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$X^{\circ}(960)$–MESON – 2^{-} OR 0^{-}?

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X^0 (960)-мезон – 2^- или 0^-?

Показано, что имеющиеся экспериментальные данные могут быть согласованы в равной мере со спин-чётностью 2^- и 0^- для X^0 (960) – мезона, гипотеза 2^- представляется даже более предпочтительной. Подчеркивается необходимость поисков спиновых корреляций в процессах с рождением X^0 (960) в сильных и электромагнитных взаимодействиях. Обсуждаются эксперименты, в которых эффекты, связанные со спином X^0 -мезона могут отчётливо проявиться.

Сообщения Объединенного института ядерных исследований

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Ogievetsky V.I., Tybor W., Zaslavsky A.N. E2-5627

X^0 (960)-Meson – 2^- or 0^- ?

It is shown that the available experimental data are equally consistent with the spin-parity 0^- and 2^- of the X^0 (960) meson, 2^- seems to be somewhat preferable.

Both spin-parity alternatives and new experiments to distinguish between them are discussed.

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1. The $X^0(960)$ meson spin-parity is not firmly established untill now[1,2]. Being poor the available experimental data allow both 0^- and 2^- values for the $X^0(960)$ spin-parity. The hypothesis 2^- seems to us to be somewhat preferable and in this paper we present some new arguments for that. The necessity of search of the spin correlations in the strong and electromagnetic $X^0(960)$ meson production processes is stressed.

We discuss some experiments in which the X^0 meson spin effects may be strongly pronounced.

2. Decay mode $X^0 \to \rho^0 \gamma$

Let θ be the angle between the relative momentum of pions from the ρ^0-decay and the photon momentum in the ρ^0-meson rest system. Then the experimental distribution[1] is

$$W(\theta) = 0{,}5^{+3.0}_{-0{,}5} + \sin^2\theta .$$

For the pseudoscalar hypothesis the $X^0 \to \rho^0 \gamma$ matrix element (M.E. below) is

$$M_{0^-}(X^0 \to \rho^0 \gamma) = g\,\varphi(Q)\,\tilde{f}_{\mu\nu}(P)\,\rho_{\mu\nu}(q)\,, \qquad (1)$$

where $\tilde{f}_{\mu\nu} = \varepsilon_{\mu\nu\lambda\rho} f_{\lambda\rho}$, $\rho_{\mu\nu} = q_\mu \rho_\nu - q_\nu \rho_\mu$ and the angular distribution $W(\theta)$ is proportional to $\sin^2\theta$.

Many authors[4] applied the classification according to the multipole transitions (M1, E2, M3). This classification originates from the nuclear physics where the photon is soft and both the initial and final nuclei have nearly the same mass. Note that in the case of X^0 meson decay the momentum of the photon is large (200 MeV) and the multipole classification seems to be unadequate to choose the simplest M.E. As the simplest relativistic matrix element it is more natural to assume the M.E. which has the smoothest momentum dependence and which is analogous to the M.E. (1) in the relativistic notation. Such a M.E. has the form:

$$M_{2^-}(X^\circ \to \rho\gamma) = g_1 T_{\mu\nu}(Q)\widetilde{F}_{\mu\lambda}(\rho)\rho_{\lambda\nu}(q) , \qquad (2)$$

where $T_{\mu\nu}$ is the 2^- polarization tensor. Matrix element (2) gives the following angular distribution

$$W(\theta) = 6 + \sin^2\theta\left[\frac{m_\rho^2}{m_X^2} + 6\frac{m_X^2}{m_\rho^2}\left(1 - \frac{m_\rho^2}{m_X^2}\right)\right] \qquad (3)$$

and inserting the mass values we have

$$W(\theta) = 1{,}48 + \sin^2\theta \qquad (4)$$

in agreement with the experiment. Note that if $\frac{m_\rho}{m_X} \to 1$ the multipole classification reappears and the Eq.(3) gives $W(\theta) \sim 6+\sin^2\theta$ corresponding to the M1 transition, which has been discussed in the previous experimental papers/4/.

3. Decay Mode $X^\circ \to \eta\pi^+\pi^-$

Recently an asymmetry in η-meson kinetic energy on the $X^\circ \to \eta\pi^+\pi^-$ Dalitz plot was found in some experiments/3-5/. For the hypothesis $I^p(X^\circ)=0^-$ the simplest M.E. is a constant in disagreement with experimental data/3/. To fit established asymmetry the M.E. must contain at least bilinear in momenta terms. For the hypothesis $I^p(X^\circ)=2^-$ the two possible simplest matrix elements ($\ell_{\pi\pi}=0, \ell_\eta=2$ and $\ell_{\pi\pi}=2, \ell_\eta=0$) are mixed with the mixing coefficient $|K|=4.1\pm0.5$/3/, $|K|\sim 3$/4/. Note that the Adler consistency condition, which has been previously used/6/ to explain the value of the slope in the decay $X^\circ \to \eta 2\pi$ in fact, does not give any restriction for $I^p(X^\circ)=0^-$*. For the 2^- hypothesis both the simplest matrix

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* The matrix element with at most bilinear momentum dependence for the decay $0^- \to \eta 2\pi$ is $M(X^\circ \to \eta 2\pi) = \alpha_1 + \alpha_2(p^+ + p^-)^2 + \alpha_3 p^+p^-$. The Adler consistency condition gives in this case $\alpha_1 = m_\pi^2\alpha_2$ and leaves the parameter α_3 arbitrary. Therefore in the case of the pions with nonvanishing masses we can get any value for the slope.

elements for the decay $X^\circ \to \eta 2\pi$ have quadratic momentum dependence and the Adler condition demands the M.E. to be of the form (p^+ , p^- are momenta of π^+ and π^- , respectively)

$$M(X^\circ \to \eta \pi^+ \pi^-) = \lambda T_{\mu\nu} P^+_\mu P^-_\nu \, . \qquad (5)$$

It gives the mixing coefficient K = -4 in a good agreement with the experiment.

4. The X°(960) width

For the 0^- alternative the different models (the current algebra, the Veneziano model and the quark model) give the X° width $\Gamma_{tot}(X^\circ)$ in the range (1-10) MeV /8/. Therefore we expect in the $\bar{0}^-$ case the upper experimental limit $\Gamma_{tot}(X^\circ) < 4$ MeV. is close to the exact value.

A quite different situation occures for the 2^- hypothesis. Due to the centrifugal barrier the decay $X^\circ \to \eta 2\pi$ is suppressed. The M.E.(5) gives $\Gamma_{tot}(X^\circ) \sim 5$ Kev if $\lambda \sim (f_\pi m_X)^2$, where $f_\pi \approx m_\pi^{-1}$ is the pion decay constant and the ρ-meson mass is chosen as the characteristic one. It is only a very crude estimate but the result is intriguing: for the 2^- alternative X°(960) meson may be very narrow, it may be considered at equal footing with η-meson as a particle and not as a resonance. In this connection the experimental search of X° in the Primakoff effect /9/ is of a considerable importance and even the upper limit for the absolute value of $\Gamma_{\gamma\gamma}(X^\circ)$ would be very interesting. In the 2^- case* the Primakoff cross-section is expected to be very small.

Recently the possibility for the X° meson production in the

*The formula of the Primakoff cross-section for the pseudoscalar particles is well-known. In the case of the 2^- hypothesis it is given in ref. /2/.

reaction $e^+e^- \to e^+e^- X^\circ$ (the Landau-Lifshits effect) has considered[10] by Budnev and Ginzburg and in the 0^- case $\sigma(e^+e^- \to e^+e^- X^\circ)$ is estimated to be $7 \cdot 10^{-33}$ cm^2 for the electron energy 2 GeV. This process may be used together with the Primakoff effect for the determination of the X° meson lifetime.

5. All arguments presented here favouring the 2^- hypothesis are aiming to draw attention to the necessity of new measurements of the X° meson spin correlations. Now let us list the most important experiments of such a kind.

a) The available experimental data[4,5] on correlations between the normal to the X° decay plane and the incoming $K^-(\pi^-)$ momentum in the $K^-p \to \Lambda X^\circ$ and $\pi^-p \to n X^\circ$ are pure and it is impossible to make any definite conclusions. The study of such correlations at the higher statistical level ($\sim$ 2.000-3.000 events) may turn out to be more decisive (correlations with the normal to the X° production plane may be more sensitive than with the direction of the incoming particle). The very existence of such correlations would prove the 2^- alternative.

b) It may happen that the X° meson polarization is not essential at high energy. Therefore it is reasonable to investigate specially collinear X° meson production. In this case X° meson must be aligned (the spin projections ± 2 are forbidden) and there are definite correlations between the direction of the incident $K^-(\pi^-)$ beam and the momenta of the decay particles[11]. For the 0^- alternative the corresponding angular distributions are isotropic.

c) Measurements of the angular distributions in the decay of the baryon resonances $\mathcal{J}^\pm \to \frac{1}{2}^+ 0^-$ with $\mathcal{J} \geq \frac{3}{2}$ which are produced in the collinear processes $0^- \frac{1}{2}^+ \to X^\circ \mathcal{J}^\pm$ for example, $\pi N \to X^\circ N^*, K^-p \to X^\circ Y_1$ etc. The deviation of the angular distribution in the isobar decay from the Adair distribution is incompatible with the pseudoscalarity of X°(960)[11].

d) Search of the X°(960) in antiproton-proton annihilation at rest in the reactions. $p\bar{p} \to X^\circ \rho^\circ (X^\circ \pi\pi)$.

It is importmant that in this case one can use both the decay and production mechanisms for the determination of the X° spin-parity, cf. the bright analysis of reaction $p\bar{p} \to E\pi\pi$ in[12]. The deviation of the distribution in the angle ($\varkappa$) between the X° and ρ°-meson relative momentum and the ρ-meson polarization from $\sin^2\varkappa$, and the deviation of other distributions from the isotropic ones would manifest the spin-parity 2^-. It is of interest to do the corresponding analysis for the X° production in the reaction $p\bar{p} \to X^\circ \pi\pi$.

e) The higher statistics is needed for the $X^\circ \to \rho^\circ \gamma$ decay discussed above. The deviation of the angular distribution from $\sin^2\theta$ is inconsistent with $I^P(X^\circ)=0^-$.

f) In the electromagnetic interactions the investigation of the X° production in the Primakoff[2,9] and Landau-Lifshits processes[10] are very important as noted above.

g) There exists an interesting possibility in the reaction[13]

$$\gamma + He \to He + X^\circ(960).$$

The choice of the helium is dictated by its spinlessness and by the absence of the low-lying excitedsstates.For the 0^- alternative the differential cross-section strongly depends on the X° production angle and vanishes at $\theta = 0^\circ$, 180° as $\sin^2\theta$. For the 2^- alternative the simplest angular distribution does not vanish in forward direction.

The dependence of the cross-section of the process $\gamma + He \to He + X^\circ$ on the incident photon polarization for $\mathcal{I}^P(X^\circ) = 0^-$ is rather strong

$$\frac{d\sigma_\xi}{d\Omega} = \frac{d\sigma_0}{d\Omega}(1+\xi), \qquad (6)$$

where the ξ is the Stokes parameter of the linear polarization of the photon along the normal to the reaction plane. The deviation from this dependence is inconsistent with the pseudoscalarity for the X^0-meson. There are also interesting threshold effects different for 0^- and 2^- alternative. (Details see in ref.[13]).

h) The possibility of the X^0-meson spin-parity determination exists also in the colliding beams experiments $e^+e^- \to X^0\gamma(X^0\rho^0)$ which are discussed now[14]. The analysis of these differential cross-section near the X^0 production threshold makes it possible to distinguish between the hypothesis 0^- and 2^-[13].

The 2^- hypothesis for the X^0-meson in the view of the existence of another candidate for the ninth pseudoscalar meson - E(1420)-meson[1,12] is very striking and worth a good deal of attention. The following classification for mesons is probable[1,15] $\pi, K, \eta, E(1420)$ for the 0^- nonet and $\pi_A(1640), K_A(1775), \eta_A(1830), X^0$ for the 2^- nonet.

We hope that the accumulation of the experimental data will permit to solve the important problem of the X°(960) meson spin-parity in the near future.

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