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HADRONIC DECAYS OF THE η_c *

Presented by Kay Königsmann
(Representing the Crystal Ball Collaboration)[1]
Stanford Linear Accelerator Center
and
Physics Department and High Energy Physics Laboratory
Stanford University, Stanford, California 94305

ABSTRACT

Results on hadronic decays of the η_c candidate state are presented. A mass value of $M = (2978 \pm 9)$ MeV is obtained. The branching fraction for the decay into $\eta\pi^+\pi^-$ is presented and an upper limit for the decay into $\pi^0K^+K^-$ is given.

INTRODUCTION

Since the discovery of the charmonium states the question of the existence of the singlet partners of the triplet states J/ψ and ψ' have been of considerable interest. In particular its mass values, its widths, and branching ratios have been considered as crucial tests for potential and dispersion relation models.[2]

As the mass of the η_c is expected to lie between 20 MeV above and 100 MeV below the mass of the J/ψ, a detector with good photon resolution in that energy range is certainly of great help. The Crystal Ball[3] is a nonmagnetic detector consisting mainly of two elements: NaJ(Tℓ) for the detection of neutral particles and two spark chambers and one multiwire proportional chamber for tagging charged particles. Two hemispherical shells of NaJ subdivided into 672 modules cover about 94% of 4π. The three chambers surrounding the beam pipe cover 94%, 80%, and 71% of 4π respectively. In addition, two endcaps with two endcap spark chambers increase the total active volume of the Crystal Ball detector to 98% of 4π steradian.

The photon energy resolution is $\sigma_E/E = 2.6\%/\sqrt[4]{E}$ (this translates into a full width of 11 MeV for a photon of $E_\gamma = 110$ MeV). The direction of photons is calculated to $\sigma_\theta = (1 \text{ to } 2)^\circ$ depending on their energy. The resolution for charged particles is $\sigma_\theta = 1^\circ$.

One problem in selecting hadronic final states in the Crystal Ball arises when hadrons interact in the sodium iodine. Apart from the initial energy deposition at the place of the impact, additional energy traces show up. These would be recognized as being due to photons. To recognize these secondary energy traces special pattern recognition algorithms have been developed. When applied to the inclusive photon spectrum from the J/ψ (Fig. 1), we see that these algorithms are most effective at low energies; above 200 MeV hardly any fake photons are found.

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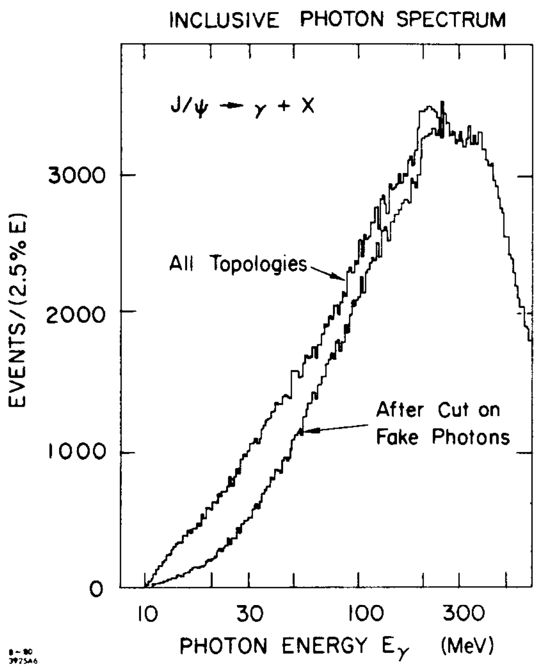
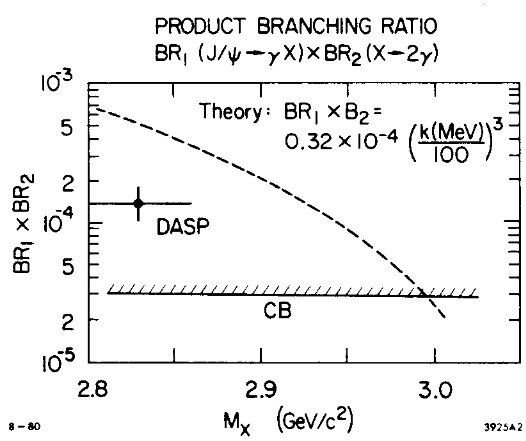


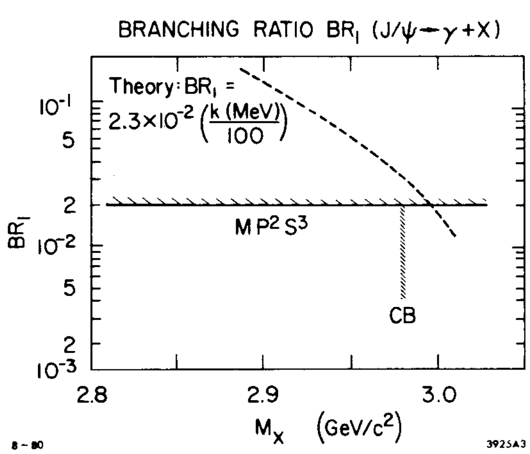
Fig. 1. Inclusive photon spectrum from J/ψ. Pattern recognition algorithms remove secondary energy depositions ('fake photons') from interacting charged particles.

Fig. 2. Product branching ratio $J/\psi \to \gamma + X$, $X \to \gamma\gamma$. Measurements from DASP[4] and the Crystal Ball[3] are indicated. The theoretical prediction is taken from E. Eichten et al.[2]

RESULTS

Our experimental knowledge on the pseudoscalar state below the J/ψ is summarized in Fig. 2 and Fig. 3. An initial candidate for the η_c state, the X(2830) [4] had a mass lower than theoretically anticipated[2] (Fig. 2). This state was not confirmed in a more sensitive experiment by the Crystal Ball Collaboration.[3] In addition, this state was also not found in inclusive photon distributions[5] from the J/ψ; an upper limit was set below the expected branching fraction[2] (Fig. 3). The Crystal Ball Collaboration has observed[6] a state at a mass M = (2981 ± 15) MeV with





a width of $\Gamma = 20^{+16}_{-11}$ MeV in inclusive photon spectra from J/ψ and ψ'. The branching ratio $BR(J/\psi \to \gamma + \eta_c)$ has not yet been determined due to problems with background subtraction, but we estimate the ratio to be (0.4 to 4) * 10^{-2}.

Fig. 3. Inclusive branching ratio $J/\psi \to \gamma + X$. The data are from Maryland, Pavia, Princeton, San Diego, SLAC, Stanford[5] and from the Crystal Ball.[6]

We have also looked for hadronic decays of the η_c candidate state by performing 3-C kinematic fits to the final states:

$$J/\psi \rightarrow \gamma + \eta + \pi^+ + \pi^-, \quad \eta \rightarrow \gamma\gamma$$
$$J/\psi \rightarrow \gamma + \pi^0 + K^+ + K^-, \quad \pi^0 \rightarrow \gamma\gamma \ .$$

The energy spectrum for the monochromatic photon is shown in Fig. 4 for events which pass the fit with a probability of χ^2 greater than 0.01. A clear signal is seen at a photon energy of 120 MeV. The region around the peak is enlarged in Fig. 5. A maximum likelihood fit gives an invariant $\eta\pi\pi$ mass of $M = (2974 \pm 2 \pm 9)$ MeV, where the first error is statistical and the second is an estimate of the systematical uncertainties. This mass value agrees well within errors with the value obtained from the inclusive spectra. Combining both mass values and the measurements of the widths[6] yields:

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

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

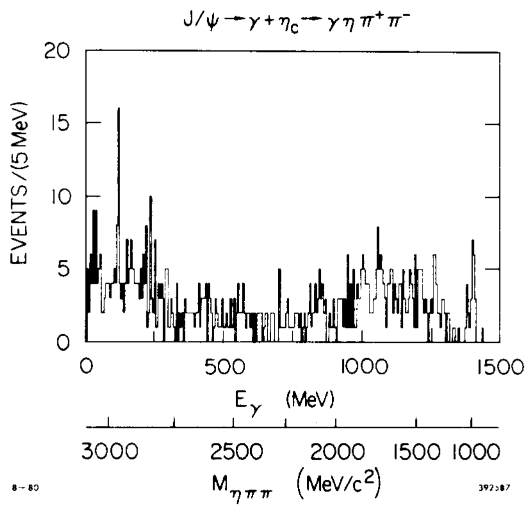


Fig. 4. Monochromatic photon energy of the decay $J/\psi \rightarrow \gamma + \eta + \pi^+ + \pi^-$.

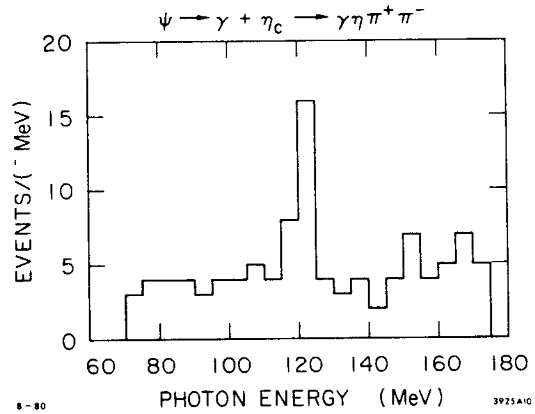


Fig. 5. Blowup of the region around $E_\gamma = 120$ MeV of Fig. 4.

A 16% detection efficiency was obtained with a Monte Carlo calculation where the η_c was assumed to have $J^P = 0^-$ and to decay with a phase space distribution. Our signal of 18 ± 6 events yields a product branching ratio:

$$BR(J/\psi \rightarrow \gamma + \eta_c) * BR(\eta_c \rightarrow \eta\pi^+\pi^-)$$
$$= (3.1 \pm 1.1 \pm 1.5) * 10^{-4} \quad ,$$

the errors being statistical and systematic respectively.

In the decay channel $\eta_c \rightarrow \pi^0 + K^+ + K^-$ we observe no signal (Fig. 6). The photon spectrum is flat in the energy range 70 MeV < 170 MeV. We deduce an upper limit on the product branching ratio of

$$BR(J/\psi \rightarrow \gamma + \eta_c) * BR(\eta_c \rightarrow \pi^0 K^+ K^-) < 1.5 * 10^{-4} \text{ (90\% C.L.)} \ .$$

The Mark II collaboration at SPEAR has observed an enhancement[7] in $\psi' \rightarrow \pi^{\pm} + K^{\mp} K^0_S$ at an invariant mass of $M = (2980 + 8)$ MeV.

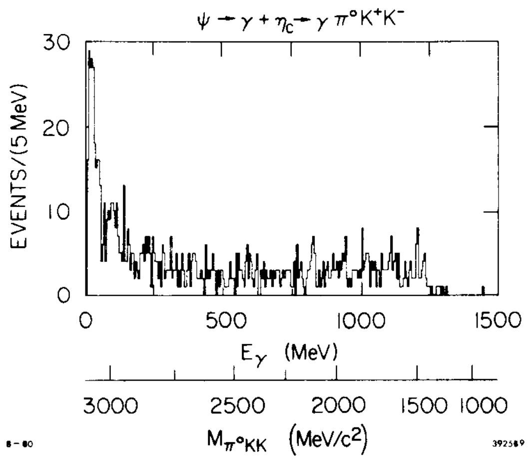


Fig. 6. Monochromatic photon energy of the decay $J/\psi \to \gamma + \pi^0 + K^+ + K^-$.

A comparison of these two results has to wait for an accurate determination of the branching ratio $J/\psi \to \gamma + \eta_c$

CONCLUSIONS

In summary, an η_c candidate state is observed at a mass of $M = (2978 \pm 9)$ MeV in both inclusive and exclusive radiative transitions from the J/ψ. The combined limit on the width is $\Gamma < 20$ MeV (90% C.L.) which is in line with theoretical expectations.[2] A final determination of this state as the pseudoscalar partner of the J/ψ has to wait for a determination of its spin-parity J^P.

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