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1. Introduction

It is still very difficult to explain experimentally observed characteristics of hadron decays of the $J/\psi(3095)$ and $\psi'(3684)$ within the framework of various quark models which were proposed for these particles. Thus, according to the predictions of the models with coloured quarks[1-3] a noticeable part of decays of ψ' should occur in the channels

$$\psi' \to \rho_c^{\pm} + \pi^{\mp} \quad \text{or} \quad \rho_c^{o} + \pi^{o}. \tag{1}$$

Here $\rho_c^{\pm}$, ρ_c^{o} is the triplet of coloured vector mesons with mass ~ 3.1 GeV. In the spectrum of charged pions produced in the decays of ψ', to processes (1) there should correspond a monochromatic peak which was not observed in ref.[4]. However, if the relative probability of processes (1) is small, it is difficult to single out them from the experimentally observed spectrum of charged pions. Note that between the total decay width of ψ'-meson and various (observed and assumed) modes of its decay, there is a noticeable gap 10-20%[5] which can be filled with the decays of the type (1).

In the present paper the authors made an attempt to construct the inclusive pion spectrum in the reaction $\psi' \to \pi^{\pm} + X$ using the available experimental data on the widths of different decay modes of ψ' and J/ψ supplemented by the statistical hypothesis concerning charge states of multipion systems which was used in ref.[6] to analyse the pion decay modes of J/ψ. Then based on the reconstructed one-pion spectrum we evaluate the possibility of presence of processes (1).

2. Decays of $\psi'(3684)$

Table 1 represents different decay modes of $\psi'(3684)$ obser-

Table 1

Balance-sheet of the $\psi'(3684)$ decay

Mode	Γ/Γ_{tot} (%)
e^+e^-, $\mu^+\mu^-$	~ 2
$J/\psi + \pi^+\pi^-$	32 ± 4
$J/\psi + \eta$	4 ± 2
total decay into $J/\psi + \dots$	57 ± 8
direct hadronic decays	~ 13.5
decays through one-photon intermediate state	~ 2.5
radiative decays	< 7
Total	82 ± 10

ved experimentally and assumed on the basis of experimental data (see also refs.[5,7]). The decay modes into lepton pairs and into $J/\psi(3095)$ are determined experimentally. As concerns the remaining modes, we only make additional assumptions. Let us consider the so-called direct transitions of $\psi'(3684)$ to usual hadrons which occur with the conservation of isospin and G-parity. At present the provisional data for the relations[8]

$$\frac{\Gamma(\psi' \to 2\pi^+2\pi^-\pi^0)}{\Gamma(J/\psi \to 2\pi^+2\pi^-\pi^0)} = 0.41; \quad \frac{\Gamma(\psi' \to K^+K^-\pi^+\pi^-)}{\Gamma(J/\psi \to K^+K^-\pi^+\pi^-)} = 0.58; \quad \frac{\Gamma(\psi' \to p\bar{p})}{\Gamma(J/\psi \to p\bar{p})} = 0.57$$

are known.

One may expect that the total width of direct decays of ψ'-meson into usual hadrons is also about half width for J/ψ-meson, i.e., about 30 KeV (or 13,5% of the total width of ψ').

The transitions of ψ'-meson to usual hadrons can also proceed through one-photon intermediate state. To estimate the total widths of such processes, we use the relation

$$\Gamma(\psi' \to \gamma^* \to hadrons) = \Gamma(\psi' \to e^+e^-) \left. \frac{\sigma(e^+e^- \to hadrons)}{\sigma(e^+e^- \to e^+e^-)} \right|_{\text{off resonance}}$$

$$\cong (2.2 \text{ Kev}) \times 2.5 = 5.5 \text{ KeV}.$$

Thus, the ratio of these decays is about 2,5%. Finally, the experiment[9] gave the upper limit about 7% for the quantity of possible radiative decays of ψ'-meson.

Thus, all the transitions presented in Table 1 comprise 82±10% of all decays of the ψ'. One may assume that the difference of 10-20% is due to experimental errors. But it can be also due to other decay modes of ψ'-meson. At present there are some indications to the existence of this isosinglet pseudoscalar heavy meson X (2800)[4]. The existence of such a meson might favour the following decays[5]:

$$\psi' \to X(2800) + 3\pi \quad \text{(including } \omega \text{)}$$

$$\psi' \to \pi^0 \gamma X(2800)$$

However, we can suggest a more drastic hypothesis on the existence of decays (1). To check up the latter, we undertake the calculations under two assumptions:

1) The decay of ψ'-meson proceeds only via the dominating modes

$$\psi' \to J/\psi + 2\pi , \tag{2}$$

$$\psi' \to J/\psi + \eta . \tag{3}$$

For the sake of simplicity, we have neglected the contribution of the direct decays of the ψ'.

2) The decay of the ψ' proceeds in channels (2), (3) and additional channels (1).

To determine the spectrum of charged pions produces in reaction (2), we have used the phenomenological expression for the Lagrangian of the interaction of mesons with 2π-system:

$$\mathcal{L}_{int} = m_{\psi'} g_{\psi' J/\psi \varepsilon} V^{\mu}_{\psi'} (V_{J/\psi})_{\mu} \varphi_{\varepsilon} + \frac{1}{m_{\varepsilon}} g_{\pi\pi\varepsilon} \partial_{\mu}\pi \partial^{\mu}\pi \varphi_{\varepsilon} \tag{4}$$

which takes into account ε-resonance (with mass $m_{\varepsilon} \sim 0.65$ Gev and width $\Gamma_{\varepsilon} \sim 0.5\, m_{\varepsilon}$) in S-wave $\pi\pi$-scattering and reproduces correctly the experimental spectrum of the effective mass of the two-pion system[10,11]. The single - particle spectrum corresponding to (4) in rest system of ψ'-meson is defined by the formula:

$$E_{\pi} \frac{d\sigma}{d^3 p_{\pi}} \sim \frac{1}{p_{\pi}} \int dM^2 \frac{(M^2 - 2m_{\pi}^2)^2}{(M^2 - m_{\varepsilon}^2 + \frac{1}{4}\Gamma_{\varepsilon}^2)^2 + m_{\varepsilon}^2 \Gamma_{\varepsilon}^2} . \tag{5}$$

The integration in (5) is performed in square of the two-pion effective mass M^2 over the domain defined by the conditions

$$[(M_{\psi'}^2 - M_{\psi}^2)E_{\pi} - 2p_{\pi}^2 M_{\psi'} - M^2(M_{\psi'} - E_{\pi})]^2 \le$$
$$\le p_{\pi}^2 [(M_{\psi'}^2 - M_{\psi}^2 + M^2 - 2E_{\pi}M_{\psi'})^2 - 4m_{\pi}^2 M_{\psi'}^2],$$
$$M_{\psi'}^2 - M_{\psi}^2 + M^2 - 2E_{\pi}M_{\psi'} \ge 2m_{\pi}M_{\psi'}$$

3. Decays of J/ψ (3095)

At present the probabilities of only those hadron decays of the J/ψ are measured in which the number of neutral particles is $N_0 \le 1$. Evidently, this is the main cause of a considerable gap between the total width of the J/ψ and the measured partial widths. There are no experimental data for multipion decay modes with the number of particles $N > 9$ also.

To calculate the probabilities of different charge configurations in the system of π, K-mesons produced in the decay of the J/ψ, in ref.[6] the statistical hypothesis on equal weights was used for the states with the same number of particles, the total isospin T and its projection T_3. The isospin and G-parity of J/ψ-meson were taken to be equal to 0^- [12]. In the case of the so-called direct decays of the J/ψ into odd number of pions and into $K\bar{K}$ + even number of pions, the isospin of the produced multiparticle system coincides with the isospin of the initial state and is equal to zero. For the decay into even number of pions which proceeds via the G-parity violation in electromagnetic interaction, the final state has isospin $T = 1$.

According to ref.[13] the probability for the system of N pions with the isospin T and its projection $T_3 = 0$ of finding in the state $(n_+ n_- n_0)$ (where n_+, n_-, n_0 are the numbers of

π^+, π^-, π^0 -mesons, respectively) is defined by the formula

$$P_{n_+ n_0 n_-} \sim \begin{cases} \dfrac{N!}{n_+!\, n_0!\, n_-!}\, 2^{-2n_+-1} \displaystyle\int_{-1}^{1} (1+x)^{2n_+} x^{n_0} dx, & \text{for } T=0, \\ \dfrac{N!}{n_+!\, n_0!\, n_-!}\, 2^{-2n_+-1} \displaystyle\int_{-1}^{1} (1+x)^{2n_+} x^{n_0+1} dx, & \text{for } T=1 \end{cases} \qquad (6)$$

For the states containing $K\bar{K}$ or nucleon-antinucleon pair plus N pions, we have (T=0)

$$P_{n_+ n_0 n_-} \sim \frac{N!}{n_+!\, n_-!\, n_0!}\, 2^{-(n_+ + n_-)-2} \int_{-1}^{1} dx\, x^{n_0} (1+x)^{n_+ + n_- + 1} \qquad (7)$$

Since the charge of the $K\bar{K}$ - or nucleon-antinucleon - system is not fixed, between n_+ and n_- there may be any of the relations

$$n_+ = n_- \ ; \quad n_+ = n_- \pm 1$$

Using (6,7) one can obtain, on the basis of the experimentally known widths of the decay into the states with $n_0 \leq 1$, the probabilities of the remaining possible (under a given multiplicity) charge configurations.

To determine the probabilities of pion decay modes with a large number of pions, we have used the Poisson distribution over multiplicity with $\langle N \rangle = 7$ proposed in ref. /6/.

According to experimental data /4/ for the relations

$$\Gamma(J/\psi \to \pi^{\pm} X) : \Gamma(J/\psi \to K^{\pm} X) : 2\Gamma(J/\psi \to \bar{p} X) = 0.78 : 0.14 : 0.062 \qquad (8)$$

the amount of decays into $K\bar{K}$ + pions should be about 24% of the total width of the J/ψ /6/. The measured widths taking account of the states obtained by the isospin invariance give the ratio about 5%. Therefore, one should expect a large contri-

bution to the total width of the J/ψ from the decays into the states with more than four pions together with the $K\bar{K}$ -pair. By rough estimation of the contributions of these modes, we simplify the calculations by considering only the decays into even number of pions and the $K\bar{K}$ -pair and put

$$\frac{\Gamma(J/\psi \to K\bar{K}6\pi)}{\Gamma_{tot}(J/\psi)} = \frac{\Gamma(J/\psi \to K\bar{K}8\pi)}{\Gamma_{tot}(J/\psi)} = \frac{\Gamma(J/\psi \to K\bar{K}10\pi)}{\Gamma_{tot}(J/\psi)} = 6\% .$$

The decays into the states with the nucleon-antinucleon pair were also considered. To satisfy the relations (8) according to which the width of all the decays into these states comprises about 6% of $\Gamma_{tot}(J/\psi)$, we put

$$\frac{\Gamma(J/\psi \to N\bar{N}\pi)}{\Gamma_{tot}(J/\psi)} = \frac{\Gamma(J/\psi \to N\bar{N}3\pi)}{\Gamma_{tot}(J/\psi)} = \frac{\Gamma(J/\psi \to N\bar{N}5\pi)}{\Gamma_{tot}(J/\psi)} = 2\%$$

(the number of pions were chosen to be odd, since the experiment gave only the decays of the J/ψ into $N\bar{N}\pi$ with the width $(0.37 \pm 0.19)\%$ of $\Gamma_{tot}(J/\psi)$).

The width of the above decays is about 59% of the total width of the J/ψ . Together with the lepton decays, it is about 73% of $\Gamma_{tot}(J/\psi)$. The authors of paper /6/ assume that the remaining 27% of the decays of the J/ψ proceed through the channels

$$\begin{aligned} J/\psi &\to \eta + n\pi, \\ J/\psi &\to \eta' + n\pi . \end{aligned} \qquad (9)$$

If G-parity in these processes is conserved, then n should be odd. For rough estimation of the contribution of processes (5) to the pion spectrum, we put $n = 5$, $n_{ch} = 4$.

Naturally, the assumptions of this kind allow the pion spectrum in the decays of the J/ψ to be only roughly evaluated. To calculate the contribution of the decay modes of the J/ψ with the given multiplicity to the total spectrum, one needs only the quantities $\Gamma/\Gamma_{tot}(J/\psi)$ and $\langle n_{ch}\rangle \Gamma/\Gamma_{tot}(J/\psi)$. The values of these quantities chosen on the basis of the above assumptions are given in table 2.

4. The calculations of the spectrum of charged pions

The results of calculations performed by the Monte-Carlo method are represented in figs. 1 and 2 as the distributions over the pion missing mass,

$$M_x^2 = M_{\psi'}^2 - 2E_\pi M_{\psi'} + m_\pi^2$$

Note, since the calculated pion spectra for the number of particles $N \sim 10$ appeared to be insensitive to the change of particles by one or two, then to estimate the contribution of modes with $N = 10 \div 13$, there have been used for them the spectra of modes with 10 particles.

In fig. 1 the solid line is the experimental histogram from ref. /4/, the dotted line represents the calculation results under the assumption that the processes of type (1) are absent. The calculated histogram is normalized in such a way that the total number of events would coincide with the experimental one for 2.4 Gev $\leq M_x \leq$ 3.48 Gev perhaps pions with energy $T \lesssim$ 60 MeV

Table 2

Values of Γ/Γ_{tot} , $\langle n_{ch}\rangle \frac{\Gamma}{\Gamma_{tot}}$ for various J/ψ decay modes

	$\frac{\Gamma}{\Gamma_{tot}}$, %	$\langle n_{ch}\rangle \frac{\Gamma}{\Gamma_{tot}}$
$\rho\pi$	2.4*)	4.8
5π	6	20
7π	7	33.2
9π	4.6	27.2
11π	2	14.6
13π	0.7	6.1
4π	1.0	2.8
6π	2.25	9
8π	2	10.5
10π	1	6.7
12π	0.37	2.9
$N\bar{N}\pi$	2	1.32
$N\bar{N}3\pi$	2	4.05
$N\bar{N}5\pi$	2	6.6
$K\bar{K}\pi\pi$	1.6	2.13
$K\bar{K}^* + \bar{K}K^*$	0.55	0.37
$K\bar{K}4\pi$	2.7	7
$K\bar{K}6\pi$	6	24
$K\bar{K}8\pi$	6	32
$K\bar{K}10\pi$	6	40
$\eta 5\pi$	13.5	54
$\eta' 5\pi$	13.5	54
$e^+e^-, \mu^+\mu^-$	14	0

*) Value from the Poisson distribution /6/.

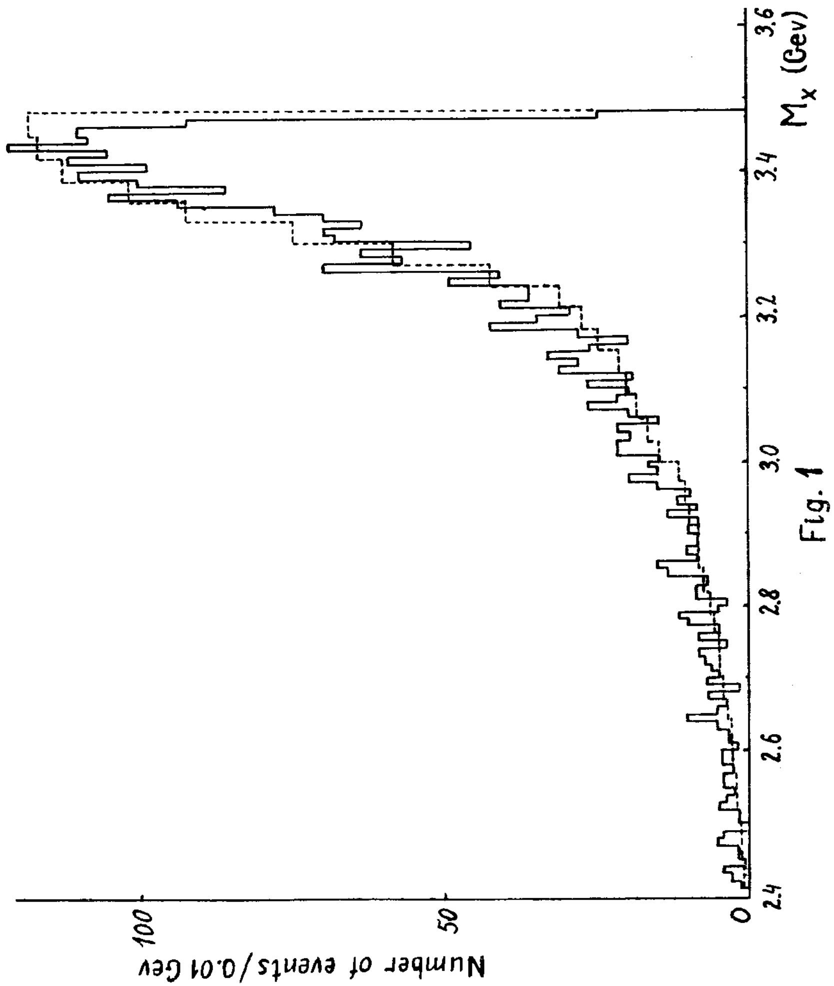

Fig. 1

were not detected in experiment). There is the satisfactory agreement with the experimental histogram within the statistical errors.

A specific feature of the experimental spectrum is a considerable number of events with low pion energy ($M_x \gtrsim 3.3$ Gev). This favours the assumption on a considerable contribution of multipion modes to the total width of the decay of the J/ψ . The dotted line in fig.2 is obtained taking account of process (1) under the assumptions:

$$m_{\rho_c} = 3.02 \text{ Gev}, \quad \Gamma_{\rho_c} = 40 \text{ Mev}, \quad \frac{\Gamma(\psi' \to \rho_c \pi)}{\Gamma(\psi' \to J/\psi + \dots)} = 10\% \qquad (10)$$

(the mass of ρ_c -particles is chosen following the "coloured" models/1,2/ as well as taking account of the fact that the experimental histogram in this range has a small shoulder). The peak corresponding to the process (1) is (under the assumptions (8)) within the statistical errors.

Thus, the assumption on the production of the "coloured" ρ_c -triplet in the decays of the ψ' cannot be finally rejected but this would invole the problems of relatively small probability of such a process and of large width of ρ_c -mesons.

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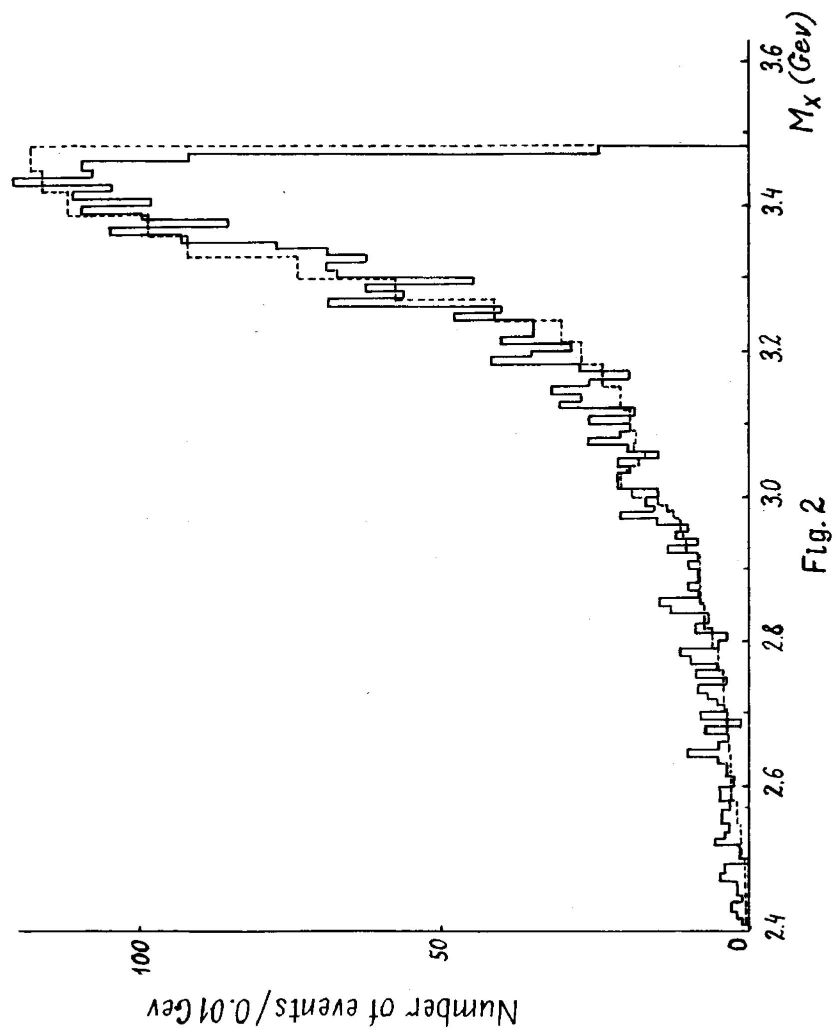

Fig. 2

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