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RADIATIVE TRANSITIONS TO AN $\eta_c(2980)$ CANDIDATE STATE AND THE OBSERVATION OF HADRONIC DECAYS OF THIS STATE *†

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Please replace equation (24) on page 13 with the following corrected equation:

$$\mathrm{Br}\left(\psi'(3684) \to \gamma\text{"}\eta_c(2980)\text{"}\right) \sim 0.35\% \qquad (24)$$

*Work supported by the Department of Energy, contract DE-AC03-76SF00515.
†Presented at the 6th International Conference on Experimental Meson Spectroscopy, BNL, Upton, New York, April 25-26, 1980.

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ABSTRACT

Preliminary results from the Crystal Ball and Mark II experiments at SPEAR are presented on radiative transitions from $\psi'(3684)$ and $J/\psi(3095)$ to an $\eta_c(2980)$ candidate state. In addition to the inclusive photon signals reported previously by the Crystal Ball, both detectors now see exclusive hadronic final state signals at masses consistent with the states inclusively determined mass of 2981±16 MeV.

INTRODUCTION

The existence of the $^1S_0$ pseudoscalar partner of the J/ψ, the η_c, and its detailed properties yield important tests of the basic charmonium model.[1] However, the difficult history of the path to the discovery of a likely candidate for the η_c leads one to proceed with some caution before finally pronouncing the task completed. In previously reported preliminary results[2,3] from the Crystal Ball collaboration[4] at SPEAR the existence of a state which I will call "$\eta_c(2980)$" was demonstrated by the examination of inclusive photon spectra from $\psi'(3684)$ and $J/\psi(3095)$. Though seen as a signal of more than five σ in the $\psi'(3684)$ inclusive spectrum, no signal was seen initially in exclusive final states by the Crystal Ball (or other detectors). Clearly, confirmation of the states existence through the observation of exclusive hadronic final state decays was needed.

In this review I will report evidence from the Mark II[5] and Crystal Ball detectors for such final state hadronic decays. In addition, I will review the parameters of the state derived from the inclusive photon spectra of the Crystal Ball.

THE INCLUSIVE PHOTON SPECTRA FROM THE CRYSTAL BALL

Figure 1 shows the inclusive photon distribution from the $\psi'(3684)$. The transitions to the well-established χ states are indicated in the figure as are the transitions from $\chi(3550)$ and $\chi(3510)$

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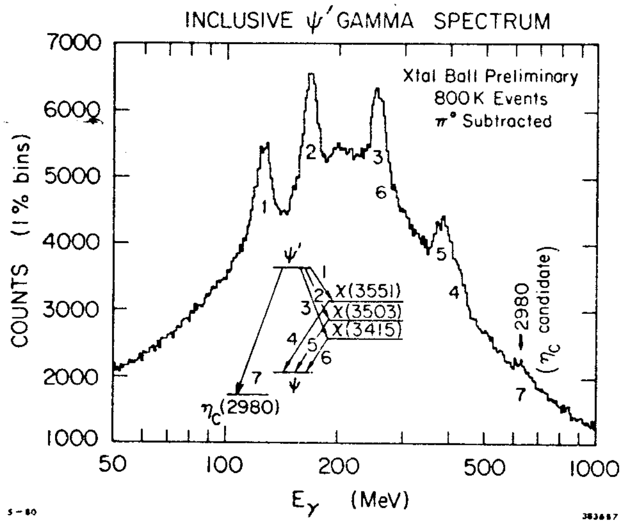
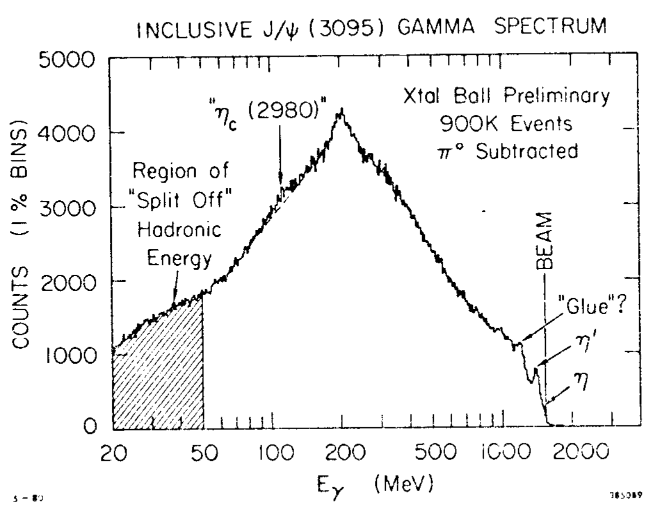


Fig. 1. The inclusive photon spectrum obtained from the decay of 800 K $\psi'(3684)$'s. The analysis leading to this spectrum and that of Fig. 2 is described in Ref. 2.

to $J/\psi(3095)$. Also clearly seen, but not relatively so large, is a greater than 5 σ signal for a state at $E_\gamma = 634\pm13$ MeV. The corresponding mass of the state is 2983 ± 16 MeV as obtained from this spectrum alone.[2]

Figure 2 shows the inclusive photon spectrum from $J/\psi(3095)$. The most obvious structure seen in this spectrum are the radiative transitions to η, η' and some additional structure (labeled "Glue"?), all at the endpoint of the spectrum. These structures are discussed in detail in another report to this conference.[6] In addition an enhancement above background can be seen at a photon energy (after fitting) of about 112 MeV corresponding to a mass of 2981 MeV. This is another indication for the state "η_c(2980)". Also seen in the spectrum is an apparent excess of photons at low energy. This region has been examined, using Monte Carlo simulation and it is found that much of the photon signal below 50 MeV is due to hadronic energy from hadronic interactions in

Fig. 2. The inclusive photon spectrum obtained from the decay of 900 K $J/\psi(3095)$'s. The data is plotted vs. $\ell n\,E$ since the resolution, $\Delta E/E$, is slowly varying in E.



the NaI(Tℓ). This energy has separated from the main hadronic track and is erroneously identified as photons by the Crystal Ball analysis software. It is expected that in the near future, using Monte Carlo codes, one will be able to subtract this background from the photon spectra and so find the true photon yield at low energy. This hadronic "split off" energy also causes some problems in the Crystal Ball when exclusive states are considered, as I will discuss later in this report.

In order to extract the best information possible regarding the mass and Γ, the natural width, of "η_c(2980)", a 9-parameter fit was simultaneously made to the ψ'(3684) and J/ψ(3095) inclusive spectra in the region of the state. The 9 fit parameters are: 3 for a background quadratic for the ψ'(3684) near 634 MeV, 3 for a background quadratic for J/ψ(3095) near 112 MeV, the amplitude for a Breit-Wigner folded with a Gaussian resolution of 43 MeV (FWHM) at the ψ'(3684), the amplitude for a Breit-Wigner folded with a Gaussian resolution of 11 MeV (FWHM) at the J/ψ(3095), and the mass of the assumed resonance. The natural line width, Γ, of the Breit-Wigner shape was also varied externally to the fit and the dependence of χ^2 on Γ was determined. Figures 3 and 4 show preliminary results of this fitting procedure.[7] In Fig. 3 is shown $\chi^2(\Gamma)$ and A(Γ) where A(Γ) is the number of counts in the extracted signal at the J/ψ(3095) as a function of Γ. A broad minimum in χ^2 is seen centered at Γ = 20 MeV.

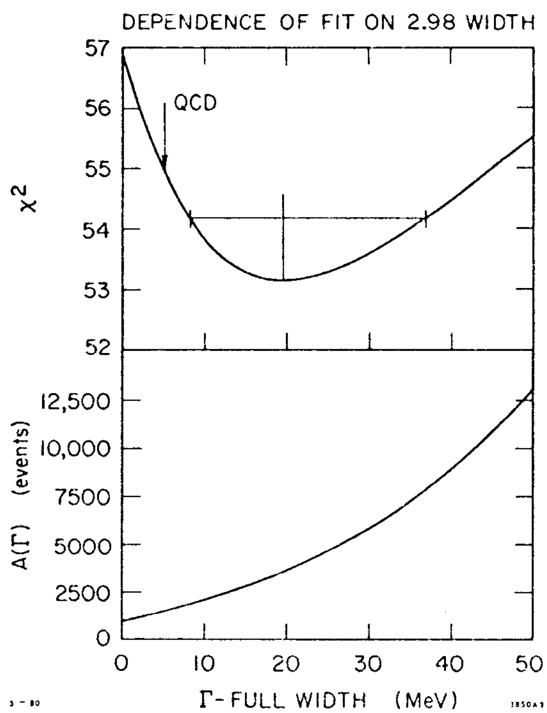


Fig. 3. Results of the 9 parameter fit discussed in the text as a function of the separately varied line with Γ. The theoretically expected[1] width is also shown: a) $\chi^2(\Gamma)$; χ^2 for the 9 parameter fit b) A(Γ); the number of counts in the extracted "η_c(2980)" signal from the J/ψ(3095) inclusive spectrum.

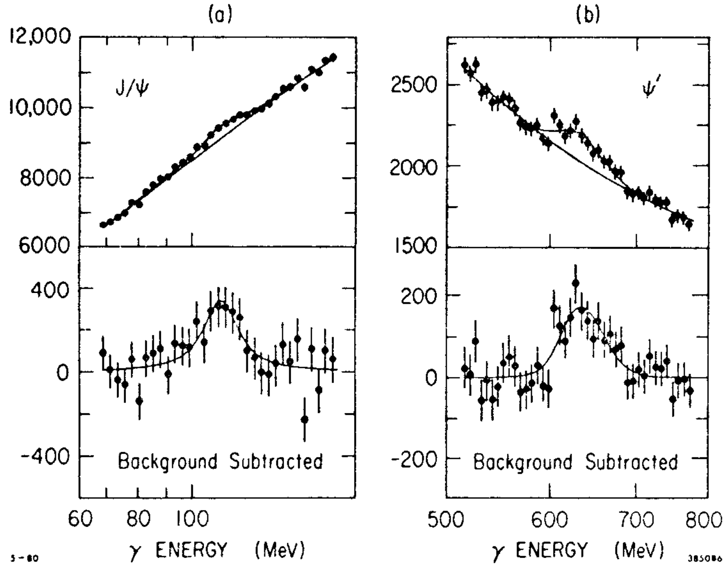
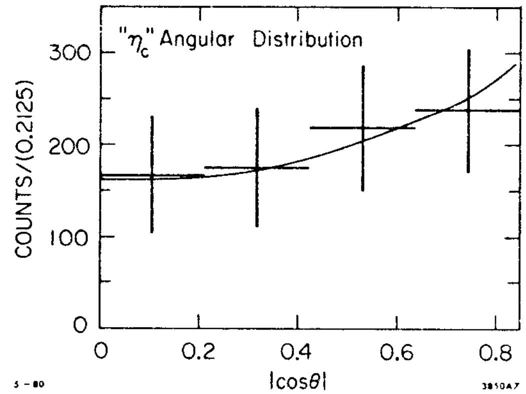


Fig. 4. Blowups of Figs. 1 and 2 in the region of "η_c(2980)" signal, with minimum χ^2-9 parameter fit results overplotted ($\Gamma = 20$ MeV). In both (a) and (b), unsubtracted, and background (from fit) subtracted spectra are shown.

However, the 1 σ limits $\left(\chi^2_{\pm} = \chi^2_{min} \pm 1\right)$ of Γ are +16 and -11 MeV. Thus, the expected QCD value[1] of ~5 MeV for the width of the standard η_c is only about 1.5 σ away from the experimentally preferred value of 20 MeV. Indeed, $\Gamma = 0$ is less than 2 σ from the experimentally preferred value. Figures 4(a),(b) show the common best fit with $M = 2981$ (± 15) MeV and $\Gamma = 20\binom{+16}{-11}$ MeV ($\chi^2 = 53.2$ for 66 degrees of freedom) overplotted on the data for the $J/\psi(3095)$ and $\psi'(3684)$ inclusive photon spectra respectively. The error on the mass of ± 15 MeV is predominantly systematic. The error on Γ, however, is purely statistical. No attempt has yet been made to realistically estimate the systematic errors of Γ from the Crystal Ball experiment. Clearly, uncertainty in the form of the background for the $J/\psi(3095)$ inclusive spectrum fit might influence the derived Γ.

Figure 5 shows an angular distribution of the photons in the region of "η_c(2980)" obtained from the $\psi'(3684)$ inclusive spectrum by dividing the data into bins of $|\cos\theta|$ and fitting the inclusive spectra of each $|\cos\theta|$ bin to a folded Breit-Wigner plus quadratic background.[7] If "η_c(2980)" is a spin-0 particle one expects the resulting

Fig. 5. The angular distribution of the radiated photon in the decay $\psi;(3684) \to \gamma''\eta_c(2980)''$. The angle is the polar angle of the photon to the e^+ beam direction. Overplotted is the expected distribution, Eq. 1 text, for a spin-0 particle.



angular distribution to be

$$\left(\frac{d\sigma}{d\Omega}\right)_{\text{spin-0}} \propto \left(1 + \cos^2\theta\right) \qquad (1)$$

The data of Fig. 5 are clearly consistent with (1); however, the data are also consistent with a flat angular distribution which would be inconsistent with a spin-0 assignment for the state.

HADRONIC FINAL STATES OF "η_c(2980)" FROM THE MARK II

First reports of the observation of hadronic decays of "η_c(2980)" came from the Mark II collaboration at SPEAR.[8] Figure 6 shows such a decay in the Mark II detector

$$\psi'(3684) \to \gamma''\eta_c(2980)'' \qquad (2)$$
$$\hookrightarrow \pi^{\pm}K^{\mp}K_S^0$$

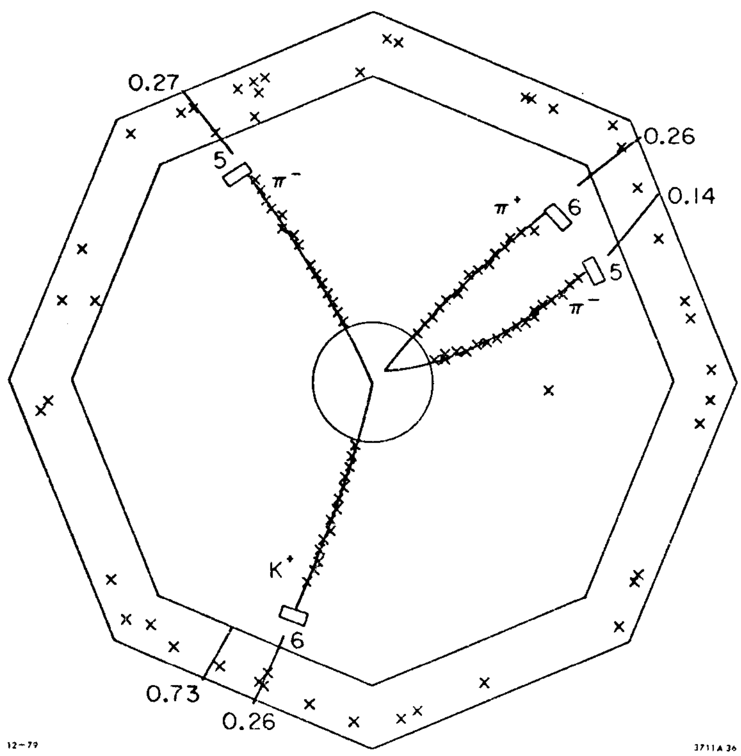


Fig. 6. The decay $\psi'(3684) \to \gamma''\eta_c(2980)''$, $''\eta_c(2980)'' \to \pi^{\pm}K^{\mp}K_S$ in Mark II detector.[8] The K_S travels several centimeters before decaying into $\pi^+\pi^-$.

Additional work has been done since the publication of Ref. 8, and I will report here the preliminary results of this recent analysis.[9]

Only data from ψ' are presented. The final states studied were,

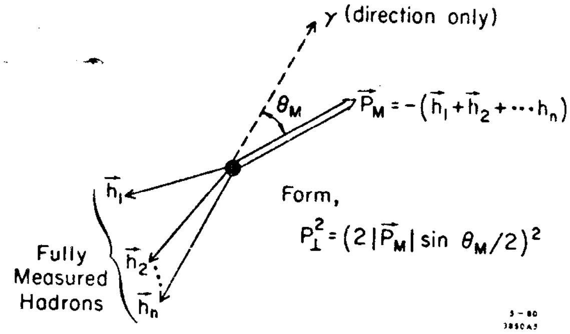


Fig. 7. Diagrammatic description of Mark II technique for separating radiative decay signal. For a true radiative decay, with only one photon in the event, $\theta_M \approx 0.0$.

$$\psi' \rightarrow \gamma + \left[\begin{array}{l} K^{\mp}K_S\pi^{\pm} \\ K^+K^-\pi^+\pi^- \\ \pi^+\pi^-\pi^+\pi^- \\ p\bar{p} \\ p\bar{p}\pi^+\pi^- \end{array}\right. \qquad (3)$$

where only the photon's direction was measured and the hadronic decay products angles and momenta were measured. From the fully measured hadrons one constructs a missing momentum, $\vec{P}_M$. As shown in Fig. 7, the direction of $\vec{P}_M$ is obtained relative to the photons direction obtaining θ_M. A quantity,

$$P_\perp^2 = \left(2|\vec{P}_M| \ \sin\theta_M/2\right)^2 \qquad (4)$$

is then calculated for each event.

Figure 8 shows the resulting $P_\perp^2$ distribution for $M < 3.35$ GeV where M is the 0-C mass obtained from the hadrons. The mass cut is made to remove contributions from the χ states.

The major background in this analysis is the process

$$\psi' \rightarrow n\pi^0 + X \quad , \qquad (5)$$

where all but one of the γ's from the π^0's are not seen.

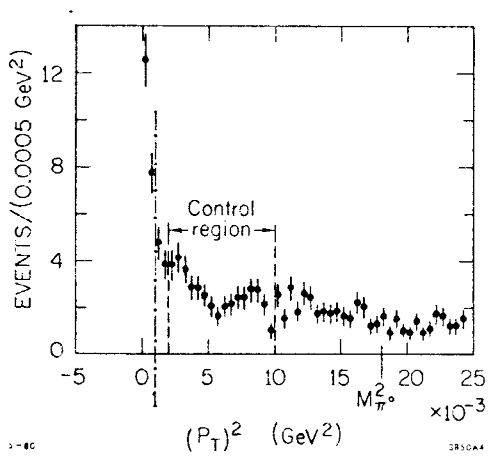
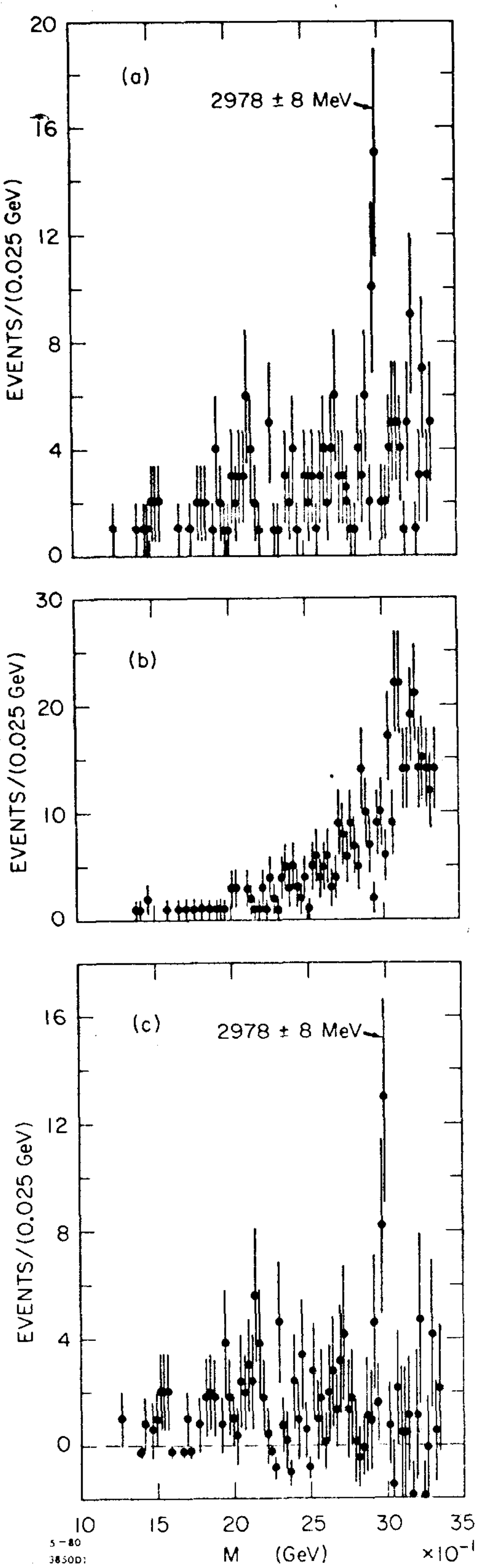


Fig. 8. $P_\perp^2$ vs. events/5×10^{-4} GeV^2, for the final states of Eq. 3 text. The radiative peak region has $P_\perp^2 \leq 1\times10^{-3}$ GeV^2, the control region has $2\times10^{-3} \leq P_\perp^2 \leq 1\times10^{-2}$ GeV^2. A mass cut of $M < 3.35$ GeV on the reconstructed hadron mass is made to remove contamination from the well known χ states.



For π^o decays it can be shown that,

$$dN_\gamma/d\left(P_\perp^2\right) \propto \frac{2\,m_{\pi^o}^2}{\left(m_{\pi^o}^2 + P_\perp^2\right)^2} \approx \text{const.}\ ,$$

$$P_\perp^2 << m_{\pi^o}^2\ . \qquad (6)$$

This yields a rather flat smoothly varying $P_\perp^2$ distribution for Fig. 8. However, for a radiative decay of ψ' to a particular mass, one expects a peak at small $P_\perp^2$ as in the case for the data of Fig. 8. This peak results from reaction (3) if only one γ is present in the final state.

Figure 9(a) shows the mass (M) distribution obtained from the data of Fig. 8 cut at $P_\perp^2 < 0.001$ GeV^2. There is a rather clear peak at a mass of 2978 ± 8 MeV in excellent agreement with the results of the Crystal Ball. In Fig. 9(b) is shown the mass distribution obtained from a "control region", 0.002 GeV$^2 \le P_\perp^2 \le$ 0.01 GeV^2.

Fig. 9. The Mark II signal for exclusive final states of "η_c(2980)". (a) The reconstructed hadron mass M (GeV) vs. events/2.5× 10^{-2} GeV obtained for $P_\perp^2 \le 1\times10^{-3}$ GeV^2. (b) M (GeV) vs. events/2.5 × 10^{-2} GeV^2 obtained from the control region of Fig. 8. (c) The background subtracted distribution for M (GeV) vs. events/2.5 × 10^{-2} GeV^2. A clear signal is seen at M = 2978 ± 8 MeV.

There is no evidence for an enhancement in this distribution at the "η_c(2980)" mass. Using the distribution of Fig. 9(b) to give the shape of the π^0 background for 9(a), one can subtract 9(b) from 9(a) after optimally normalizing the distribution; one obtains Fig. 9(c) which shows a somewhat enhanced signal at 2978 ± 8 MeV.

Table I shows a summary of the preliminary results from the Mark II collaboration. As shown in the Table, an upper limit has

TABLE I. MARK II Preliminary Results for $\psi' \to \gamma$"η_c(2980)" $\to$ f

$M_{"\eta_c"} = 2978 \pm 8$ MeV, $\Gamma_{"\eta_c"} < 30$ MeV (90% C.L.)

Final State - f	$Br(\psi' \to \gamma"\eta_c") * Br("\eta_c" \to f)$
$K_s K^{\pm} \pi$	$(1.5 \pm 0.6) \times 10^{-4}$
$K \bar{K} \pi$ (from I-spin conservation)	$(4.5 \pm 1.8) \times 10^{-4}$
$p\bar{p}$	$\left(0.8^{+0.8}_{-0.4}\right) \times 10^{-5}$
$2\pi^+ 2\pi^-$	$\left(4.5^{+3}_{-2}\right) \times 10^{-5}$

been placed on Γ for the state of Γ<30 MeV (90% C.L.). This result is comparable to the mass resolution of the detector in this mass range. It should be noted, however, that the best fit to the peak has Γ = 0.

HADRONIC FINAL STATES OF "η_c(2980)" FROM THE CRYSTAL BALL

The crystal Ball collaboration has recently reported[10] preliminary results on observation of the decay "η_c(2980)" $\to \eta\pi^+\pi^-$. The results were obtained using a 3-constraint fit in the Ball for the process,

$$J/\psi(3095) \to \gamma + "\eta_c(2980)" \to \text{hadrons} \quad . \qquad (7)$$

No indication for an exclusive signal has been seen yet at ψ'(3684);

however, preliminary estimates of inclusive branching fractions (see below) yield a larger number of "η_c(2980)" from the J/ψ(3095) data sample by a factor of about 3 as compared to the ψ'(3684) data sample.

Exclusive hadronic final states are reconstructed in the Crystal Ball by measuring both the energy and angles of the photons, while only measuring the angles of the charged hadrons. Thus for exclusive final states of the type,

$$J/\psi, \psi' \rightarrow \gamma + n\pi^0 + m\eta^0 + C^+ + C^-, \quad m,n=1,2,\ldots \qquad (8)$$

the π^0's and η's can be completely reconstructed as is the radiative γ. The four constraints of energy-momentum conservation are reduced to two by the loss of information of $E_{C^\pm}$. Various assumptions are made for the masses of $C^\pm$ and 2-C fits are made for each mass assumption. Particle identification for $C^\pm$ is thus made through the fitting process. Fits with C.L. < 0.10 are discarded. Additional constraints are added by assuming π^0 or η^0 mass assignments to the correctly paired photons. These additional constraints improve the mass resolution obtained from the fit.

Presently the Crystal Ball has an anomalous loss of about a factor of 2 in the efficiency for reconstructing exclusive final states like (8). This loss of efficiency is due to the "split off" hadronic energy mentioned previously. The split off energy fakes extra low energy photons in the event, and so confuses the topology routines, i.e., events which should be classified as having 2n + 2m + 1 photons, are found with addition photons and thrown out of the correct topology class. Work with the Monte Carlo codes is progressing toward a solution of this problem. It's worth mentioning that the Mark II collaboration had a similar problem with split off energy in the Lq Argon and has solved it quite successfully.

In order to estimate the efficiency for detecting states like (7) quantitatively, a known process was examined in detail. The exclusive state chosen was,

$$\begin{aligned} J/\psi(3095) &\rightarrow \gamma\,\eta' \\ &\quad\;\; \hookrightarrow \gamma\,\rho \\ &\quad\quad\quad\; \hookrightarrow \pi^+\pi^- \end{aligned} \qquad (9)$$

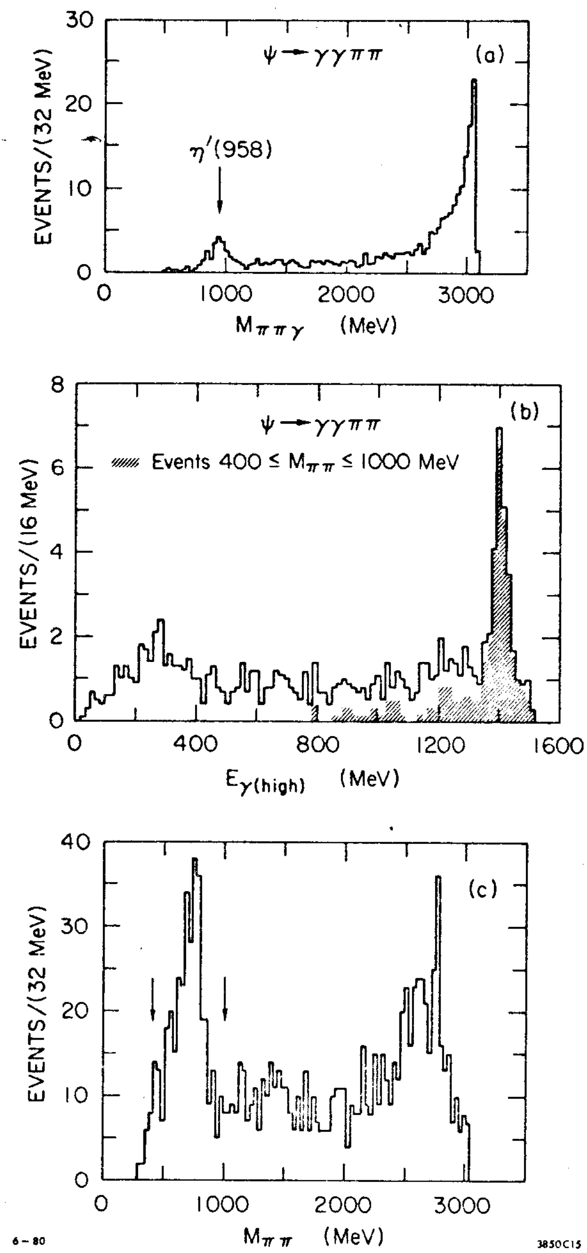


Fig. 10. Examination of the processes of Eq. 9 and 10 text in the Crystal Ball; 2-C fit results are shown. (a) $M_{\pi\pi\gamma}$ (MeV) vs. events/32 MeV, an η' signal is seen at $M_{\pi\pi\gamma}$=956±65 MeV. (b) E_{γ}^{hi} (MeV) vs. events/16 MeV, an η' signal is seen at 1400±20 MeV. The shaded histogram shows events with $400 \leq M_{\pi\pi} < 1000$ MeV. (c) $M_{\pi\pi}$ (MeV) vs. events/32 MeV, a ρ signal is seen at about 770 MeV.

The general topology of these events is,

$$J/\psi \rightarrow \gamma\gamma C^+C^- \quad . \qquad (10)$$

Figure 10(a) shows the results of 2-C fits to events of topology(10) when the minimum χ^2 fit preferred $C^+C^- = \pi^+\pi^-$. The confidence level for all events shown is greater than 0.10. A clear indication of an η' at the mass of 965±65 MeV is observed. The mass error is due entirely to the uncertainty in the proton energy measurement. The unshaded histogram of Fig. 10(b) shows the corresponding distribution in the high proton energy with the η' peak at 1400±20 MeV. A cleaner η' signal is obtained by cutting on the $\pi\pi$ mass distribution about the ρ mass. Figure 10(c) shows the $\pi\pi$ mass distribution obtained from the events of Fig. 10(a). A clear indication of a ρ is seen. On cutting at $400 \leq M_{\pi\pi} \leq 1000$ the photon energy distribution shown as the shaded histogram of Fig. 10(b) results. Using the η' signal from the shaded histogram of Fig. 10(b), we obtain 365 ± 30 η' events resulting from a sample of 800K $J/\psi(3095)$ decays.

Using previously measured branching fractions of[11]

$$\mathrm{Br}\left(J/\psi(3095) \rightarrow \gamma\eta'\right) \sim 7\times 10^{-3} \qquad (11)$$

and[12]

$$\mathrm{Br}(\eta' \rightarrow \rho\gamma) = 0.298 \pm 0.017 \;, \qquad (12)$$

plus a Monte Carlo estimate of geometrical efficiency of 0.53 ± 0.1, we expect 905 ± 120 η' events. The efficiency for correctly identifying topology (9) is thus estimated as 0.4 ± 0.1. One should note that (11) was obtained through measurement of the process

$$J/\psi \rightarrow \gamma\eta' \;,\; \eta' \rightarrow \gamma\gamma \;, \qquad (13)$$

while (12) was obtained by direct measurement of the ργ final state. So far the two decays of η' into γγ and ργ have not been measured well in the same detector. The Crystal Ball hopes to accomplish this in the near future and so possibly reduce the systematic errors on the inclusive η' measurements. Of course, in order to obtain superior measurements, resolution of the split off problem is needed.

Figure 11 shows the preliminary $K^+K^-\pi^0$ mass distribution obtained from 3-C fits to the topology

$$J/\psi(3095) \rightarrow \gamma\gamma\gamma\, K^+K^- \qquad (14)$$

The branching fraction of "η_c(2980)" is, using I-spin conservation, a factor of two smaller for the $K^+K^-\pi^0$ final state than for the $K^0_S\pi^\pm K^\mp$ final state observed by the Mark II. As is indicated in Fig. 11, no signal is seen yet by the Crystal Ball. Assuming $K^\pm$ split off effects are the same as $\pi^\pm$, an upper limit on the produced branching ratio is obtained.

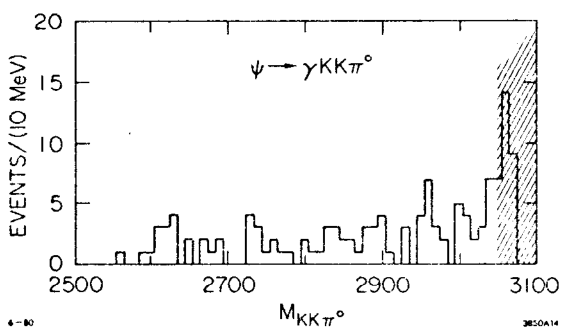


Fig. 11. $M_{KK\pi^0}$ (MeV) vs. events/10 MeV for events in the mass range of "η_c(2980)". No signal is evident. The region above 3045 MeV is contaminated by split off photons as described in the text; 3-C fit results of the Crystal Ball are shown.

$$\mathrm{Br}\left(J/\psi(3095)\to\gamma''\eta_c(2980)''\right)*\mathrm{Br}\left(''\eta_c(2980)''\to K^+K^-\pi^0\right)<1.5\times10^{-4}\ (90\%\ \mathrm{C.L.}) \qquad (15)$$

As shown in the summary section, this upper limit is consistent within error with the Mark II measurement.

Figure 12 shows the preliminary $\eta\pi^+\pi^-$ mass distribution obtained from 3-C fit to the topology

$$J/\psi(3095)\to\gamma\gamma\gamma\pi^+\pi^- \qquad (16)$$

A signal is seen at a mass of $M_{\eta\pi^+\pi^-}$=2972±15 MeV in excellent agreement with previously reported masses. The mass error is primarily due to the poor statistics of the measurement; 14±6 events are observed above background. Indicated in both Fig. 11 and 12 is the region where fake split off photons become a serious background. These regions are excluded from consideration.

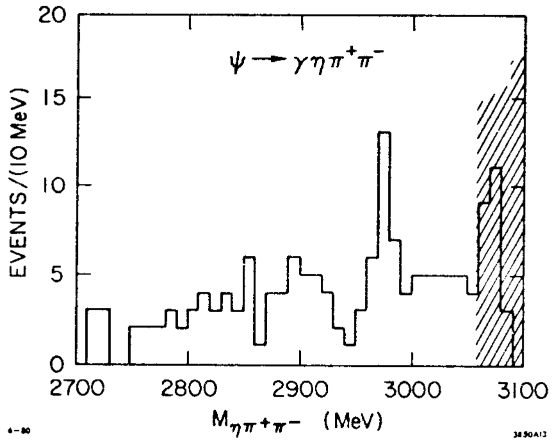


Fig. 12. Evidence for an exclusive final state signal for J/ψ(3095) radiative decay to ηππ. $M_{\eta\pi\pi}$ (MeV) vs. events/10 MeV is shown for events in the mass range of "η_c(2980)". A signal is evident at $M_{\eta\pi\pi}$=2972±15 MeV. The region above 3045 MeV is contaminated by split off photons as described in the text; 3-C fit results of the Crystal Ball are shown.

Using the previously determined estimates of efficiency for topology (15) the Crystal Ball collaboration obtains a preliminary product branching fraction.

$$\mathrm{Br}\left(J/\psi(3095)\to\gamma''\eta_c(2980)''\right)*\mathrm{Br}\left(''\eta_c(2980)''\to\eta\pi^+\pi^-\right)=(2.7\pm1.5)\times10^{-4} \qquad (17)$$

Figure 13 shows the angular distribution of the radiated photon obtained from events in the region of the peak in Fig. 12.

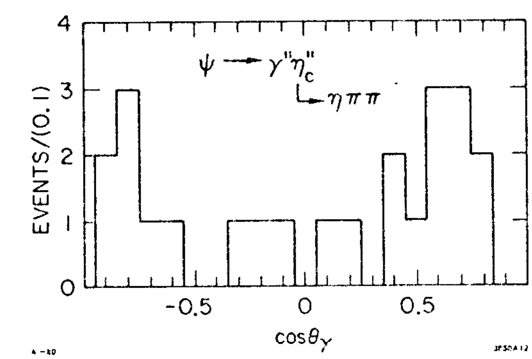


Fig. 13. The angular distribution of the radiated photon obtained from the region of the peak in Fig. 12. θ_γ is the polar angle of the radiated photon relative to the e^+ beam direction.

Though the statistics are poor, the distribution is consistent with the expected distribution (1) for spin-0.

SUMMARY

(a) A candidate η_c state has been observed in radiative transitions from the $\psi'(3684)$ and $J/\psi(3095)$. The mass obtained from the inclusive spectra of the Crystal Ball is,

$$M_{"\eta_c"} = 2981 \pm 15 \text{ MeV} \tag{18}$$

the width obtained is,

$$\Gamma = 20\binom{+16}{-11} \text{ MeV (statistical error only).} \tag{19}$$

rough estimates of the branching fractions are[3] (very preliminary),

$$Br\left(\psi'(3684) \to \gamma "\eta_c(2980)"\right) \sim 0.2 - 0.5\% \tag{20}$$

$$Br\left(J/\psi(3095) \to \gamma "\eta_c(2980)"\right) \sim 1\% \tag{21}$$

where $J/\psi(3095)$ branching fraction is strongly correlated to Γ.

(b) The "$\eta_c(2980)$" has been observed in exclusive decays from the $\psi'(3684)$. The mass obtained from the exclusive fits of the Mark II is,

$$M_{"\eta_c"} = 2978 \pm 8 \text{ MeV} \tag{22}$$

an upper limit has been obtained for the width,

$$\Gamma < 30 \text{ MeV (90\% C.L.)} \quad . \tag{23}$$

The final states observed and their product branching fractions are given in Table I. Using the Crystal Ball value of,

$$Br\left(\psi'(3684) \to \gamma "\eta_c(2980)"\right) \sim 0.35\% \tag{24}$$

The "$\eta_c(2980)$" branching fractions of Table II(a) are obtained.

(c) The "$\eta_c(2980)$" has been observed in exclusive decays from the $J/\psi(3095)$. The mass obtained from the exclusive fits of the Crystal Ball is consistent with the inclusively obtained mass. The poor statistics of the present measurement don't allow a significant measurement of the width.

Using the value (21) (1%) for the radiative branching fraction, the "$\eta_c(2980)$" branching fractions of Table II(b) are obtained.

TABLE II(a). Mark II Branching Fractions Assuming $Br(\psi'(3684) \to \gamma "\eta_c(2980)") \approx 0.35\%$

Final State - f	$Br("\eta_c(2980)" \to f)\%$
$K_S K^{\pm} \pi$	4.3 ± 1.7
$K \bar{K} \pi$ (from I-spin conservation)	12.9 ± 5.1
$p\bar{p}$	$0.2\binom{+0.2}{-0.1}$
$2\pi^+ 2\pi^-$	$1.3\binom{+0.9}{-0.6}$

TABLE II(b). Crystal Ball Branching Fractions Assuming $Br(J/\psi(3095) \to \gamma "\eta_c(2980)") \approx 1\%$

Final State - f	$Br("\eta_c(2980)" \to f)\%$
$K^+ K^- \pi^0$	< 1.5 (90% C.L.)
$\eta \pi^+ \pi^-$	3 ± 1.5
$\gamma\gamma$	< 0.5 (90% C.L.)

(d) Determination of the spin-parity of the "η_c(2980)" is central to the assignment of this candidate as the theoretically desired η_c. So far no decays of the type,

$$"\eta_c(2980)" \to \pi^+\pi^- , \quad \text{or } K^+K^- \tag{25}$$

have been reported. However, the limits on these decays should be improved before one can state with confidence that they are substantially smaller than the branching fractions into presently observed states. The lack of these decays (25) imply that

$$J^P_{"\eta_c"} = 0^- , 1^+ , \ldots \tag{26}$$

There is evidence (Figs. 5,12) that the radiative photon's angular distribution with respect to the incident e^+ beam is consistent with,

$$\frac{d\sigma}{d\Omega} \propto (1+\cos^2\theta) \quad . \tag{27}$$

If measurement eventually provides stronger evidence for (27), and if the radiative transition can be shown to be a magnetic dipole transition,[13] then the 0^- assignment will be established.

CONCLUSIONS

A candidate η_c state at $M = 2980 \pm 10$ MeV with radiative transitions from $\psi'(3684)$ and $J/\psi(3095)$ has been firmly established by the results of two experiments and with inclusive and exclusive evidence from both $\psi'(3684)$ and $J/\psi(3095)$. The challenge remains to unambiguously identify this candidate state with the theoretically desired η_c, the $^1S_0$ pseudoscalar partner of the $J/\psi(3095)$. The present sample of data which has led to the establishment of the candidate state is about 10^6 $\psi'(3684)$ decays for both the Crystal Ball and Mark II experiments, and about 10^6 $J/\psi(3095)$ decays for the Crystal Ball experiments. Clearly, in order to make further progress toward uniquely assigning J^P for this state, at least 4×10^6 decays must be gathered by one experiment having at least the capabilities of the Crystal Ball or Mark II detectors.

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