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SOFT PIONS AND DECAY $\Psi' \to \Psi\pi\pi$

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SOFT PIONS AND DECAY $\psi' \to \psi\pi\pi$

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It is shown that application of the Adler selfconsistency condition to the decay $\psi' \to \psi\pi^+\pi^-$ provides an explanation for the experimental distribution in invariant masses of the $\pi\pi$ - system.

Recently the SLAC-LBL group reported the discovery of the decay $\psi' \to \psi \pi^+ \pi^-$ /1/. Analysis of the events $\psi' \to \psi + \pi^+\pi^-$, $\psi \to \mu^+\mu^- (e^+e^-)$ gave evidence for production of pions in a state with I=J=0 and exhibited small contribution of states with low invariant masses $m_{\pi\pi}$ /2/. In this work the decay $\psi' \to \psi\pi\pi$ is considered under the assumption that $J^P = 1^-$ for both ψ' and ψ, and it is shown that application of the Adler selfconsistency condition provides an explanation for the observed $m_{\pi\pi}$ distribution.

The decay matrix element is described by 5 independent amplitudes

$$M = f_1(\epsilon\epsilon') + f_2(\mathcal{P}\epsilon)(\mathcal{P}\epsilon') + f_3(Q\epsilon)(Q\epsilon') + f_4(\mathcal{P}\epsilon)(Q\epsilon') + f_5(\mathcal{P}\epsilon')(Q\epsilon) , \qquad (1)$$

where f_i - scalar functions of the invariants $\mathcal{P}^2$, $(\mathcal{P}\Delta')$, $(Q\Delta')$; Δ' - 4-momentum of ψ'; ϵ', ϵ - 4-polarizations of ψ' and ψ; $\mathcal{P} = k_1 + k_2$, $Q = k_1 - k_2$; k_1, k_2 - 4-momenta of pions.

The energy release in the decay is rather small ($\delta = M' - M - 2\mu = 309$ Mev, where $M' = 3684$ Mev, $M = 3095$ Mev - masses of ψ' and ψ respectively, μ - pion mass), thus produced pions have small energy. This allows to retain in (1) only the terms quadratic in small momenta $\mathcal{P}$ and Q. Due to zero isotopic spin of the $\pi\pi$ - system the matrix element must be symmetric with respect to k_1 and k_2. Then at $k_1 \leftrightarrow k_2$ f_1, f_2, f_3 do not vary while f_4, f_5 change their sign, i.e. are proportional to $(Q\Delta')$. Therefore the fourth and fifth terms in (1) contain third powers of small momenta and can be neglected. Expanding f_1 in a series one obtains for the matrix element in the quadratic approximation

$$M = [a_1 + a_2(\mathcal{P}\Delta') + a_3\mathcal{P}^2 + a_4(\mathcal{P}\Delta')^2 + a_5(Q\Delta')^2](\epsilon\epsilon') + a_6(\mathcal{P}\epsilon)(\mathcal{P}\epsilon') + a_7(Q\epsilon)(Q\epsilon') , \qquad (2)$$

where a_i - constants.

Use now the Adler selfconsistency condition according to which the decay amplitude vanishes at zero 4-momentum of the pion. Then (2) gives

$$a_1 + a_3\mu^2 = 0 , \quad a_2 = 0 , \quad a_4 + a_5 = 0 , \quad a_6 + a_7 = 0 . \qquad (3)$$

Neglecting the terms $\sim\mu^2$ one obtains finally the following expression for the matrix element:

$$M = A_1(k_1k_2)(\epsilon\epsilon') + A_2(k_1\Delta')(k_2\Delta')(\epsilon\epsilon') + A_3[(k_1\epsilon)(k_2\epsilon') + (k_1\epsilon')(k_2\epsilon)], \quad (4)$$

where $A_1 = 2a_3$, $A_2 = 2a_4$, $A_3 = 2a_6$.

Relative values of A_i are unknown, therefore we consider each term in (4) separately. The corresponding $m_{\pi\pi}$ distributions are shown in Fig.1. It is clear that distributions differ considerably from each other, the first term in (4) giving the $m_{\pi\pi}$ spectrum consistent with the experimental one (obviously quantitative comparison must take into account the experimental conditions). Thus small contribution of states with low $m_{\pi\pi}$ to the experimental spectrum can be accounted for providing that $A_2 = A_3 = 0$. One should note the essential role of the factor (k_1k_2) appearing in the matrix element due to the Adler selfconsistency condition and giving a factor in the spectrum proportional to $m_{\pi\pi}^4$ at large $m_{\pi\pi}$.

Smallness of the second and third terms in (4) is confirmed by experimental angular distributions. In fact the first term in (4) corresponds to a pure S-wave for the $\pi\pi$ - system and to the correlation between momenta of leptons from ψ decay and the ψ' spin in consistence with the observations /1,2/. The second term in (4) leads to pion anisotropy due to the factor $(k_1\Delta')(k_2\Delta')$, while the third one corresponds to correlations between pion momenta and spins of ψ' and ψ in contrast with the experiment.

Putting now $A_2 = A_3 = 0$ in (4) and using the dimensionless constant g ($A_1 = g/F_\pi^2$, $F_\pi \approx 93$ Mev - $\pi\to\mu\nu$ decay constant) the following expression is obtained for the $m_{\pi\pi}$ spectrum:

$$\frac{d\Gamma}{dm_{\pi\pi}} = \frac{g^2}{4\pi}\,\frac{(E^2-M^2)^{1/2}}{192\pi^2 M'^2 F_\pi^4}\, m_{\pi\pi}(m_{\pi\pi}^2 - 2\mu^2)^2 (1-4\mu^2/m_{\pi\pi}^2)^{1/2}, \quad (5)$$

where $E = (M'^2 + M^2 - m_{\pi\pi}^2)/2M'$ - ψ-meson energy. Integration over $m_{\pi\pi}$ gives

$$\Gamma_{\psi'\to\psi\pi^+\pi^-} = 1.42\ (g^2/4\pi)\ \text{Mev}. \quad (6)$$

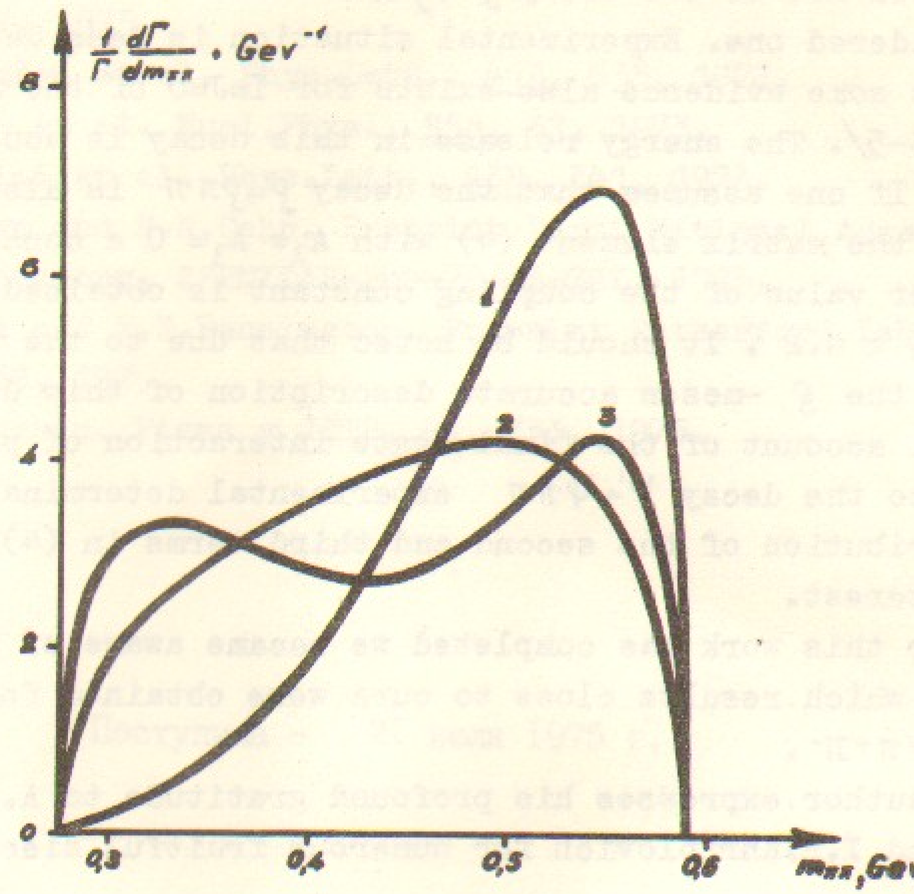

Fig.1. Distribution in invariant mass $m_{\pi\pi}$ for each term in (4) separately: 1 - $A_2 = A_3 = 0$, 2 - $A_1 = A_3 = 0$, 3 - $A_1 = A_2 = 0$.

Using $\Gamma_{\psi'}$=220 kev and the branching ratio of the decay mode $\psi' \to \psi\pi^+\pi^-$ equal to 32% one obtains from (6) $g^2/4\pi \approx 0.05$.

Proceed now to the decay $\rho' \to \rho\pi\pi$ which is similar to the considered one. Experimental situation is less definite here, but some evidence also exists for I=J=0 of the $\pi\pi$ - system /3-5/. The energy release in this decay is about 550 Mev. If one assumes that the decay $\rho' \to \rho\pi\pi$ is also described by the matrix element (4) with $A_2 = A_3 = 0$ a considerably greater value of the coupling constant is obtained: $g^2_{\rho' \to \rho\pi\pi}/4\pi \approx 4.2$. It should be noted that due to the large width of the ρ -meson accurate description of this decay requires an account of the final state interaction of pions. Similarly to the decay $\psi' \to \psi\pi\pi$ experimental determination of the contribution of the second and third terms in (4) is of great interest.

After this work was completed we became aware of the papers /6-8/ in which results close to ours were obtained for the decay $\psi' \to \psi\pi^+\pi^-$.

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