SLAC-PUB-2655
November 1980
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A BRIEF REVIEW OF RECENT RESULTS FROM THE CRYSTAL BALL DETECTOR AT SPEAR*

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Presented at the SLAC Summer Institute

Stanford Linear Accelerator Center

Stanford, California

July 28 - August 8, 1980

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*Work supported by the Department of Energy, contract DE-AC03-76SF00515.

INTRODUCTION

A large number of papers have been recently published by other members of the Crystal Ball Collaboration on the subjects covered in my topical conference presentation. Thus, when relevant publications exist, I have not repeated the results contained therein. For most subjects covered, this report will sketch the Crystal Ball results presented in my talk and refer heavily to these publications.

INCLUSIVE PHOTON SPECTRA FROM J/ψ and ψ' DECAYS

Inclusive photon spectra have been obtained from the decay of 810kψ' and 790kJ/ψ. These spectra are shown in Figs. 1 and 2. Recently published results[2,3] discuss two topics of interest.

The discovery of an $\eta_c(2980)$ candidate state is discussed in Ref. 2. The mass and width of this state are

$$M = 2978 \pm 9 \text{ MeV}$$

and (1)

$$\Gamma < 20 \text{ MeV}.$$

The branching fraction from the ψ' is

$$Br(\psi' \to \gamma\eta_c \text{ candidate}) = (0.43 \pm 0.08 \pm 0.18)\% \quad . \tag{2}$$

The value for $Br(J/\psi \to \gamma\eta_c$ candidate) has not been published. The reason for this is illustrated in Fig. 3 where $Br(J/\psi \to \gamma\eta_c$ candidate) vs Γ is shown. Clearly the branching ratio is strongly dependent on the width of the η_c candidate. Depending on the width (Γ = 0-20 MeV), values for the branching ratio between 0.3% and 4% are possible. This range

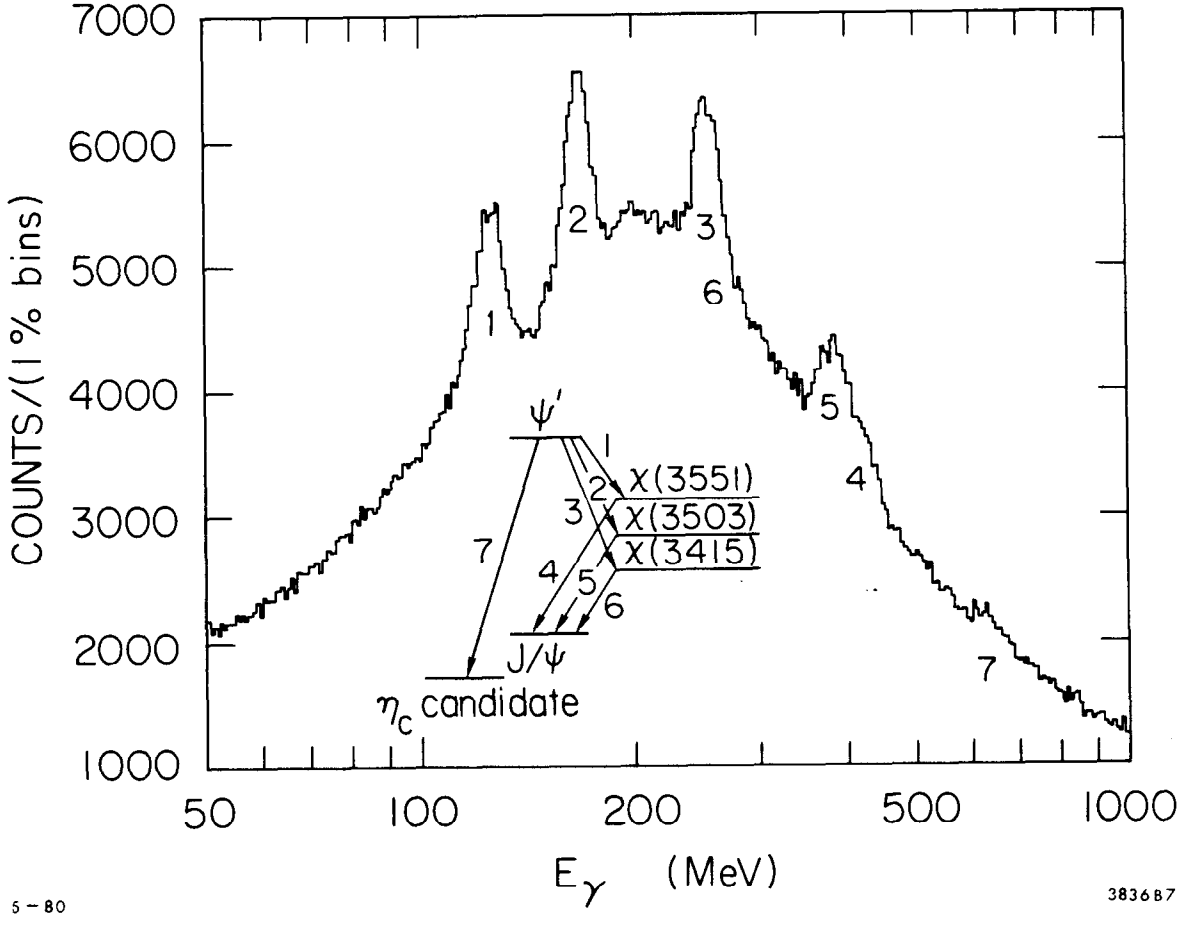

Fig. 1. The inclusive photon spectrum obtained from the decay of 800k ψ'(3684)'s. The analysis leading to this spectrum and that of Fig. 2 is described in Ref. 2.

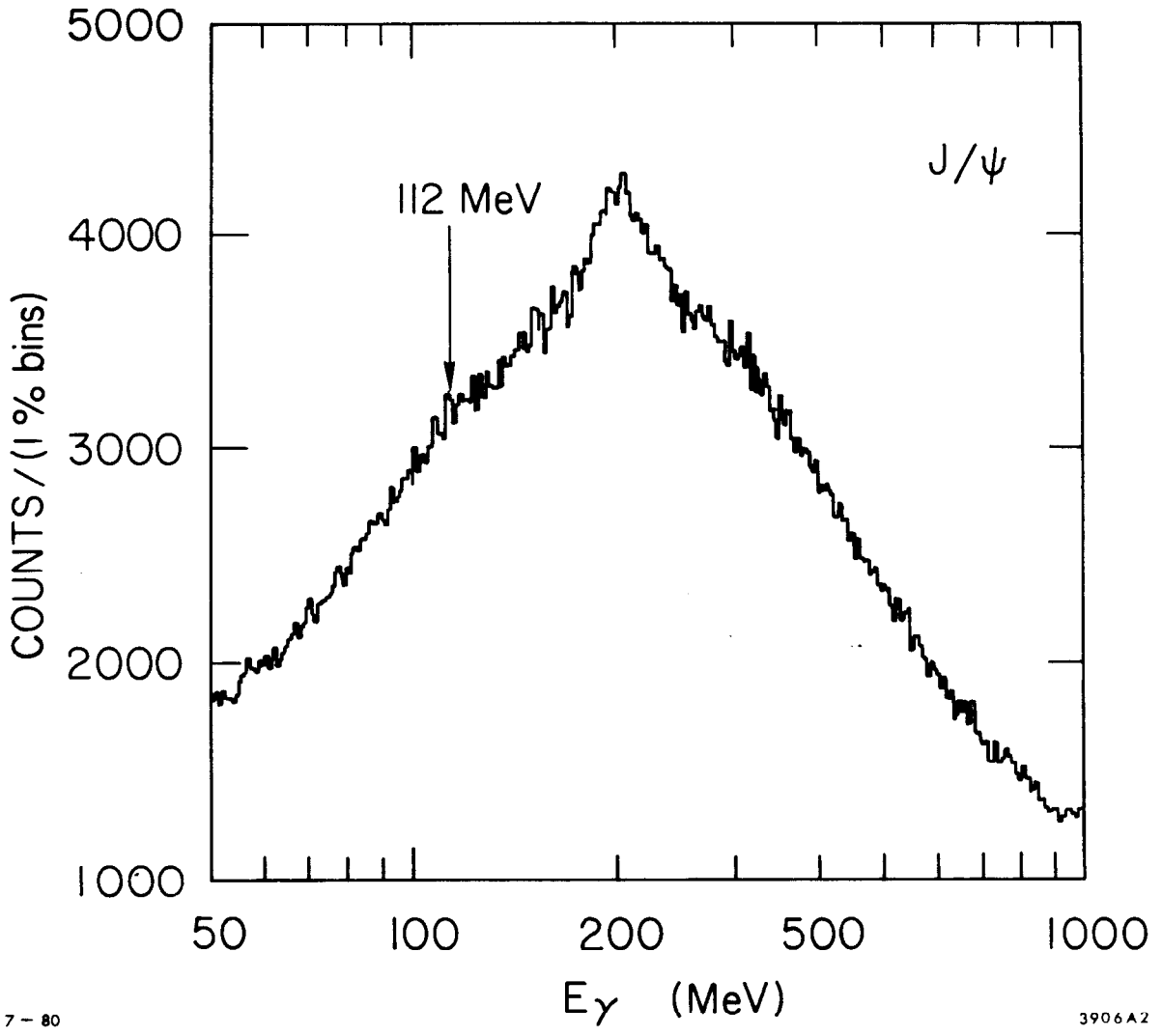

Fig. 2. The inclusive photon spectrum obtained from the decay of 900k J/ψ(3095)'s. The data are plotted vs $\ell n\ E_\gamma$ since the resolution $\Delta E_\gamma/E_\gamma$ is slowly varying in E_γ.

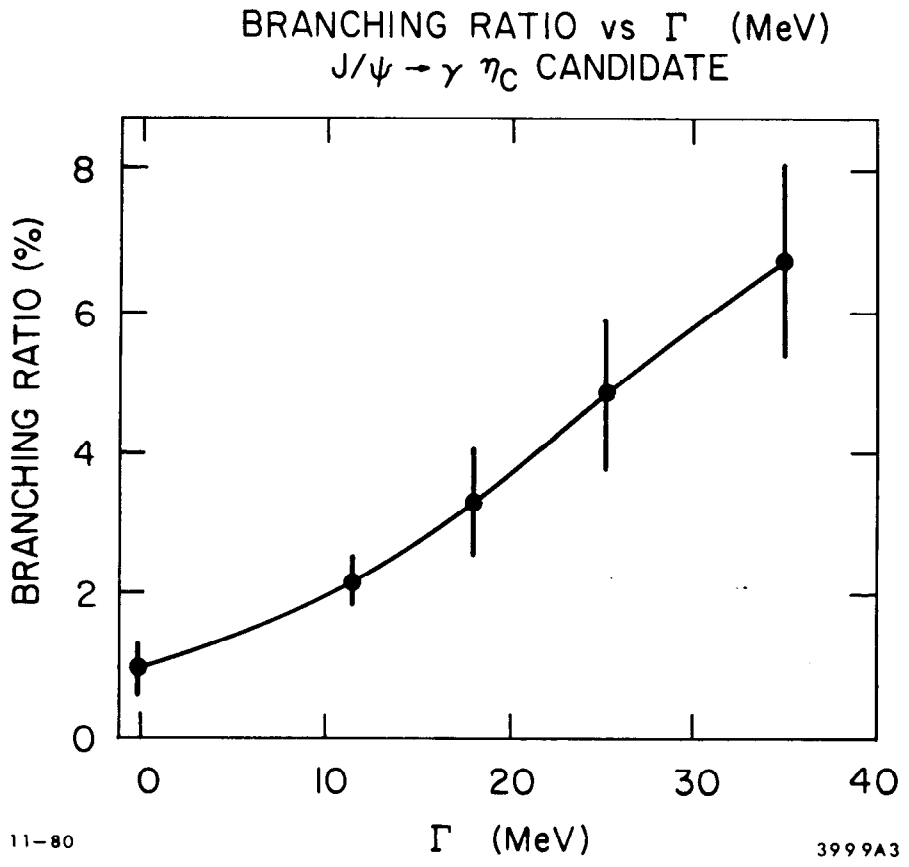

Fig. 3. Br($J/\psi \to \gamma\eta_c$ candidate) (%) vs Γ of the η_c candidate as obtained from a simultaneous fit to the spectra of Figs. 1 and 2 in the region of the η_c candidate state.

includes the uncertainties introduced by the acceptance calculations (shown as the error bars in Fig. 3). Thus a good measurement of the width is needed before a branching ratio can be reliably obtained. This question is not relevant in the ψ' decay due to the high energy of the photon, $E_\gamma = 634 \pm 13$ MeV.

At present two measurements of the width exist as obtained from inclusive γ measurements and exclusive final state measurements of $\gamma\eta\pi\pi$ (the exclusive final state separation is discussed in Ref. 2). Figure 4 shows the results obtained from a simultaneous fit to the inclusive photon spectra of ψ' and J/ψ. Γ vs χ^2 is plotted, and the width obtained is,

$$\Gamma = 20 \begin{matrix} + 16 \\ - 11 \end{matrix} \text{ MeV.} \qquad (3)$$

Figure 5a shows Γ vs χ^2 as obtained from fitting a Breit-Wigner, folded with a Gaussian resolution function ($\sigma_{res.} = 5.0$ MeV @ 119 MeV), plus a constant background, to the exclusive $\gamma\eta\pi\pi$ data shown in Fig. 6. The $\chi^2(\Gamma)$ function prefers $\Gamma = 0$ with a 90% C.L. of $\Gamma < 8.5$ MeV. However, given the limited statistics of the exclusive final state data, we prefer to combine the $\chi^2(\Gamma)$ function of Fig. 3 with that of Fig. 4a, thus obtaining the function shown in Fig. 5b. This combined $\chi^2(\Gamma)$ function yields

$$\Gamma < 20 \text{ MeV (90\% C.L.)} \quad , \qquad (4)$$

which we presently take as the best estimate, from our data, of the width of the η_c candidate.

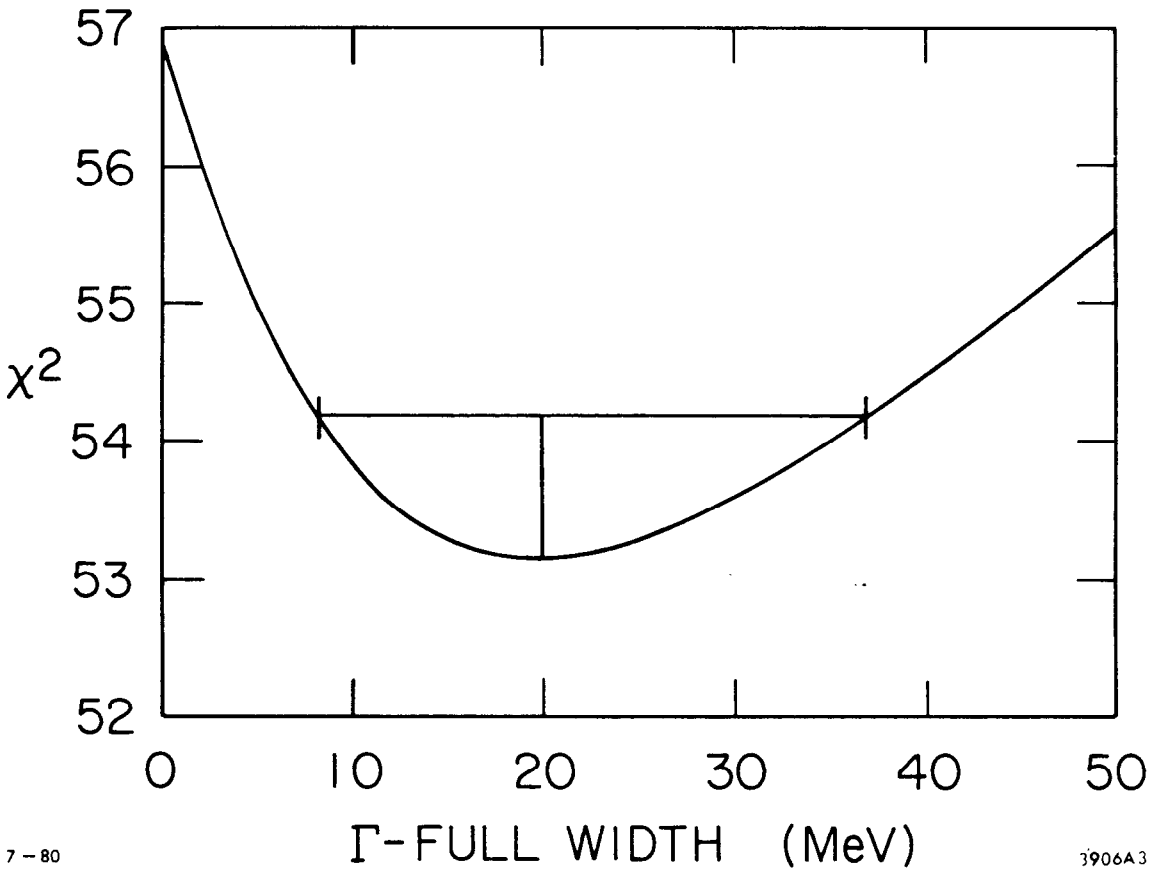

Fig. 4. χ^2 vs Γ resulting from the simultaneous fit to the inclusive spectra of Figs. 1 and 2 in the region of the η_c candidate state. This fitting procedure is described in Ref. 2.

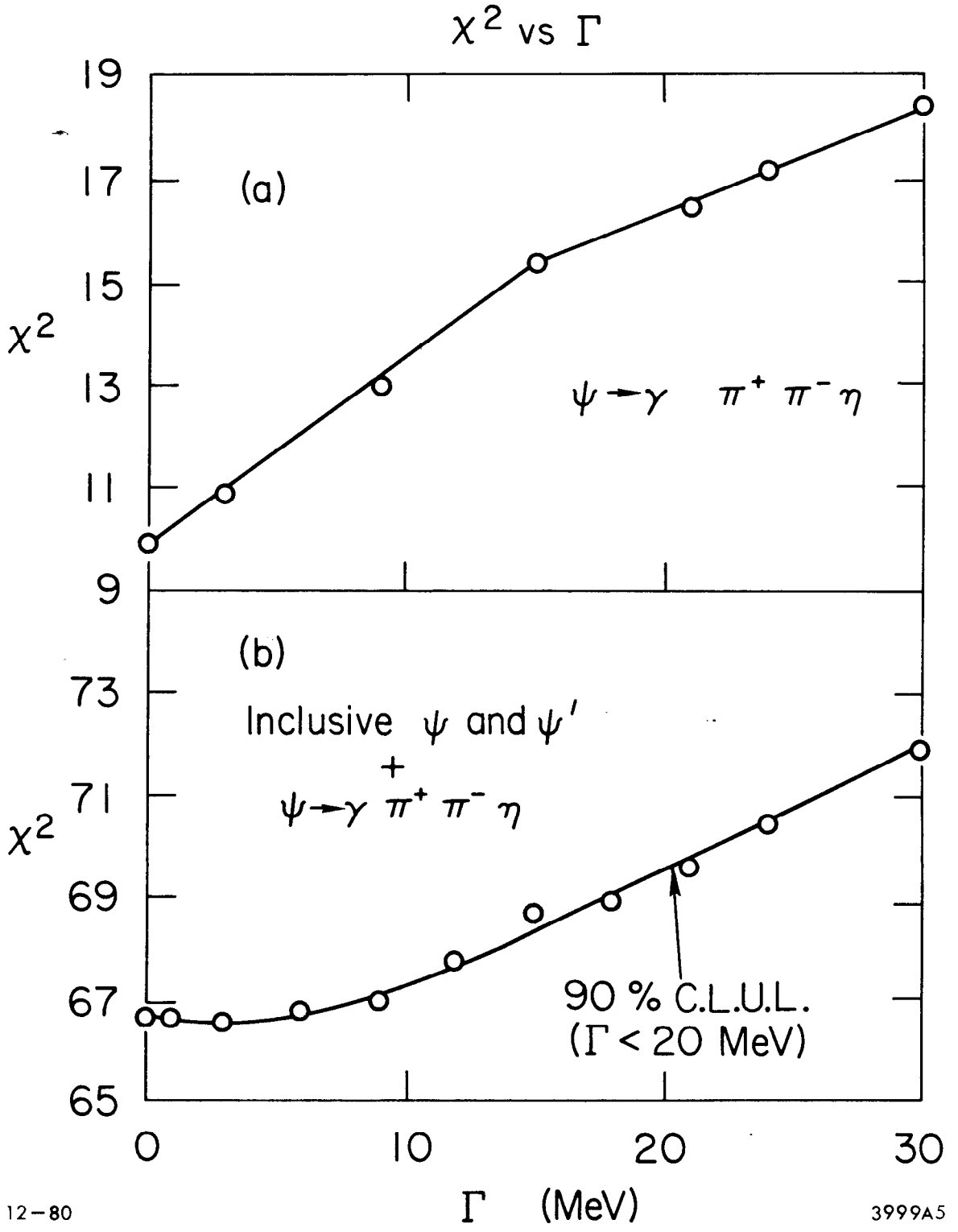

Fig. 5. a) Γ vs χ^2 obtained from a maximum likelihood fit of a Breit- Wigner, folded with a Gaussian resolution function (σ_{res} = 5.0 MeV @ 119 MeV), plus a constant background to the data of Fig. 6. b) The sum of $\chi^2(\Gamma)$ from Figs. 4 and 5a. This $\chi^2(\Gamma)$ function yields the best estimate of the width of the η_c candidate state from current Crystal Ball data. Γ < 20 MeV (90% C.L.).

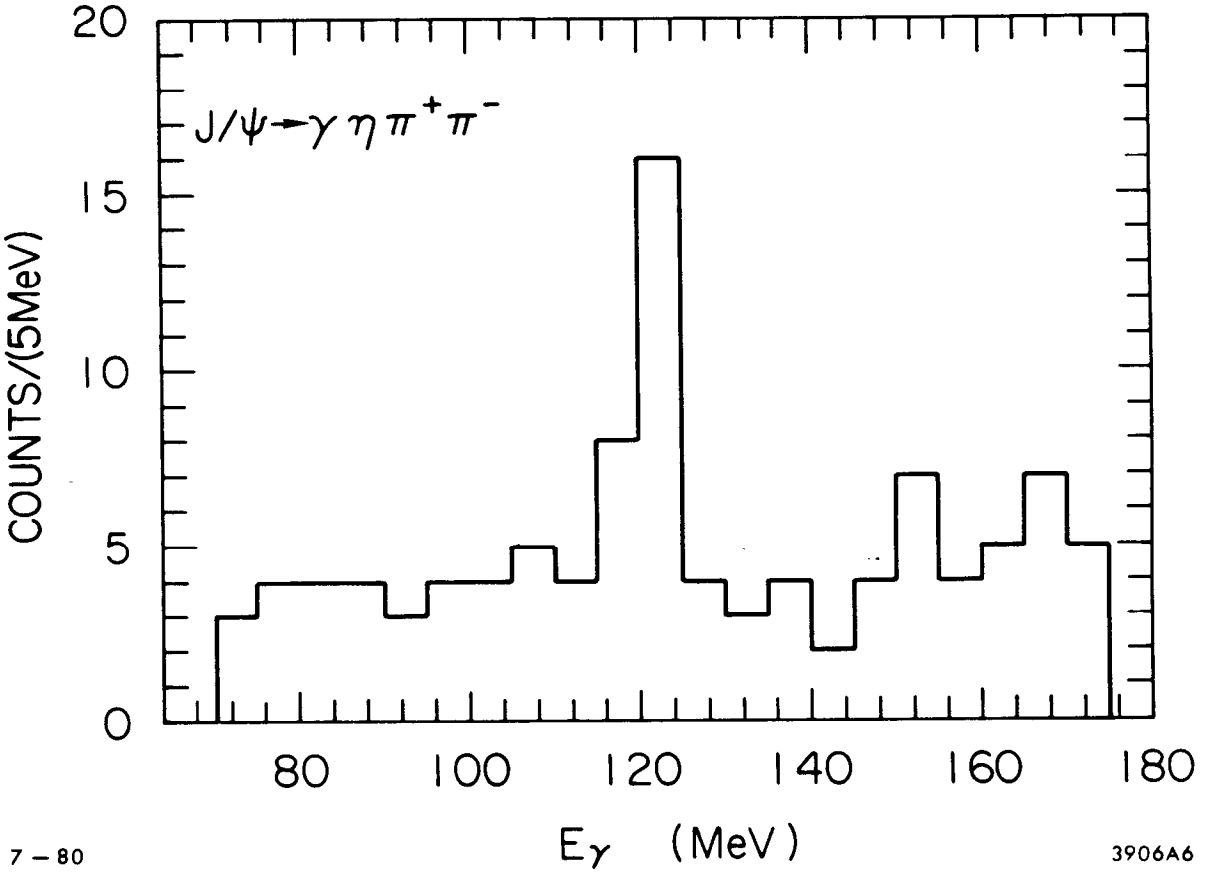

Fig. 6. Evidence for an exclusive final state signal for J/ψ (3095) radiative decay to ηππ. E_γ (MeV) vs events/5 MeV is shown for events in the mass range of the η_c (2980) candidate. A signal is evident at E_γ = 119 MeV corresponding to a mass, M_{η_c} = 2974 ± 2 ± 9 MeV where the first error is statistical and the second is systematic. See Ref. 2 for details.

The Mark II has also seen exclusive final state decays of the η_c candidate; these results are presented in Ref. 4. They obtain,

$$M = 2980 \pm 8 \text{ MeV}$$

and

$$\Gamma < 40 \text{ MeV (90\% C.L.)} \quad . \tag{5}$$

The radiative transitions from ψ' and J/ψ to ordinary hadrons are discussed in Ref. 3. Of particular interest is the nature of the bump in the inclusive photon spectrum of the J/ψ at $E_\gamma = 1220$ MeV ($M = 1420$ MeV) as shown in Fig. 7. This state is probably the E(1420); however, its strong production in J/ψ radiative decays has led to speculation that it may be a gluonium state. This possibility is discussed in detail in Ref. 3. The Crystal Ball has also obtained evidence for the decay

$$E(1420) \rightarrow K^+K^-\pi^\circ. \tag{6}$$

We obtain,[3]

$$Br(J/\psi \rightarrow \gamma E(1420)) * Br(E \rightarrow K^+K^-\pi^\circ) = (3.4 \pm 2.0) \times 10^{-4} \tag{7}$$

assuming the E is an isoscalar,

$$Br(J/\psi \rightarrow \gamma E(1420)) * Br(E \rightarrow K\bar{K}\pi) = (2.0 \pm 1.2) \times 10^{-3}. \tag{8}$$

This compares well with the Mark II result[3] of

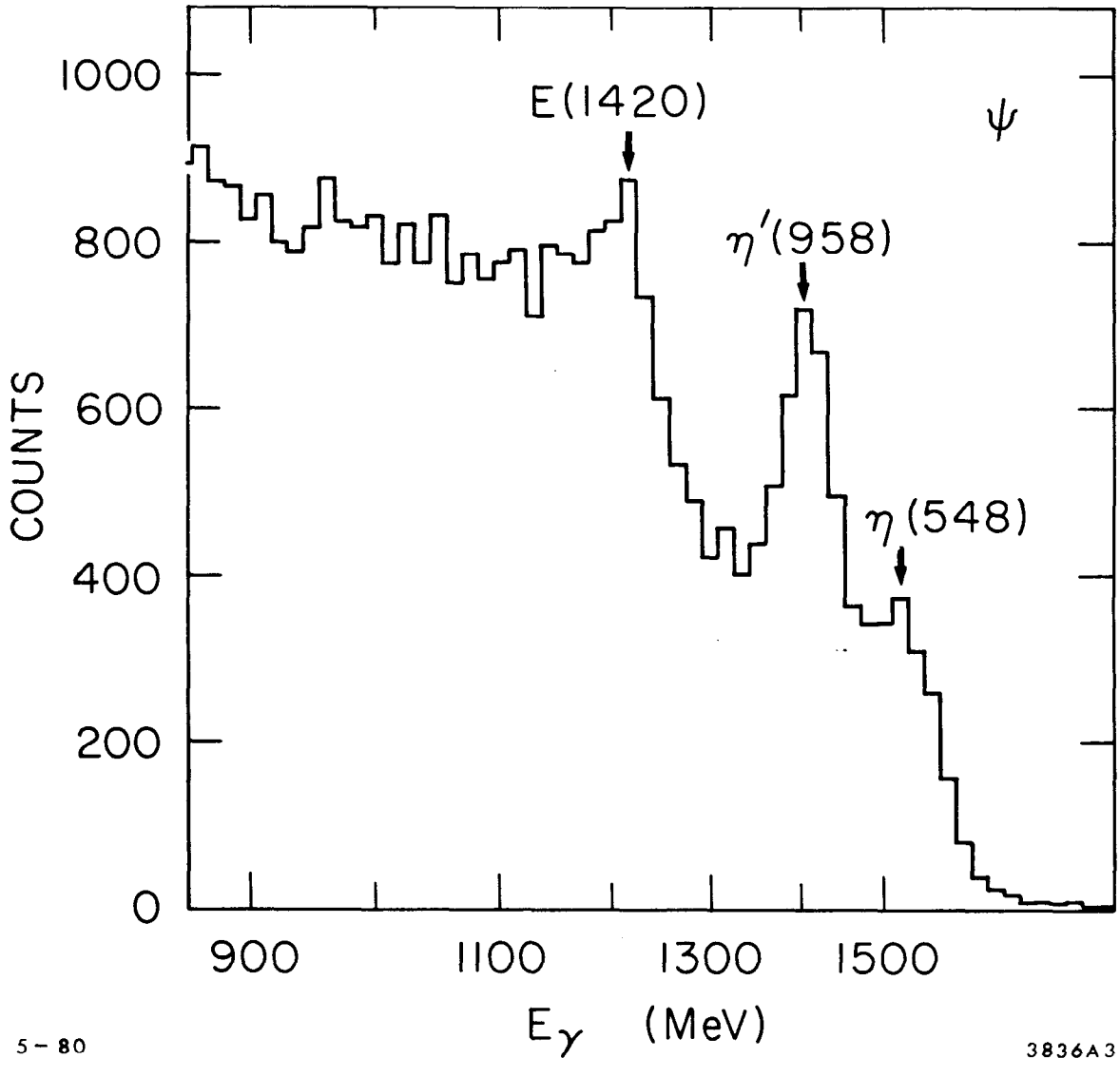

Fig. 7. The inclusive photon spectrum from J/ψ drawn to emphasize the endpoint region. The well-known states η(548), η'(958) are evident; f(1240) is not evident in this spectrum though the process $J/\chi \to \gamma f$ has been observed in exclusive final states. Quite prominent is an indication for $J/\chi \to \gamma$ E(1420) leading to the speculation that E(1420) may have a gluonium component; see Ref. 3 for details.

$$\text{Br}(J/\psi \to \gamma E(1420)) * \text{Br}(E \to K\bar{K}\pi) = (3.6 \pm 1.4) \times 10^{-3}. \quad (9)$$

PHOTON CASCADE DECAYS OF THE ψ'

We have completed a study of the processes

$$\psi' \longrightarrow \gamma\chi \longrightarrow \gamma J/\psi \longrightarrow e^+e^- \quad (10)$$

and

$$\psi' \longrightarrow \eta(\pi^o) + J/\psi \longrightarrow e^+e^- \quad . \quad (11)$$

The latter process is reported in Ref. 5. We find

$$\text{Br}(\psi' \to \eta J/\psi) = (2.18 \pm 0.14 \pm 0.35)\% \quad (12)$$

and

$$\text{Br}(\psi' \to \pi^o J/\psi) = (0.09 \pm 0.02 \pm 0.01)\% \quad (13)$$

where the first errors are statistical and the latter are systematic.

These values compare well to the Mark II values[6] of

$$\text{Br}(\psi' \to \eta J/\psi) = (2.5 \pm 0.6)\% \quad (14)$$

and

$$\text{Br}(\psi' \to \pi^o J/\psi) = (0.15 \pm 0.06)\% \quad . \quad (15)$$

However, the branching ratios, (12) and (14) above, are about a factor of two lower than all previous measurements.[7] The relatively large π^o branching ratio implies that isospin is violated in that decay.

Process (10) and (11) are the subject of the Ph.D. thesis of M. J. Oreglia, which can be obtained as Ref. 8. In particular the most complete treatment available from the Crystal Ball of process (10) is presented therein; though other sources also exist,[9] they are relatively incomplete.

We have determined that three χ states exist with cascade rates large enough to be detected with our present sensitivity. These are $\chi(3554 \pm 3$ MeV), $\chi(3509 \pm 4$ MeV), $\chi(3410 \pm 6$ MeV). The cascade branching fractions for these states along with measurements from other experiments are shown in Table I. The agreement among all experiments is excellent for the first two major states. Only the Crystal Ball has a clear indication for the cascade process for $\chi(3410)$; however, a strong signal is seen in the ψ' inclusive photon spectrum at this mass (see Fig. 1). Previously reported measurements indicating states $\chi(3455)$ and $\chi(3591)$ are in disagreement with Crystal Ball measurements. We see no indication for these states at the limits of our present sensitivity.

In addition to transition rates we have determined the multipolarity of the transitions for $\chi(3554)$ and $\chi(3509)$ and their spins. We find $\chi(3554)$ to have $J = 2$ and $\chi(3510)$ to have $J = 1$. In addition we have determined that the transitions in the cascades for these states are all dominated by electric dipole amplitudes; see Refs. 8,9 for details. This information, together with information on the hadronic decays[10,11] of the χ states yields parity plus for both states.

The Crystal Ball experiment has obtained preliminary evidence for the decays

TABLE I.

Observed branching fractions for the cascade process

$$\psi' \longrightarrow \gamma\chi \quad \chi \longrightarrow \gamma J/\psi$$

from various experiment, including those from the Crystal Ball (C.B.). The mass values shown for the established states are obtained from Crystal Ball data. The upper limits are 90% C.L. limits.

Mass	$Br(\psi' \to \gamma\chi) \cdot Br(\chi \to \gamma\psi)$ 90%			
MeV/C (C.B.)	C.B.	Mk II[10]	Mk I[11]	DESY-Heidelberg[7b]
3554 ± 3	1.26 ± 0.22	1.1 ± 0.3	1.0 ± 0.6	1.0 ± 0.2
3509 ± 4	2.38 ± 0.40	2.4 ± 0.6	2.4 ± 0.8	2.5 ± 0.4
3410 ± 4	0.06 ± 0.02	<0.56	0.2 ± 0.2	0.14 ± 0.09
3455	<0.04 (e,μ final states) <0.02 (μ final states)	<0.13	0.8 ± 0.4	<0.25
3591	<0.04	--	--	0.18 ± 0.06

$$\chi(3554) \to \gamma\gamma \text{ and } \pi^o\pi^o, \quad \chi(3410) \to \pi^o\pi^o \tag{16}$$

by examination of the process

$$\psi' \to \gamma\gamma\gamma \text{ and } \gamma\pi^o\pi^o. \tag{17}$$

Some details of this analysis are presented in Ref. 9.

THREE-γ DECAYS OF J/ψ AND ψ'

Results from the crystal ball for the process

$$J/\psi \to 3\gamma \tag{18}$$

have been published[12] some time ago and so I won't discuss these results here. A preliminary analysis has been recently completed of the process

$$\psi' \to 3\gamma \ . \tag{19}$$

We find 3γ decays to be much less probable from ψ' as compared to J/ψ. In particular,

$$\begin{aligned} &Br(\psi' \to \gamma\eta) < 10^{-4} \ (90\% \text{ C.L.}) \\ &Br(\psi' \to \gamma\eta') < 8 \times 10^{-4} \ (90\% \text{ C.L.}) \end{aligned} \tag{20}$$

where these upper limits are about a factor of 9 smaller than the observed branching fractions for $\gamma\eta$, $\gamma\eta'$ from J/ψ. This somewhat surprising result is discussed in Ref. 3.

In addition, we find

$$Br(\psi' \to \gamma\eta_c(2980)\text{candidate}) * Br(\eta_c\text{candidate} \to \gamma\gamma) < 3 \times 10^{-5} (90\%\ \text{C.L.}) \tag{21}$$

using the Crystal Ball measurement of the inclusive photon branching fraction, e.g. (2), we find

$$Br(\eta_c\text{candidate} \to \gamma\gamma) < 10^{-2} \quad . \tag{22}$$

This upper limit does not impact the estimated theoretical value[13] of 1.3×10^{-3}.

INCLUSIVE η PRODUCTION

This subject is treated in great detail in Ref. 14. Thus I will only state the conclusions of our investigations of the process

$$e^+e^- \to \eta + X. \tag{23}$$

As is evidenced in Fig. 8:

1) We observe no strong variation of $R_\eta \equiv \sigma_\eta/\sigma_{\mu\mu}$ as a function of $E_{c.m.}$ for 3670 MeV < $E_{c.m.}$ < 5200 MeV (omitting ψ'), where by strong variation I mean no variation greater than 0.5 units of R. In particular, we estimate

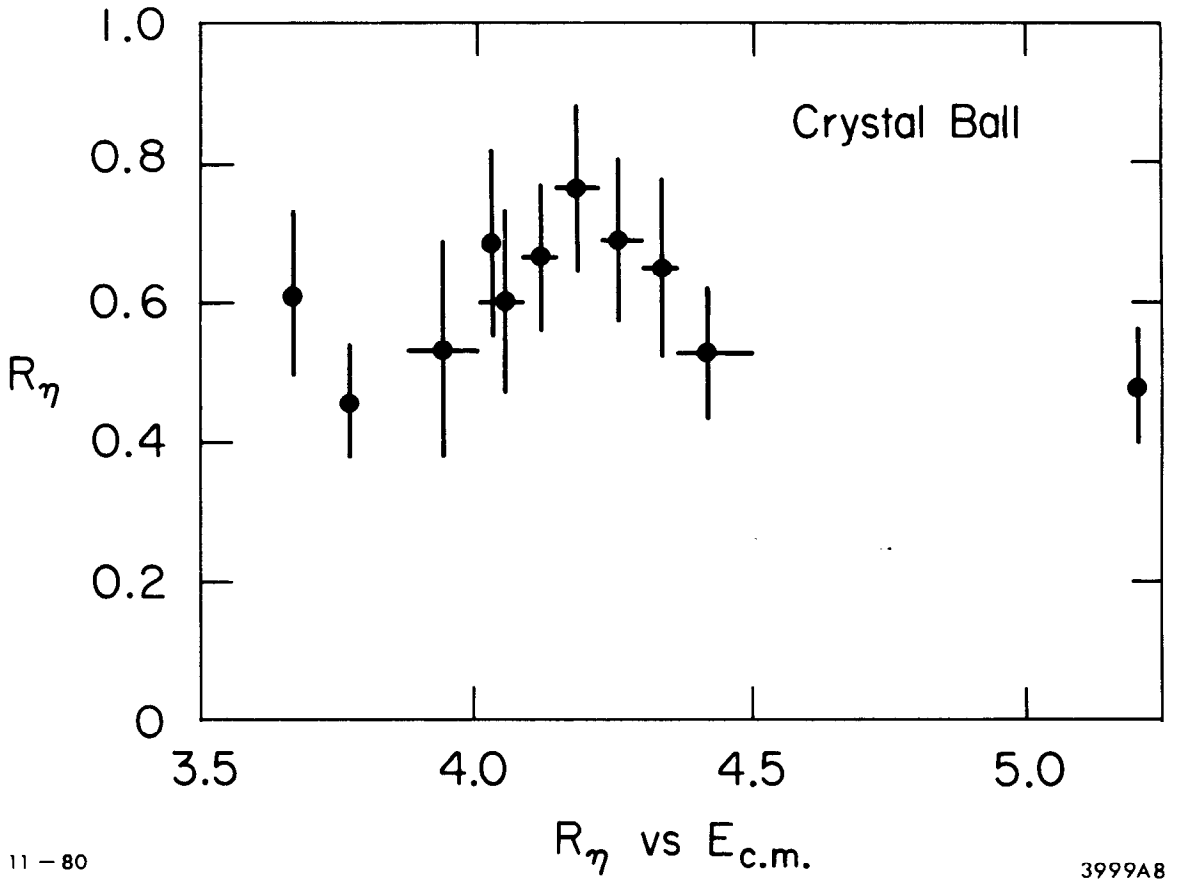

Fig. 8. The inclusive $R_\eta = \sigma(e^+e^- \to \eta X)/\sigma(e^+e^- \to \mu^+\mu^-)$ as a function of $E_{c.m.}$. R_η at ψ' is off scale; see Ref. 15 for details.

$$R(e^+e^- \to F\bar{F}X) \cdot Br(F \to \eta X) < 0.31 \text{ (90\% C.L.)} \quad . \tag{24}$$

2) From measurements at $\psi'(3772)$ we conclude that

$$Br(D \to \eta X) < 0.1 \quad . \tag{25}$$

It thus appears that η production is not strongly correlated to charm production.

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