# Measurement of the Branching Ratio of $\Upsilon(3S) \to \pi^+\pi^-\Upsilon(1S)$

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The branching ratio of $\Upsilon(3S) \to \pi^+\pi^-\Upsilon(1S)$ has been measured to be $(4.9 \pm 0.9 \pm 0.5)\%$. The di-pion invariant-mass distribution for this decay is flatter than that for the decays $\Upsilon(2S) \to \pi^+\pi^-\Upsilon(1S)$ and $\psi' \to \pi^+\pi^-\psi$.

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There are many possible di-pion transitions between states in the $\Upsilon$ family of resonances.[1] Hitherto, only the properties of the transition $\Upsilon(2S) \to \pi^+\pi^-\Upsilon(1S)$ have been adequately measured.[2] In this Letter we present the branching ratio of $\Upsilon(3S) \to \pi^+\pi^-\Upsilon(1S)$ and discuss the properties of the di-pion system in this decay.

In quantum chromodynamics (QCD) the hadronic transitions between heavy-quark bound states are described as occurring via soft-gluon emission, with the gluons fragmenting into hadrons. Within the framework of heavy-quark potential models the decay rates can be calculated from a multipole expansion of the gluon fields, while the properties of the $(\pi\pi)$ system are constrained by partial conservation of axial-vector current (PCAC) and current algebra.[1,3] This treatment has been successful in describing the decays $\Upsilon(2S) \to \pi^+\pi^-\Upsilon(1S)$ and $\psi' \to \pi^+\pi^-\psi$.

We have observed the decay $\Upsilon(3S) \to \pi^+\pi^-\Upsilon(1S)$ by using the CLEO detector at the Cornell Electron Storage Ring (CESR). The detector has been described previously.[4] A recent major improvement is that the conventional spectrometer magnet has been replaced by a superconducting solenoid capable of producing a field of 1.0 T.

Hadronic events were selected as described in Ref. 4. The data sample consists of 11 249 (1682) $nb^{-1}$ of accumulated luminosity and 73 778 (4987) hadronic events taken at energies at (below) the $\Upsilon(3S)$. The data were obtained under three different magnetic field conditions: conventional coil at 0.42 T (1504 $nb^{-1}$); superconducting coil at 0.5 T (1959 $nb^{-1}$); and superconducting coil at 1.0 T (9468 $nb^{-1}$).

We determine the branching ratio, $B(\Upsilon(3S) \to \pi^+\pi^-\Upsilon(1S))$, in two different ways. The first involves computing the missing mass, $M_x$, recoiling against pairs of opposite-sign pions observed at the $\Upsilon(3S)$. In Fig. 1 we show the $M_x$ distribution for data obtained with a 1.0-T field in the CLEO solenoid. A peak is observed at the mass of the $\Upsilon(1S)$. (The data sample is too small and the resolution insufficient to observe a signal for data taken with the field less than 1.0 T.) We have tried three different functions to fit the distribution in the region of the $\Upsilon(1S)$. In all cases a second-order polynomial background function has been used, and (a) a single Gaussian of unconstrained full width at half maximum (FWHM) and area; (b) a single Gaussian constrained to have the FWHM found from a complete Monte Carlo simulation (described later) of the $\Upsilon(3S) \to \pi^+\pi^-\Upsilon(1S)$ decay; or (c) two Gaussians with common means and different widths determined from the Monte Carlo. The results of the three different methods agree to within 2%, and we quote the result of fit (c).

After correcting for the di-pion acceptance (described later), we find $1656 \pm 401 \pm 120$ $\pi^+\pi^-\Upsilon(1S)$ decays of the $\Upsilon(3S)$, where the systematic error (listed last) arises primarily from uncertainties in the di-pion acceptance. At the $\Upsilon(3S)$ peak we find that $(45 \pm 1)\%$ of the 53 417 hadronic events (obtained with a magnetic field of 1.0 T) are nonresonant, leaving $29\,379 \pm 534$ $\Upsilon(3S)$ decays. Since the leptonic branching ratio of the $\Upsilon(3S)$ $[B_{\mu\mu}(3S)]$ is small[5] ($\lesssim 3\%$), we ignore the $1/[1 - 3B_{\mu\mu}(3S)]$ correction in obtaining the total number of observed $\Upsilon(3S)$ decays. We correct

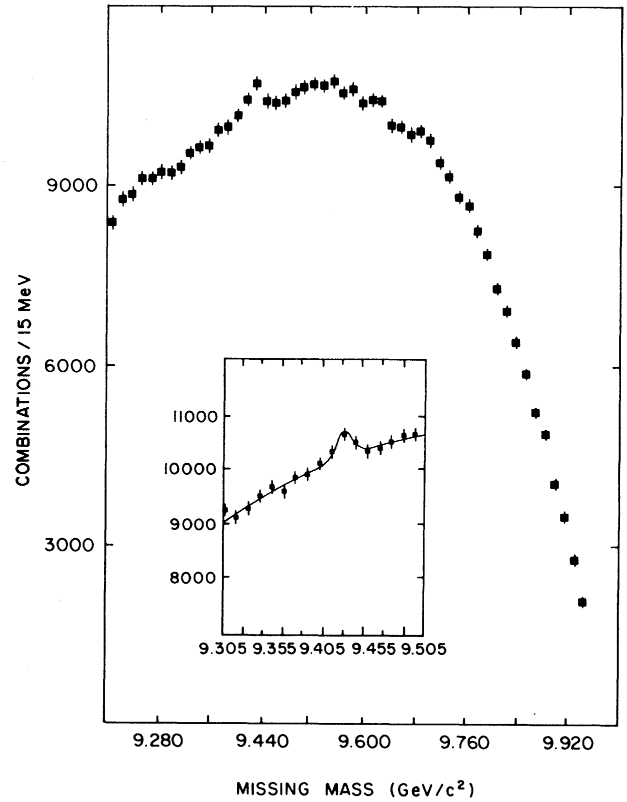


FIG. 1. The missing mass recoiling against $\pi^+\pi^-$ in $\Upsilon(3S)$ events. Inset: the result of the fit described in the text.

for the hadronic event acceptance (0.83) for all $\Upsilon(3S)$ decays relative to the acceptance (0.87) for $\Upsilon(1S)$ decays. The branching ratio is then found to be

$$B(\Upsilon(3S) \to \pi^+\pi^-\Upsilon(1S)) = (5.4 \pm 1.3 \pm 0.5)\%.$$

The second method of measuring the branching ratio involves detecting $\Upsilon(3S) \to \pi^+\pi^-\Upsilon(1S)$, $\Upsilon(1S) \to e^+e^-$ or $\mu^+\mu^-$. After a series of selection cuts were made, all potential candidates were visually examined by at least two physicists. All of the events in the final sample come from $\Upsilon(3S)$ decays, and none from the continuum below the $\Upsilon(3S)$. We find 34 (29) events from the complete (with the superconducting coil) data sample. In order to calculate a branching ratio we use only the data taken with the superconducting magnet and make additional fiducial and trigger requirements. This yields thirteen ($\pi^+\pi^-e^+e^-$) and nine ($\pi^+\pi^-\mu^+\mu^-$) events.

The di-pion acceptance ($\epsilon_{\pi\pi}$) is estimated by a Monte Carlo program which includes the effects of multiple scattering, drift chamber resolution and efficiency, absorption, and pion decay. The acceptance depends only slightly on the di-pion mass and we use a phase-space distribution to calculate the overall acceptance. We assume that the di-pion system is produced isotropically in the laboratory frame (this is consistent with our observed distribution). We find $\epsilon_{\pi\pi}=0.55\pm0.04$. The lepton detection efficiency is estimated to be $0.32\pm0.02$ with use of Bhabha and muon pair events. We also correct the total number of detected $\Upsilon(3S)$ decays (35 092) obtained with the superconducting coil by the hadronic event acceptance, $0.83\pm0.06$. The total number of $\Upsilon(3S)$ decays in the sample then becomes $42\,280\pm769\pm2537$.

Combining the above yields

$$B(\Upsilon(3S)\to\pi^+\pi^-\Upsilon(1S))B(\Upsilon(1S)\to l^+l^-) =(1.45\pm0.32\pm0.15)\times10^{-3}$$

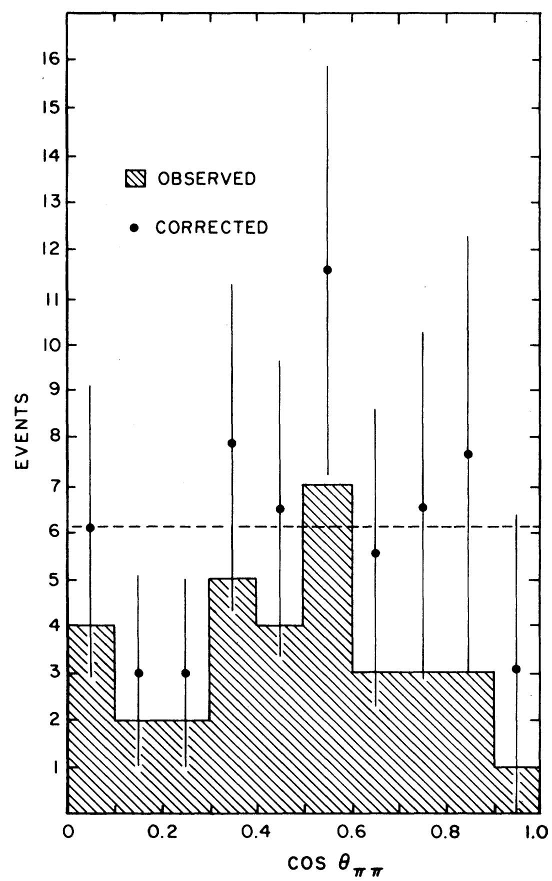


FIG. 2. The angular distribution of the di-pion system with respect to the colliding-beams axis. The dotted line represents an isotropic distribution normalized to the corrected distribution.

or

$$B(\Upsilon(3S)\to\pi^+\pi^-\Upsilon(1S))=(4.4\pm1.2\pm0.5)\% ,$$

where we have used[6] $B_{\mu\mu}(1S)=0.033\pm0.005$. Since both measurements of the branching ratio are dominated by their respective statistical errors, we average the two results to obtain

$$B(\Upsilon(3S)\to\pi^+\pi^-\Upsilon(1S))=(4.9\pm0.9\pm0.5)\%.$$

Recently Kuang and Yan,[3] in the framework of the multipole expansion of QCD, have made predictions for $B(\Upsilon(3S)\to\pi^+\pi^-\Upsilon(1S))$. Their predictions range from 1.3% to 3.4%, depending upon the particular form of the $b\bar{b}$ potential. Our result should serve to further constrain these predictions.

The 34 ($\pi\pi ll$) events have been used to study the properties of the di-pion system. In Fig. 2 we show $dN/d\cos\theta$, where $\theta$ is the angle of the di-pion system with respect to the beam axis. The acceptance-corrected distribution is consistent with isotropy although we cannot rule out some dependence on $\cos\theta$. A flat distribution is expected for a $(^3S_1{}')\to\pi\pi(^3S_1)$ decay.

The di-pion mass distribution ($x=m_{\pi\pi}/2m_\pi$) is shown in Fig. 3 and is uniform. Within the PCAC and multipole-expansion framework, the transition amplitude for ($\pi\pi$) creation in hadronic cascades may be written[1,3,7]

$$M\propto Aq_{1\mu}q_2{}^\mu+Bq_{1_0}q_{2_0},$$

where $q_1$ and $q_2$ are the pion four-momenta. The properties of the decays $\psi'\to\pi^+\pi^-\psi$ and $\Upsilon(2S)\to\pi^+\pi^-\Upsilon(1S)$ suggest that $B=0$ which results in curve $a$ in Fig. 3. No such peaking at large $x$ is

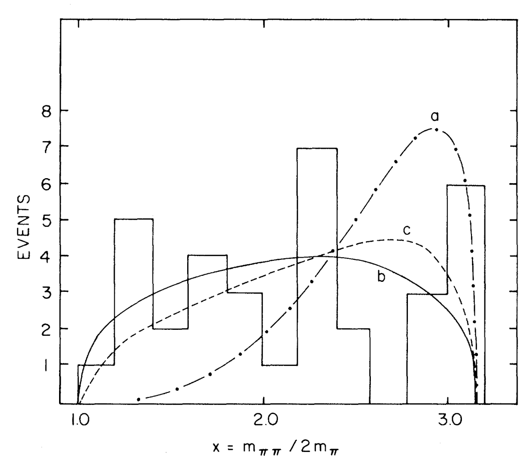


FIG. 3. The di-pion invariant-mass distribution. The curves are described in the text.

observed for the $\Upsilon(3S) \to \pi^+\pi^-(1S)$ decay. From the di-pion mass distribution for $\Upsilon(3S) \to \pi^+\pi^-\Upsilon(1S)$ we have determined that the best value of $A/B$ is $-0.15 \pm 0.12$, yielding curve $b$ in Fig. 3. Our data are also reasonably represented by a phase-space distribution (curve $c$ in Fig. 3). This result indicates that the form of the transition amplitude is sensitive to relatively small changes in the energy available in the decay and/or it depends on the heavy-quark states in the decay.

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[1]T. M. Yan, Phys. Rev. D 22, 1652 (1980).

[2]G. Mageras *et al.*, Phys. Rev. Lett. 46, 1115 (1981); J. J. Mueller *et al.*, Phys. Rev. Lett. 46, 1181 (1981). The CLEO collaboration has obtained a new value for the branching ratio of $\Upsilon(2S) \to \pi^+\pi^-\Upsilon(1S)$ and it is $(21.2 \pm 2.6 \pm 2.1)\%$. This supercedes the value given by Mueller *et al.* See D. A. Herrup, Ph.D. thesis, Cornell University, 1982 (unpublished).

[3]L. Brown and R. Cahn, Phys. Rev. Lett. 35, 1 (1975); Y. P. Kuang and T. M. Yan, Phys. Rev. D 24, 2874 (1981).

[4]D. Andrews *et al.*, Phys. Rev. Lett. 44, 1108 (1980), and 45, 219 (1980).

[5]The measured value of $B(\Upsilon(2S) \to \mu^+\mu^-)$ is $1.6 \pm 1.0\%$ [see *Proceedings of the 1981 International Symposium on Lepton and Photon Interactions at High Energies, Bonn, 1981*, edited by W. Pfeil (Physikalisches Institut, Universität Bonn, Bonn, 1981), CLNS 81/513].

[6]*Proceedings of the 1981 International Symposium on Lepton and Photon Interactions at High Energies, Bonn, 1981*, edited by W. Pfeil (Physikalisches Institut, Universität Bonn, Bonn, 1981), CLNS 81/513.

[7]The form used is

$$\frac{dN}{dM_{\pi\pi}} = K(M_{\pi\pi}^2 - 4M_\pi^2)^{1/2}\Big\{A^2(M_{\pi\pi}^2 - 2M_\pi^2)^2 + \tfrac{1}{3}AB(M_{\pi\pi}^2 - 2M_\pi^2)\Big[(M_{\pi\pi}^2 - 4M_\pi^2) + 2(M_{\pi\pi}^2 + 2M_\pi^2)\frac{K_0^2}{M_{\pi\pi}^2}\Big] + \tfrac{1}{20}B^2\Big[(M_{\pi\pi}^2 - 4M_\pi^2)^2 + \tfrac{4}{3}(M_{\pi\pi}^2 - 4M_\pi^2) \times (M_{\pi\pi}^2 + 6M_\pi^2)\frac{K_0^2}{M_{\pi\pi}^2} + \tfrac{8}{3}(M_{\pi\pi}^4 + 2M_\pi^2 M_{\pi\pi}^2 + 6M_\pi^4)\frac{K_0^4}{M_{\pi\pi}^4}\Big]\Big\},$$

where $M_{\pi\pi}$ is the di-pion invariant mass and $M_\pi$ is the pion mass.

$$K = (2M')^{-1}\{[(M' + M)^2 - M_{\pi\pi}^2][(M' - M)^2 - M_{\pi\pi}^2]\}^{1/2}$$

and $K_0 = (2M')^{-1}(M'^2 + M_{\pi\pi}^2 - M^2)$, where $M'$ $(M)$ is the mass of the $\Upsilon(3S)$ $[\Upsilon(1S)]$. T. M. Yan, private communication.