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FURTHER STUDY OF MESONS WHICH DECAY INTO $\omega\omega$

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(Joint CERN - IHEP experiment)

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Abstract

The $\pi^- p \rightarrow \omega\omega n$ reaction has been further studied at 38 GeV/c with increased statistics. The peak at 2 GeV that has been previously observed in the $\omega\omega$ -mass spectrum is due to two resonances. The first one is a tensor meson with a mass of 1920 MeV. The second is $f_4(2050)$. The branching ratio $BR [f_4(2050) \rightarrow \omega\omega] = 0.26 \pm 0.06$ has been measured.

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In a previous paper [1], first results on $\omega\omega$ -systems produced in hadronic collisions have been reported. Two states that decay into $\omega\omega$ were observed : a narrow tensor meson near threshold with a mass of 1640 MeV and a wide tensor state with a mass of 1960 MeV with a possible contribution of the spin-4 $f_4(2050)$ -meson (former h-meson) [2].

The present study is a continuation of the search for neutral mesons that decay into a pair of ω -mesons and are produced in the charge-exchange reaction

with twice the statistics of the earlier result [3]. The experimental setup and the data analysis have been described elsewhere [1,4]. The method for selecting ω -pairs has been improved since the first work [1]. Previously, the lowest χ^2 combination was selected after a 4-C fit, fixing the π^0 mass, the neutron mass and the mass of one $\pi^0\gamma$ -subsystem ($M_{\pi^0\gamma} = m_\omega$). In the present work, all combinations with $\chi^2 \leq 9$ have been kept. They contribute with a weight that is inversely proportional to the number of such combinations in the event, the total weight for each event in all distributions being one.

The spectrum of the $\omega\omega$ -system invariant masses after subtraction of the background and correction for the setup efficiency, is shown on fig. 1 for $|t| < 0.4$ (GeV/c)² and for two choices of the cosine of the polar angle of the decay $M^0 \rightarrow \omega\omega$ in the Gottfried-Jackson frame, favoring different spin states of the $\omega\omega$ -system. In the region favoring states with larger spin ($\cos \theta_{GJ} > 0.65$) a clear peak is seen with a mass of about 2 GeV. With the opposite choice ($\cos \theta_{GJ} < 0.5$) this peak disappears and a narrow state dominates with a lower mass (fig. 1). So the wide ($\Gamma \approx 220$ MeV) peak which has been reported earlier in the region of 2 GeV, is the superposition of two resonances with comparable masses and different spins. The statistical significance of each resonance is more than six standard deviations.

Masses and widths of the $\omega\omega$ -resonances have been determined by a fit of the mass spectrum with three resonances and a continuum (fig. 1). The parameters of the resonance near the mass threshold, X(1640), agree within the error limits with the previous ones [1] :

$$M = 1635 \pm 7 \text{ MeV}, \quad \Gamma < 70 \text{ MeV}.$$

The upper limit to the width is given with a 90% confidence level. It has been determined from the measured width of the peak, $92 \pm 19 \text{ MeV}$, taking the resolution of GAMS (55 MeV) into account.

The mass and width of the resonance X(1920) which dominates for $\cos \theta_{GJ} < 0.5$ (fig. 1) are

$$M = 1924 \pm 14 \text{ MeV}, \quad \Gamma = 91 \pm 50 \text{ MeV}.$$

The measured width of $123 \pm 38 \text{ MeV}$ is close to the instrumental one, 80 MeV in this mass range.

The parameters of the third $\omega\omega$ -resonance agree with those of $f_4(2050)$ [2] :

$$M = 2060 \pm 20 \text{ MeV}, \quad \Gamma = 170 \pm 60 \text{ MeV}.$$

It dominates for $\cos \theta_{GJ} > 0.65$ (fig. 1).

The t -dependence of the cross-section of reaction (1) is characteristic of one -pion exchange (OPE) [1]. The OPE dominance for the production of X(1920) and of $f_4(2050)$ is confirmed by the distribution in Treiman-Yang angle, ϕ_{TY} , of both resonances (fig. 2). The distribution in ϕ_{TY} is isotropic for X(1920). For the $f_4(2050)$, a possible small linear $\cos \phi_{TY}$ dependence might be linked to interference between the OPE mechanism and an other production process in this mass range.

The determination of the spin of X(1920) is given by the analysis of the angular distribution using this observed OPE dominance in reaction (1) [1] and with the assumption that interference effects are negligible. The distribution of the events on angles α and β (cf. [1]) and also on θ_{GJ} in the mass interval from 1790 MeV to 1920 MeV

are shown on figs. 3 and 4. The contribution of the neighbouring $f_4(2050)$ -meson in this mass range is less than 5%. Figs. 3 and 4 exclude spin 4 for $X(1920)$ in agreement with the suppression of this resonance for $\cos \theta_{GJ} > 0.65$. The distribution is compatible with the hypothesis $J^{PC} = 0^{++}$ or 2^{++} .

The spin of $X(1920)$ may be further determined using the cross-section of reaction (1), which is measured to be:

$$\sigma [\pi^- p \rightarrow X(1920) n] * BR [X(1920) \rightarrow \omega\omega] = 0.65 \pm 0.24 \mu b.$$

From OPE and SU(3) it follows that [1,5]

$$BR [X(1920) \rightarrow \omega\omega + \rho\rho] * BR [X(1920) \rightarrow \pi\pi] = (0.76 \pm 0.28)/(2J + 1),$$

which further restricts the quantum numbers of the resonance to:

$$J^{PC} = 2^{++}, \quad I^G = 0^+$$

(isospin and the G-parity are determined by the decay mode).

The angular distributions of the cascade decay of $f_4(2050) \rightarrow \omega\omega \rightarrow 2(\pi^0\gamma)$ shown in figs.3 and 4 (mass interval from 1960 MeV to 2200 MeV, the contribution of the neighbouring resonance $X(1920)$ being less than 10%), support $J = 4$, as expected for the f_4 -meson.

The production cross-section of $f_4(2050)$ in reaction (1) is

$$\sigma (\pi^- p \rightarrow f_4 n) * BR (f_4 \rightarrow \omega\omega) = 1.1 \pm 0.4 \mu b.$$

Normalising to $\sigma (\pi^- p \rightarrow f_4 n) * BR (f_4 \rightarrow \pi^0\pi^0)$ [6], which has been measured in the same setup, it is possible to determine the ratio of the partial widths: $\Gamma(f_4 \rightarrow \omega\omega)/\Gamma(f_4 \rightarrow \pi^0\pi^0) = 4.6 \pm 1.0$, or

$$\Gamma[f_4(2050) \rightarrow \omega\omega]/\Gamma[f_4(2050) \rightarrow \pi\pi] = 1.5 \pm 0.3,$$

in good agreement with the theoretical evaluations of this quantity [7,8]. Given $BR (f_4 \rightarrow \pi\pi) = 0.17 \pm 0.02$ [2], one may deduce the branching ratio for the $\omega\omega$ channel :

$$BR [f_4(2050) \rightarrow \omega\omega] = 0.26 \pm 0.06.$$

These values and the ratio $\Gamma(f_4 \rightarrow \rho\rho)/\Gamma(f_4 \rightarrow \omega\omega) \approx 2$ [8] show that the decay channels $\rho\rho$, $\omega\omega$ and $\pi\pi$ almost saturate the full width of $f_4(2050)$.

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Figure Captions

- Fig. 1 Efficiency corrected invariant mass spectrum of $\omega\omega$ -systems in reaction (1), measured in two regions of $\cos\theta_{GJ}$. The detection efficiency ϵ is 0.09 and 0.07 in the regions of $X(1920)$ and $f_4(2050)$, respectively. The full curves are the results of the fit with three resonances and a continuum (dashed curves, see [1]).
- Fig. 2 The distribution of $X(1920) \rightarrow \omega\omega$ and $f_4(2050) \rightarrow \omega\omega$ events versus Treiman-Yang angle. The dashed curve shows the fit to $1 + \beta \cos\phi_{TY}$, β being consistent with zero : $\beta = -0.22 \pm 0.11$.
- Fig. 3 Angular distributions of the cascade decays $X(1920) \rightarrow \omega\omega \rightarrow 2(\pi^0\gamma)$ and $f_4(2050) \rightarrow \omega\omega \rightarrow 2(\pi^0\gamma)$. The curves are the result of the fit over α , β and θ_{GJ} angles considering OPE dominance. Spin-parities J^P are indicated on the curves.
- Fig. 4 Angular distributions of the decays $X(1920) \rightarrow \omega\omega$ and $f_4(2050) \rightarrow \omega\omega$ in the Gottfried-Jackson frame. The curves are the result of a joint fit of the distributions versus α , β and θ_{GJ} in the case of OPE dominance for $J^P = 2^+$ and 4^+ .

Fig. 1

Fig. 2

Fig. 3

Fig. 4