\%$ [14], which has triggered considerable theoretical effort [18-21] to calculate the ratio

$$r = \frac{\Gamma(\psi(3685) \rightarrow \pi^\circ\ J/\psi)}{\Gamma(\psi(3685) \rightarrow \eta\ J/\psi)} . \tag{7}$$

In the context of the multipole expansion the ratio r is given by [21]

$$r = \left[\frac{\langle 0|O_g|\pi^\circ\rangle}{\langle 0|O_g|\eta\rangle}\right]^2 \cdot \left[\frac{p_\pi}{p_\eta}\right]^3 , \tag{8}$$

where O_g is a purely gluonic operator with $J^P = 0^-$ and the factor $(p_\pi/p_\eta)^3$ is due to the P-wave nature of the decays. Ioffe and Shifman [21] showed that the ratio r can be expressed in terms of the current quark mass ratio $\mathrm{m_d}/\mathrm{m_u}$ yielding

$$r \simeq 3 \cdot \left[\frac{m_d - m_u}{m_d + m_u}\right]^2 \cdot \left[\frac{m_\pi}{m_\eta}\right]^4 \cdot \left[\frac{p_\pi}{p_\eta}\right]^3 . \tag{9}$$

For $(\mathrm{m_d} - \mathrm{m_u})/(\mathrm{m_d} + \mathrm{m_u}) \approx 0.4$ this is in good agreement with the experimental charmonium value of $r = (3.7 \pm 1.2) \cdot 10^{-2}$.

Applying the above expression to the corresponding transitions in the bottonium system we obtain

$$\frac{\Gamma(\Upsilon(2S) \rightarrow \pi^\circ\ \Upsilon(1S))}{\Gamma(\Upsilon(2S) \rightarrow \eta\ \Upsilon(1S))} \approx 0.14 . \tag{10}$$

Using the estimate $\Gamma(\Upsilon(2S) \rightarrow \eta\ \Upsilon(1S)) \approx 0.03$ keV [17] this yields a predicted rate $\Gamma(\Upsilon(2S) \rightarrow \pi^\circ\ \Upsilon(1S))$ of about $4 \cdot 10^{-3}$ keV. Our upper limit of $\Gamma(\Upsilon(2S) \rightarrow \pi^\circ\ \Upsilon(1S)) < 0.3$ keV (90% C.L.) is still two orders of magnitude above this prediction.

An estimate of $\Gamma(\Upsilon(2S) \rightarrow \pi^\circ\ \Upsilon(1S))$ can also be obtained by scaling $\Gamma(\psi(3685) \rightarrow \pi^\circ\ J/\psi)$ according to equation (5), because the same multipole operators contribute to the η and π° transitions. Neglecting small differences in phase space we obtain

$$\frac{\Gamma(\Upsilon(2S) \rightarrow \pi^\circ\ \Upsilon(1S))}{\Gamma(\psi(3685) \rightarrow \pi^\circ\ J/\psi)} \simeq \left[\frac{m_c}{m_b}\right]^4 \simeq \frac{1}{70} . \tag{11}$$

Our upper limit on the rate of $\Upsilon(2S) \rightarrow \pi^\circ\ \Upsilon(1S)$, compared to the measured value of $\Gamma(\psi(3685) \rightarrow \pi^\circ\ J/\psi) = (0.22 \pm 0.08)$ keV, yields an upper limit on this ratio of about one.

In summary we have obtained upper limits for $\Gamma(\Upsilon(2S) \rightarrow \eta\ \Upsilon(1S))$ and for $\Gamma(\Upsilon(2S) \rightarrow \pi^\circ\ \Upsilon(1S))$. Our result on the η transition supports the validity of describing the hadronic transitions in the framework of the multipole expansion formalism. The upper limit obtained for the isospin violating decay $\Upsilon(2S) \rightarrow \pi^{\circ}\ \Upsilon(1S)$ is not sensitive enough to test existing model predictions.

ACKNOWLEDGMENTS

We would like to thank the DESY and SLAC directorates for their support. This experiment would not have been possible without the dedication of the DORIS machine group as well as the experimental support groups at DESY. Those of us from abroad wish to thank the DESY laboratory for the hospitality extended to us while working at DESY. Z.J., B.N., and G.N. thank DESY for financial support. D.W. acknowledges support from the National Science Foundation. E.D.B., R.H., and K.S. have benefitted from financial support from the Humboldt Foundation. S.C. acknowledges support from the Dept. of Physics and Laboratory of Nuclear Science of the Massachusetts Institute of Technology. The Nijmegen group acknowledges the support of FOM-ZWO. The Erlangen, Hamburg, and Würzburg groups acknowledge financial support from the German Federal Minister for Research and Technology (BMFT) under the contract numbers 054 ER 11P(5), 054 HH 11P(7), 054 WU 11P(1) and from the Deutsche Forschungsgemeinschaft (Hamburg). This work was supported in part by the U.S. Department of Energy under Contract No. DE-AC03-81ER40050 (CIT), No. DE-AC02-76ER03066 (CMU), No. DE-AC02-76ER03064 (Harvard), No. DE-AC02-76ER03072 (Princeton), No. DE-AC03-76SF00515 (SLAC), No. DE-AC03-76SF00326 (Stanford), and by the National Science Foundation under Grants No. PHY75-22980 (CIT), No. PHY81-07396 (HEPL), No. PHY82-08761 (Princeton).

References

[1] L. S. Brown and R. N. Cahn, Phys. Rev. Lett. **35**,1 (1975)

[2] K. Gottfried, Phys. Rev. Lett. **40,** 598 (1978)

[3] V. Voloshin, Nucl. Phys. **B154,** 365 (1979)

[4] Tuang-Mow Yan, Phys. Rev. **D22,** 1652 (1980)

[5] V.A. Novikov and M.A. Shifman, Z. Phys. **C8,** 43 (1981)

[6] B. Niczyporuk *et al.*, (LENA Collaboration), Phys. Lett. **100B,** 95 (1981); G. Mageras *et al.*, (CUSB Collaboration), Phys. Rev. Lett. **46,** 1115 (1981); J. Mueller *et al.*, (CLEO Collaboration), Phys. Rev. Lett. **46,** 1181 (1981)

[7] D. Besson *et al.*, (CLEO Collaboration), Phys. Rev. **D30,** 1433 (1984)

[8] V. Fonseca *et al.*, (CUSB Collaboration), Nucl. Phys. **B242,** 31 (1984)

[9] H. Albrecht *et al.*, (ARGUS Collaboration), Phys. Lett. **134B,** 137 (1984)

[10] D. Gelphman *et al.*, (Crystal Ball Collaboration), Phys. Rev. **D32,** 2893 (1985)

[11] E.D. Bloom and C.W Peck, Ann. Rev. Nucl. Part. Sci. **33,** 143 (1983); M. Oreglia *et al.*, (Crystal Ball Collaboration), Phys. Rev. **D25,** 2259 (1982).

[12] W. Walk *et al.*, (Crystal Ball Collaboration), Phys. Rev. **D34,** 2611 (1986)

[13] In our previous analysis of the radiative transitions $\Upsilon(2S) \rightarrow \gamma\chi_b \rightarrow \gamma\gamma\ \Upsilon(1S)$ of ref. 12 only the two higher mass χ_b-states were observed in the $\gamma\gamma\ell\ell$ final state. Events originating from these two transitions contain a low energy photon in the energy range from 95 MeV to 145 MeV and fall into the indicated kinematic regions of fig. 1.

[14] Particle Data Group, Review of Particle Properties, Phys. Lett. **170B,** 1 (1986)

[15] H. Albrecht *et al.*, (ARGUS Collaboration), DESY 86-169, December 1986

[16] Yu-Ping Kuang and Tuang-Mow Yan, Phys. Rev. **D24,** 2874 (1981)

[17] M. Voloshin and V. Zakharov, Phys. Rev. Lett. **45,** 688 (1980)

[18] G. Segré and J. Weyers, Phys. Lett. **62B,** 91 (1976)

[19] H. Genz, Lett. Nuovo Cimento **21,** 270 (1978)

[20] P. Langacker, Phys. Lett. **90B,** 447 (1980)

[21] B. L. Ioffe and M. A. Shifman, Phys. Lett. **95B,** 99 (1980)

Table 1: *Number of observed events and efficiencies for the decay channels studied. The first error on the efficiencies is of statistical, the second of systematic origin.*

decay mode	number of events	efficiency in %
$ee\eta(\gamma\gamma)$	4	$30.8 \pm 1.0 \pm 0.5$
$\mu\mu\eta(\gamma\gamma)$	1	$24.2 \pm 0.4 \pm 0.5$
$\ell\ell\eta(3\pi^\circ)$	0	$19.0 \pm 1.2 \pm 0.5$
$ee\pi^\circ(\gamma\gamma)$	1	$10.4 \pm 1.2 \pm 0.5$
$\mu\mu\pi^\circ(\gamma\gamma)$	2	$8.8 \pm 0.3 \pm 0.5$

FIGURE CAPTIONS

Fig. 1 : *Dalitz plot of di-photon mass* $M^2_{\gamma\gamma}$ *versus effective mass* $M^2(\Upsilon(1S), \gamma)$ *for fitted a)* $\gamma\gamma ee$ *and b)* $\gamma\gamma\mu\mu$ *events resulting from the* $\Upsilon(2S)$ *resonance data. Indicated are the* η *and* π° *bands for the hadronic transitions* $\Upsilon(2S) \rightarrow \eta\ \Upsilon(1S)$ *and* $\Upsilon(2S) \rightarrow \pi^\circ\ \Upsilon(1S)$ *(horizontal dashed lines) and the kinematic regions of the cascade transitions* $\Upsilon(2S) \rightarrow \gamma\chi_b \rightarrow \gamma\gamma\ \Upsilon(1S)$ *(vertical and slightly skewed dot-dashed lines). The kinematic boundaries are marked by solid lines.*

Fig. 2 : *Scatter plot for background events obtained from the analysis of* $\Upsilon(1S)$ *and* $\Upsilon(4S)$ *data with the same cuts as applied to the* $\Upsilon(2S)$ *data. Fig.2a and 2b show the distributions for the fitted* $\gamma\gamma ee$ *and* $\gamma\gamma\mu\mu$ *events, respectively. Superimposed are the kinematic boundaries of fig. 1.*

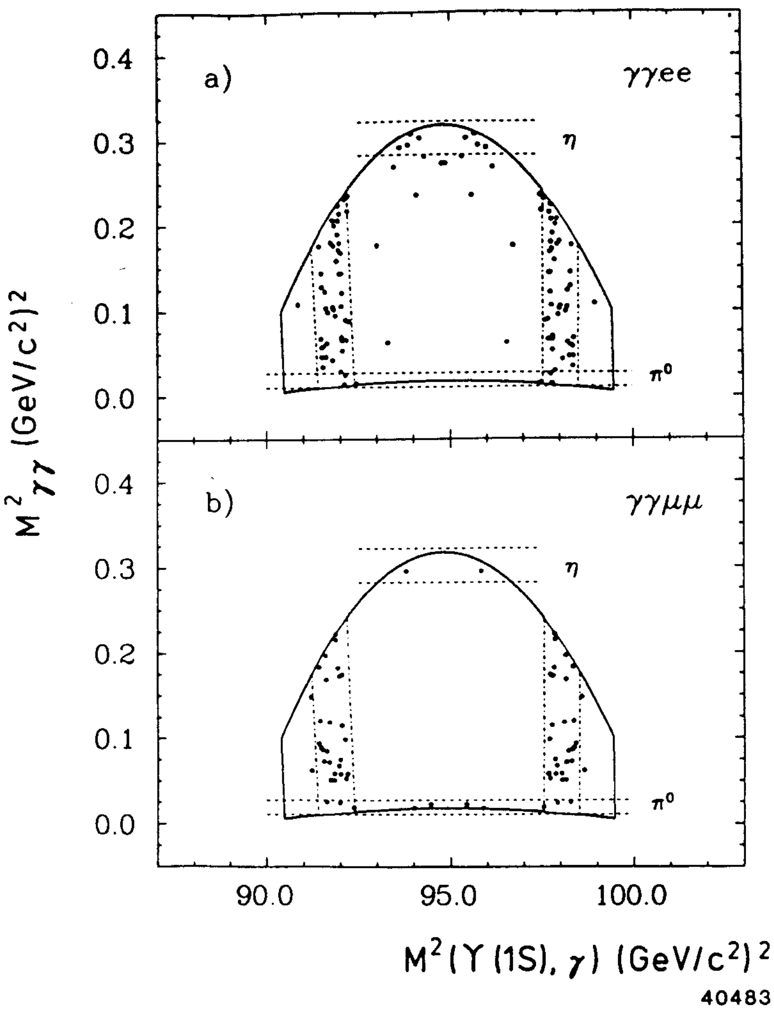
a)
γγee
η
π⁰
b)
γγμμ
0.4
0.3
0.2
0.1
0.0
90.0
95.0
100.0
M²γγ (GeV/c²)²
M²(Υ(1S), γ) (GeV/c²)²
40483

Figure 1:

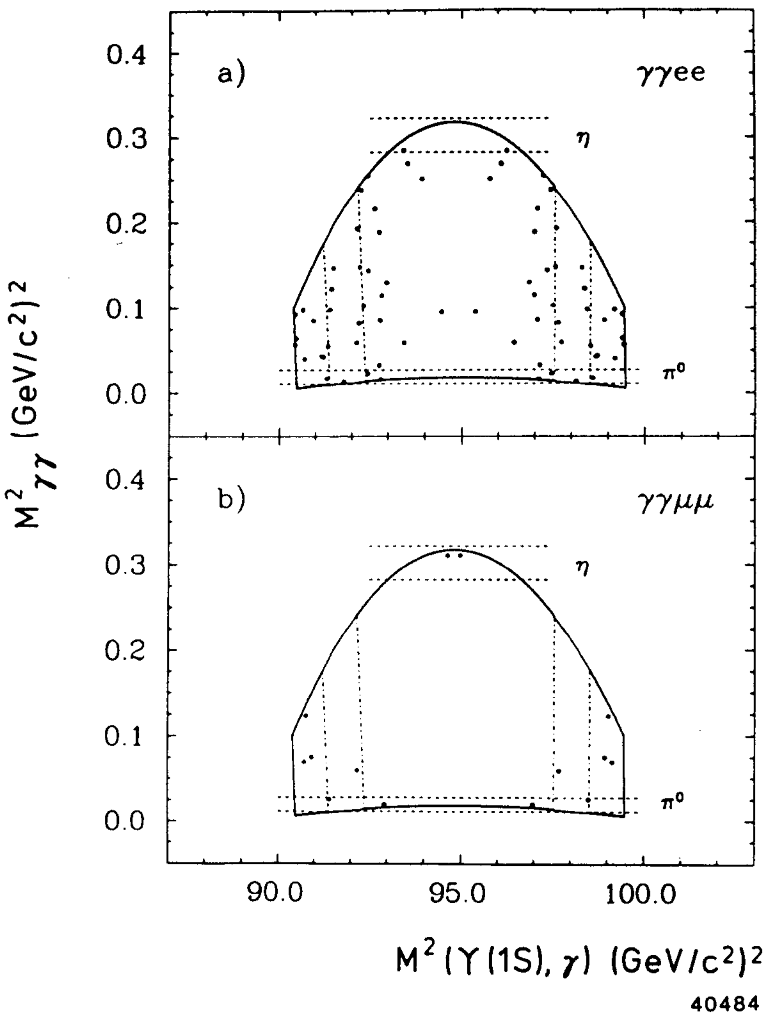
0.4
0.3
0.2
0.1
0.0
a)
γγee
η
π⁰
b)
γγμμ
90.0
95.0
100.0
M²γγ (GeV/c²)²
M²(Υ(1S), γ) (GeV/c²)²
40484

Figure 2: