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*Invited talk presented by Luca Stanco*
*at the Workshop RHEINFELS'90 on the Hadron Mass Spectrum*
*Rheinfels (Germany), Sept. 3-8, 1990*

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## Abstract

A review is given of the signals observed in the $J/\psi$ radiative decays in the 1100 : 1500 $MeV$ energy range from the DM2 analysis of the $\gamma K\bar{K}\pi$ and $\gamma\eta\pi\pi$ channels. The Partial Wave Analyses of these modes give evidence of a rich spectroscopy which suggests an exotic activity in this mass interval. The contradiction between a pseudoscalar state decaying into $K\bar{K}\pi$ via $a_0\pi$ dynamics and not into $\eta\pi\pi$ is still present.

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## 1. INTRODUCTION

One of the most important results in the study of the $J/\psi$ radiative decays was the observation in the early 80's by Crystal Ball[1] and Mark II[2] of a pseudoscalar signal, the $\iota$ (now $\eta(1440)$), decaying into $K\bar{K}\pi$. It was claimed for the discovery of a glueball state because of the large measured branching ratio. Presently, the nature of this structure is still controversial since an analogous peak has been observed in hadroproduction with possible $1^{++}$ assignment[3]. In addition, clear pseudoscalar productions have been observed into the vector-vector channels[4] in particular in $\rho^0\rho^0$ where three states are present at 1490, 1760 and 2100 $MeV/c^2$.

A somehow related point of interest is the existence of a narrow signal at 1285 $MeV/c^2$, an example of which is found in the $J/\psi \to \gamma 4\pi^{\pm}$ channel. Its identification with the $D/f_1$ axial vector meson seems more and more supported[5]. Nevertheless the spin-parity of this signal must be carefully studied for the contemporary presence of another pseudoscalar state at roughly the same mass, the $\eta(1295)$ [6].

Radial excitations of the standard $\eta$, $\eta'$ mesons are foreseen by previous theoretical works[7] in the mass region above 1000 $MeV/c^2$ . Actually the Godfrey-Isgur model predicts only two states, the $\eta(1280)$ and the $f_1(1285)$, between 1000 and 1500 $MeV/c^2$. Therefore the two $qq$ nonets $0^{-+}$ and $1^{++}$ are far from settled in the experimental observations and are then suspected to let room for glueball or exotic states.

In a recent paper[8] DM2[9] reported on studies of $J/\psi$ radiative decays into $K^0_S K^{\pm}\pi^{\mp}$, $K^+K^-\pi^0$ and $\eta\pi^+\pi^-$ from the 8.6 million of $J/\psi$ events collected at the Orsay $e^+e^-$ storage ring DCI. The $\eta(1440)$ was observed in both $K\bar{K}\pi$ modes and, in the hypothesis of a single spin-parity production, its pseudoscalar character was stated together with a $K^*(892)K$ dynamical contribution. No signal was observed at the $\eta(1440)$ mass in the $\eta\pi^+\pi^-$ channel, but a peak at 1400 $MeV/c^2$ consistent with a $a_0(980)\pi$ dynamics.

In this paper results from Partial Wave Analysis (PWA) of the observed signals in the $1100 \div 1500$ $MeV$ mass range are given for the coupled channels $K^0_S K^{\pm}\pi^{\mp}$ and $K^+K^-\pi^0$, and for the $\eta\pi^+\pi^-$ channel.

## 2. TOTAL SIGNALS

The final mass distributions of the $J/\psi \to \gamma K^+K^-\pi^0$ and $\gamma K^0_S K^{\pm}\pi^{\mp}$ events are drawn in Fig.1. One can see, in particular from the $K^0_S K^{\pm}\pi^{\mp}$ events distribution where the background level is very small, that the shape of the $\eta(1440)$ is asymmetric, suggesting a threshold effect and/or the presence of more than one state. In any case a total product branching ratio can be computed from a single fit using a Breit-Wigner curve folded with $K^*K$ phase space over a polynomial background, $BR(J/\psi \to \gamma X) \times BR(X \to K\bar{K}\pi) = (3.8 \pm 0.3 \pm 0.6) \times 10^{-3}$.

The selection of the events $J/\psi \to \gamma\eta\pi\pi$ leads to the scatter plot $m_{\eta\pi}$ versus $m_{\eta\pi\pi}$ in the 1000 $MeV/c^2 \leq m_{\eta\pi\pi} \leq 1800$ $MeV/c^2$ mass region shown in Fig.2. The $\eta\pi\pi$ mass projection (Fig.2$a$) gives evidence of two structures centered at 1265 and 1400 MeV/c$^2$

on a rising background. The performances of the $\gamma\eta\pi\pi$ analysis are demonstrated by the measured[8] $\eta' \to \eta\pi\pi$ signal ($\Delta m = 0.7\ MeV/c^2$ from PDG [10]).

A first look to the scatter plot gives evidence for different dynamical contributions. There, an overall $a_0\pi$ dynamics is clear from the $\eta\pi$ mass projection (Fig.2*b*), but it is related only to the lower mass part of the structure at 1400 MeV/$c^2$, nothing being possible to say about the dynamics of the 1265 MeV/$c^2$ structure (due to limited phase space available) as well as higher part of the 1400 $MeV/c^2$ structure, which is clearly not dominated by the $a_0\pi$ intermediate state.

The whole $\eta\pi\pi$ distribution has been fitted with two Breit-Wigner functions, leading to 108 ± 17 events and a product branching ratio $BR(J/\psi \to \gamma X(1264)) \times BR(X \to \eta\pi^+\pi^-) = (0.26 \pm 0.04 \pm 0.01) \times 10^{-3}$ for the lower mass structure, and 61 ± 24 events, $BR(J/\psi \to \gamma X(1398)) \times BR(X \to \eta\pi^+\pi^-) = (0.70 \pm 0.06 \pm 0.11) \times 10^{-3}$ for the upper one. However both of them present difficulties to be identified as single resonances: from one side the $X(1264)$ owns an unlike shape, while the $X(1398)$ corresponds to different dynamical contributions in separate parts of its mass distribution.

## 3. SIGNALS FROM THE PWA

The two modes $\gamma K^+K^-\pi^0$ and $\gamma K^0_SK^\pm\pi^\mp$ show coherent results from the PWA, such that a coupled analysis can be developed. The result [11] for the only 5 contributing waves is reported in Fig.3 where 3 signals arise in different mass positions. The dominant one is a pseudoscalar $a_0\pi$ production at 1460 $MeV/c^2$, together with a $K^*K(0^{-+})$ at 1420 $MeV/c^2$. The third signal is the $K^*K(1^{++})$ at roughly 1460 $MeV/c^2$. The product branching ratios (PBR) $BR(J/\psi \to \gamma X) \times BR(X \to KK\pi)$ are respectively: $PBR_1 = (1.8 \pm 0.2 \pm 0.3) \times 10^{-3}$, $PBR_2 = (0.83 \pm 0.13 \pm 0.18) \times 10^{-3}$, $PBR_3 = (0.76 \pm 0.15 \pm 0.21) \times 10^{-3}$. Moreover a small but rather stable contribution in $a_0\pi(1^{++})$ at 1400 $MeV/c^2$ can be identified. Its PBR amounts to $\sim 1.5 \times 10^{-4}$, with a width of $\sim 20\ MeV/c^2$.

The decay chain $J/\psi \to \gamma\eta\pi\pi$ is analyzed taking into account only the $a_0^\pm(980) \to \eta\pi^\pm$ isobar[12] as well as the direct 3-body decay. The $a_0$ resonance is described via the Flatté parametrization which is equivalent to the Breit Wigner function within the concerned mass region. The $X \to a_0\pi \to \eta\pi^+\pi^-$ leads to 2 waves if the spin $J$ of $X$ is limited to 1, namely $0^{-+}$ and $1^{++}$. A total of 6 different waves is considered, 3 waves with the $a_0$ dynamics (phase space, $0^{-+}$ and $1^{++}$) and 3 without (phase space, $0^{-+}$ and $1^{++}$). The results do not depend on the different binning choices. Interference between different waves has not been included, leading to too many free parameters in the PWA fits with subsequent instabilities.

Monte Carlo checks have shown that the detector acceptance is rather critical for the separation of the waves $0^{-+}$ and $1^{++}$, while a quite good discrimination between waves with and without $a_0$ dynamics is possible (more than 90%). The determination of $x = A_1/A_0$ owns an error of roughly 30%. Feedthrough between $a_0\pi(0^{-+})$ and $a_0\pi(1^{++})$ is possible (up to 30%) for $x = 1$ at the $\eta(1440)$ energy range.

When all the six waves are considered, the PWA result shows important fluctuations.

The $\eta\pi\pi$ (P.S.) is not able to collect the background shape, which is split into the 3 $\eta\pi\pi$ waves so indicating that the spin-parity identification of a possible signal, which decays into $\eta\pi\pi$ directly, is not possible within our analysis. In the following only the $\eta\pi\pi$ $(0^{-+})$ wave which is subjected to minor fluctuations is kept, but this choice, which *remains arbitrary*, does not affect the results of the analysis. The unphysical $a_0\pi$ (P.S.) which should collect $a_0\pi$ non-resonant production as well as part of higher spin events, is also discarded. The result of the PWA limited to the three selected waves $\eta\pi\pi$ $(0^{-+})$, $a_0\pi$ $(0^{-+}, 1^{++})$ shows (Fig.4) no significant $a_0\pi$ contribution above 1400 $MeV/c^2$, as observed in the scatter plot of Fig.2. The $a_0\pi$ $(0^{-+})$ wave does not collect any significant signal, in particular it is rather flat in the $\eta(1440)$ mass range. Conversely the $a_0\pi$ $(1^{++})$ *contributes* to both the peaks at 1265 and 1400 $MeV/c^2$, but only to the upper and lower parts of the mass distribution, respectively, the rest of these peaks decaying through a direct $\eta\pi\pi$ production.

From a simple Breit-Wigner fit (drawn in Fig.4), naming $PBR = BR(J/\psi \to \gamma X) \cdot BR(X \to \eta\pi^+\pi^-)$, the following parameters are obtained for the two structures in $a_0\pi(1^{++})$:

- $X(1290)$: $m = 1290 \pm 16$ $MeV/c^2$, $PBR = (1.3 \pm 0.4) \cdot 10^{-4}$, $x = 0.45 \pm 0.15$;
- $X(1385)$: $m = 1385 \pm 15$ $MeV/c^2$, $PBR = (2.7 \pm 0.8) \cdot 10^{-4}$, $x = 1.0 \pm 0.3$.

The widths attain roughly 30 ÷ 40 $MeV/c^2$. Care should be taken for the parameters of the $X(1^{++})(1385)$ due to the possible feedthrough between the two waves $a_0\pi(0^{-+})$ and $a_0\pi(1^{++})$.

What has been analyzed as direct $\eta\pi\pi(0^{-+})$ production, when fitted with simple Breit-Wigner over a linear increasing background leads to the values: $m_1 = 1270 \pm 15$ $MeV/c^2$, $PBR_1 = (0.7 \pm 0.3) \cdot 10^{-4}$, and $m_2 = 1397 \pm 9$ $MeV/c^2$, $PBR_2 = (2.4 \pm 0.8) \cdot 10^{-4}$. The spin-parities of these possible productions are not really known as stated above.

In any case strong confidence is retained in the $X(1290) \to a_0\pi(1^{++})$ signal identification, due to its stability. The signal is fully consistent with the $f_1(1285)$ identification since from the DM2 result [5] on $J/\psi \to \gamma\rho^0\pi^+\pi^-$ showing a $f_1$ production and the current branching ratios for $f_1$ decays [10] the following product branching ratio is computed: $BR(J/\psi \to \gamma f_1) \cdot BR(f_1 \to \eta\pi^+\pi^-) = (0.9 \pm 0.3 \pm 0.2) \cdot 10^{-4}$.

Moreover no $a_0\pi$ signal is observed which corresponds to the resonant $a_0\pi(0^{-+})$ production observed at 1460 $MeV/c^2$ in the $KK\pi$ radiative channel. By using its mass and width [11], the following upper limit (at 90% of C.L.) is derived:

$$BR(J/\psi \to \gamma X(1460)) \cdot BR(X \to a_0\pi \to \eta\pi^+\pi^-) < 0.8 \cdot 10^{-4}$$

The fit has been performed over the sum of the $0^{-+}$ and $1^{++}$ $a_0\pi$ distributions in order to be independent of the possible feedthrough between the two waves.

## 4. CONCLUSIONS

The PWA of the DM2 results on the $J/\psi \to \gamma K\bar{K}\pi$ and $J/\psi \to \gamma\eta\pi^+\pi^-$ channels shows a rich spectroscopy in the $\eta(1440)$ mass region. In particular one finds out:

1. a strong confirmation for the $f_1(1285)$ in the $J/\psi$ radiative decays;
2. a signal observed at 1270 $MeV/c^2$ in the $\eta\pi\pi$ mode (not $a_0\pi$); however it seems difficult to relate it with the $\eta(1295)$ observed by other experiments[6] to decay into $\eta\pi\pi$ via $a_0\pi$;
3. one pseudoscalar signal at 1460 $MeV/c^2$ decaying into $K^*K$ with a width ~ 50 $MeV/c^2$;
4. one pseudoscalar signal at 1420 $MeV/c^2$ decaying into $a_0\pi \to K\bar{K}\pi$ with a width ~ 50 $MeV/c^2$; as no corresponding $0^{-}$ signal is present in $a_0\pi \to \eta\pi\pi$, the question is raised of whether it is real $a_0$ production or some other dynamical effect, resulting in a $K\bar{K}$ mass distribution sharply peaked near its threshold;
5. a $1^{++}$ production around 1460 $MeV/c^2$ decaying into $K^*K$;
6. a $1^{+-}$ signal at ~ 1400 $MeV/c^2$ decaying via $a_0\pi$ into $\eta\pi\pi$ and possibly into $K\bar{K}\pi$;
7. a bump at 1400 $MeV/c^2$ into $\eta\pi\pi$ (not $a_0\pi$).

To conclude, the presence of such a large number of possible states points out for exotic physical activities in the considered mass range. The quantitative and precise measurement of those is however beyond the limits of the available statistics.

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12. $(\pi^+\pi^-)^{++}\eta$ states could be foreseen, but they are unpractical in this analysis. Else the exotic $a_0\pi(2^{-+})$ wave has been added, resulting no contribution.

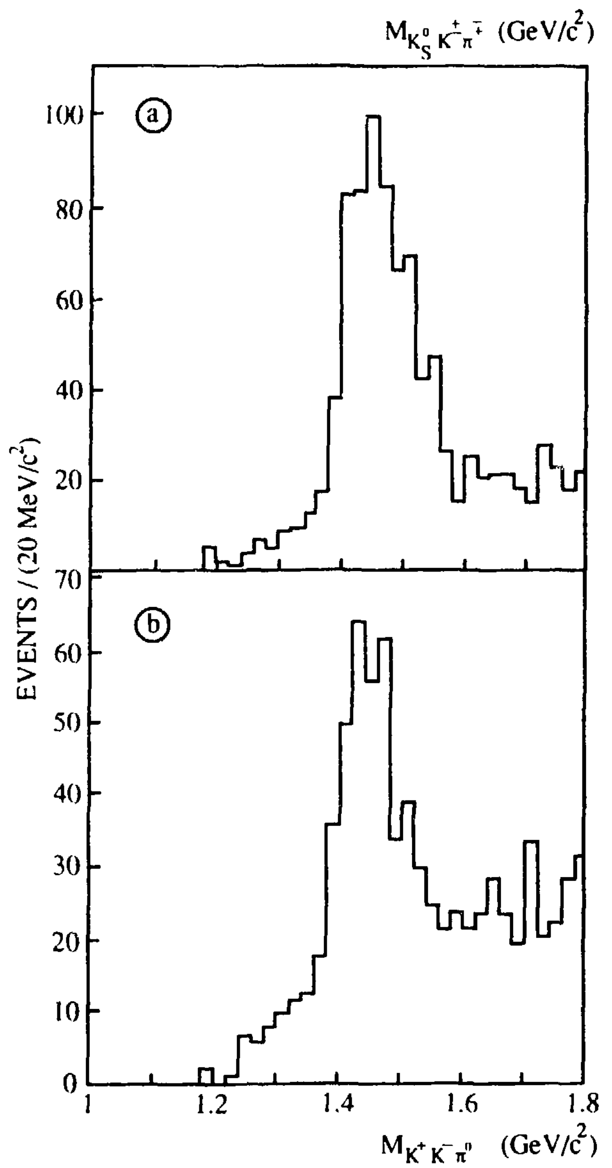

Fig.1 Mass distributions for the two $J/\psi \to \gamma K\bar{K}\pi$ modes:
(a) $K^0_S K^\pm \pi^\mp$ channel;
(b) $K^+ K^- \pi^0$ channel.

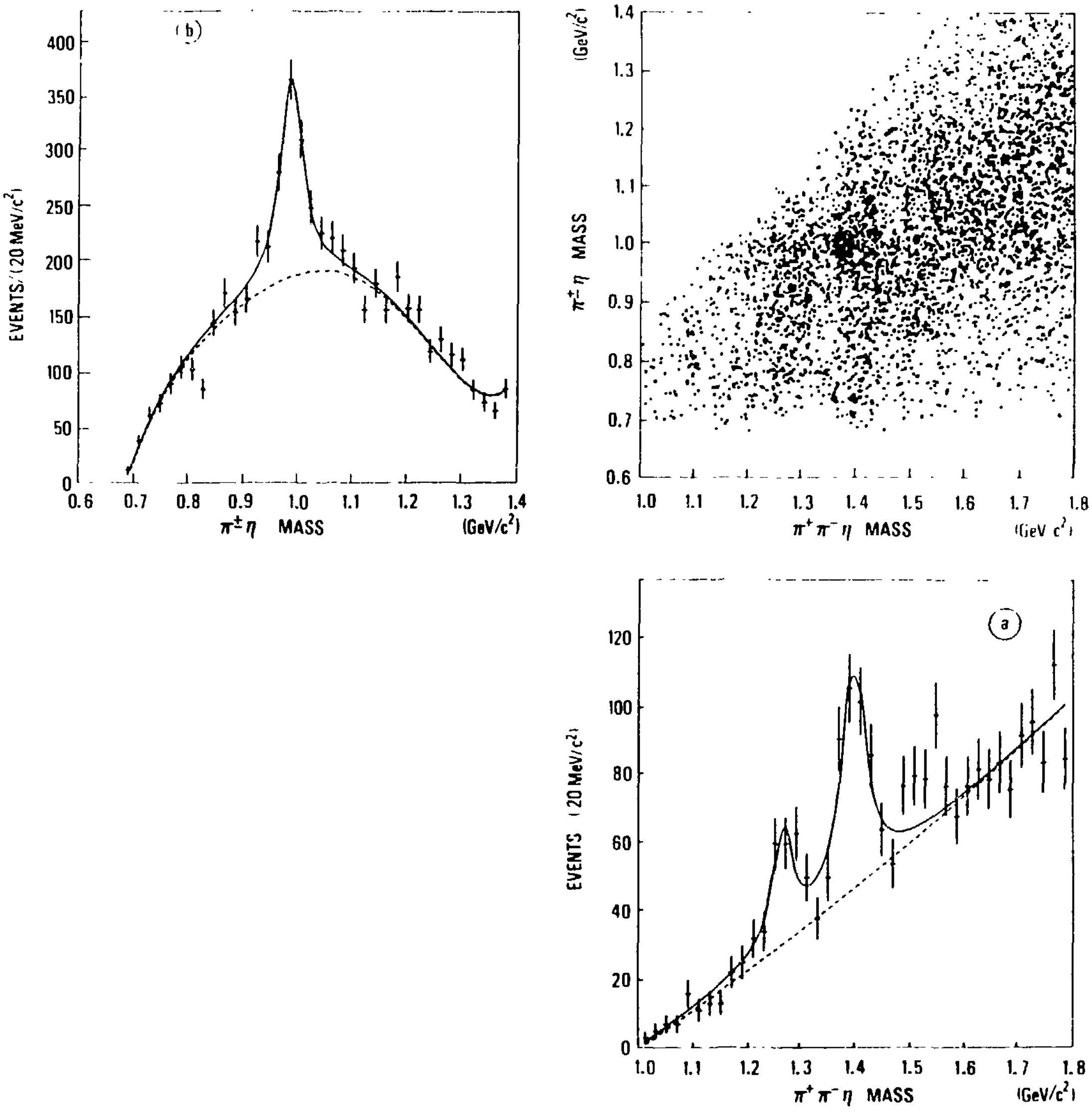

Fig.2 $\eta\pi^{\pm}$ mass versus $\eta\pi^{+}\pi^{-}$ mass scatter plot (2 entries per event).

(a) $\eta\pi^{+}\pi^{-}$ mass projection

(b) $\eta\pi^{\pm}$ mass projection

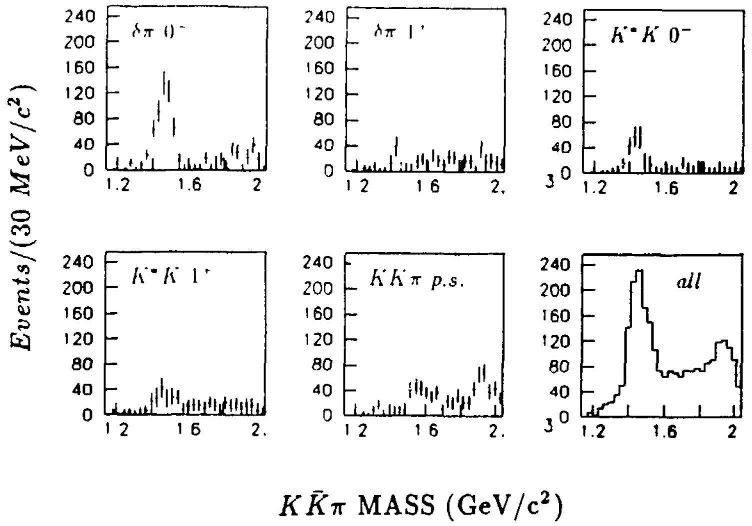

Fig.3 Coupled $K\bar{K}\pi$ channel PWA; 5 waves considered.

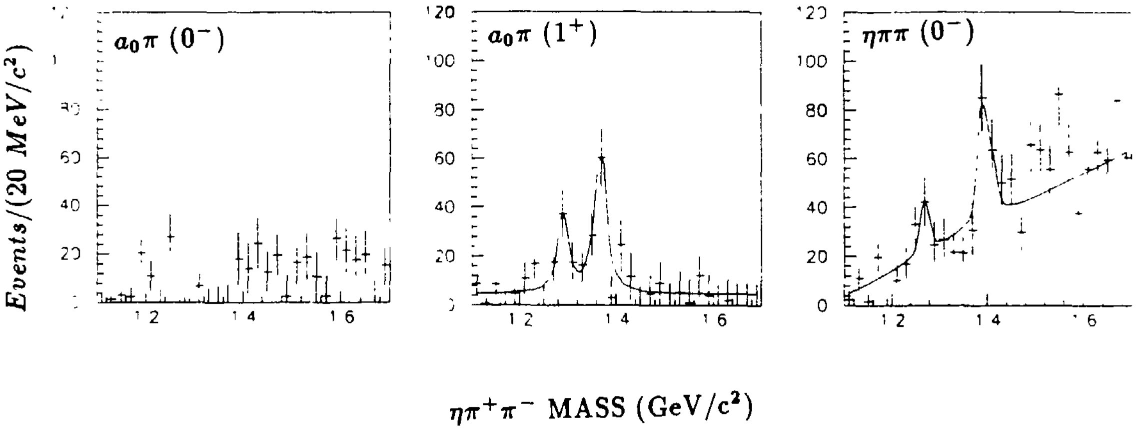

Fig.4 PWA results of the $\eta\pi^+\pi^-$ channel; 3 waves considered.