СООБЩЕНИЯ
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ЯДЕРНЫХ
ИССЛЕДОВАНИЙ

Дубна

E2 - 6144

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ЛАБОРАТОРИЯ ВЫСОКИХ ЭНЕРГИЙ

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ON THE X°(960) MESON SPIN PARITY DETERMINATION IN ANTIPROTON-PROTON ANNIHILATION AT REST

Submitted to ЯФ

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At present there is an ambiguity in the determination of the $X^0(960)$ meson spin parity /I,2,3/. The available experimental data can be equally consistent with either 2^- or 0^- hypotheses for the $X^0(960)$ meson spin parity; the 2^- hypothesis even seems to be somewhat preferable /3/. The analysis of the mechanism only of the known X^0 decays $X^0 \to \eta 2\pi$, $X^0 \to \rho\gamma$ and $X^0 \to 2\gamma$ does not permit the exclusion of the $J^P(X^0) = 2^-$ at any practical statistics. For the first two cases this is due to the absence of the sharply expressed exclusions on the Dalitz plots and a large number of free parameters in the $2^- \to \eta 2\pi$, $2^- \to \pi\pi\gamma$ reactions. The indistinguishability of the $J^P(X^0) = 0^-$ and 2^- hypotheses by the $X^0 \to 2\gamma$ decay follows from the Landau-Yang theorem on the spin states of two photons.

Thus, the hypothesis $J^P(X^0) = 2^-$ cannot be distinguished, in principle, from the $J^P(X^0) = 0^-$ with a high confidence by all the known X^0 meson decays. For this reason the study of the $X^0(960)$ meson production together with the mechanism of the decay in the strong and electromagnetic interactions becomes important /3,4/.

In this work the $X^0(960)$ meson production in antiproton proton annihilation at rest in the reaction

$$p\bar{p} \longrightarrow X^0 \rho^0 \; (X^0 \pi\pi) \qquad \text{(I)}$$

is analyzed. There are obtained anagular correlations between the momenta of the particles from the decays of the X^0 and ρ mesons and the direction of the X^0 meson momentum, the experimental investigation of which will enable to distinguish between the 2^-

and 0^- hypotheses for the $X^0(960)$ spin parity. Let us note that the study of analogous correlations in the reaction $p\bar{p} \to E\pi\pi$ has given an convincing argument in favour of E meson pseudoscalarity /9/.

2. The amplitude of the $p\bar{p}(^3S_1) \to X^0\rho^0$ reaction in the case of $J^P(X^0) = 2^-$ has the form **in the total c.m.**

$$A_n(^3S_1) = \alpha\, \varepsilon_{imn} \bar{X}_{ij} \bar{\rho}_j K_m + \beta\, \varepsilon_{imj} \bar{X}_{in} \bar{\rho}_j K_m , \qquad (2)$$

where X_{ij} is the polarization tensor for the 2^- spin, $\vec{\rho}$ is the ρ meson polarization vector, $\vec{K}$ is the X^0 meson momentum. The annihilation at rest $p\bar{p} \to X^0\rho^0$ may proceed only in the triplet $^3S_1$ state; annihilation in the $^1S_0$ state is forbidden because of the charge parity conservation. The energy release in this reaction is small ($Q \sim 150$ MeV), and the approximation of the low orbital moments in (2) is a good one.

The density matrix elements of the X^0 meson ($\rho^{(2)}_{mn}$) and ρ meson ($\rho^{(1)}_{mn}$) are related with the complex numbers α and β in the following way:

$$\begin{aligned}
\sigma_0 \rho^{(2)}_{22} &= \sigma_0 \rho^{(2)}_{-2-2} = |\alpha|^2 + |\beta|^2 + 2\,\mathrm{Re}\,\alpha^*\beta , \\
\sigma_0 \rho^{(2)}_{11} &= \sigma_0 \rho^{(2)}_{-1-1} = \tfrac{1}{2}\left(|\alpha|^2 + |\beta|^2\right), \\
\sigma_0 \rho^{(1)}_{00} &= |\alpha|^2 , \\
\sigma_0 &= \tfrac{10}{3}\left(|\alpha|^2 + |\beta|^2 + \mathrm{Re}\,\alpha^*\beta\right),
\end{aligned} \qquad (3)$$

where σ_0 is the cross section of the unpolarized particle production, the axis Z is chosen along the direction of the X^0 meson momentum $\vec{K}$.

There is a relation between the elements of the density matrix

$$3\rho_{00}^{(2)} + \rho_{22}^{(2)} = 4\rho_{11}^{(2)} \tag{4}$$

this is because we neglect in (2) the contribution of the higher orbital moments. The possible violation of eq. (4) will mean that higher orbital moments are essential in this case.

Below are obtained distributions with respect to the angles between the momenta of particles from the X^0 and meson decays and direction of the X^0 meson momentum for each $X^0 \to 2\gamma$, $X^0 \to \rho\gamma$ and $X^0 \to \eta 2\pi$ decays.

a) <u>$X^0 \to 2\gamma$ decay</u>

For $J^P(X^0) = 2^-$ the matrix element for the $X^0 \to 2\gamma$ decay in the X^0 meson rest frame has the form

$$M_{2^-}(X^0 \to 2\gamma) \sim X_{ij}\, q_i q_j \,(\vec{q}\cdot \vec{e}_1 \times \vec{e}_2), \tag{5}$$

where $\vec{q}$, $\vec{e}_1$ $(\vec{e}_2)$ are the momentum and polarization vectors of photons. We introduce the following notations for the angular variables:

$$\cos\varphi = \frac{(\vec{q}\cdot\vec{K})}{|\vec{q}|\,|\vec{K}|}, \quad \cos\psi = \frac{(\vec{q}\cdot\vec{P})}{|\vec{q}|\,|\vec{P}|} \quad \cos\varkappa = \frac{(\vec{P}\cdot\vec{K})}{|\vec{P}|\,|\vec{K}|}, \tag{6}$$

where $\vec{P}$ is the relative momentum of the π^+ and π^- mesons in the ρ^0- meson rest frame in the reaction $p\bar{p} \to X^0 \rho^0_{\hookrightarrow \pi^+\pi^-}$ 1/.

The distributions $W_{1,2,3}$ with respect to the angles $\varphi, \psi, \varkappa$ have the form

$$W_1(\varphi) = \frac{1}{8\pi}\left\{3\sin^2\varphi + 5\rho_{00}^{(2)}(3\cos^2\varphi - 1)\right\},$$

$$W_2(\psi) = \frac{1}{8\pi}\left\{2 + 5(\rho_{00}^{(1)} - \rho_{00}^{(2)})(3\cos^2\psi - 1)\right\}, \tag{7}$$

$$W_3(\varkappa) = \frac{3}{8\pi}\left\{\sin^2\varkappa + \rho_{00}^{(1)}(3\cos^2\varkappa - 1)\right\},$$

1/ As the Z-axis is chosen along the direction of the momentum $\vec{k}$, the angles φ, $\varkappa$ coincide with polar angles θ^X, θ^ρ defined in the X^0, ρ^0- meson rest frames. The angle ψ depends also on corresponding azimuthal angles ϕ^X, ϕ^ρ : $\cos\psi = \cos(\phi^X - \phi^\rho)\sin\theta^X \sin\theta^\rho + \cos\theta^X \cos\theta^\rho$.

where $\rho^{(2)}_{00}$ and $\rho^{(1)}_{00}$ are the density matrix elements for the X^0 and ρ mesons.

b) $X^0 \rightarrow \rho\gamma$ decay

For the 2^- hypothesis the matrix element for the $X^0 \rightarrow \rho\gamma$ decay involves three amplitudes of MI, E2 and M3 transitions

$$M_{2^-}(X^0 \rightarrow \rho\gamma) = \{ g_1 b_i [\vec{q} \times \vec{e}]_j + g_2 e_i [\vec{q} \times \vec{b}]_j + f q_i q_j (\vec{q} \cdot \vec{e} \times \vec{b}) \} X_{ij}, \quad (8)$$

where $\vec{q}, \vec{e}\ (\vec{b})$ are the momentum and polarization vectors of photon (ρ meson).

The contribution of the M3 transition amplitude can be neglected at $Q \sim 200$ MeV ($f = 0$). As it is shown in /3/, the simplest relativistic matrix element is well consistent with the experimental data and brings to $\varepsilon \equiv \frac{g_1 - g_2}{2g_1 + g_2} \simeq 0{,}31$.

The angular distributions $W_{I,2,3}$ in this case have the form

$$W_1(\varphi) \sim \frac{4}{5} A - B\left(\rho^{(2)}_{22} - \frac{1}{5}\right)\left(3\cos^2\varphi - 1\right),$$

$$W_2(\psi) \sim \frac{4}{5} A + B\left(\rho^{(2)}_{22} + \rho^{(1)}_{00} - \frac{2}{5}\right)\left(3\cos^2\psi - 1\right),$$

$$W_3(\varkappa) \sim \frac{6}{5} A \left\{ \sin^2\varkappa + \rho^{(1)}_{00}\left(3\cos^2\varkappa - 1\right)\right\}, \quad (9)$$

$$A = 2\varepsilon^2 - 2\varepsilon + 3, \quad B = \varepsilon^2 + 6\varepsilon - 5, \quad \varepsilon = \frac{g_1 - g_2}{2g_1 + g_2},$$

where the angles φ, ψ and χ are determined by eq.(6).

c) $X^0 \to \eta 2\pi$ decay

The angular correlations in the reaction $p\bar{p} \to \rho^0 X^0_{\hookrightarrow \eta\pi^+\pi^-}$ are of most interest from the experimental point of view since the branching ratio of the $X^0 \to \eta 2\pi$ is great $\sim 64\%$ /I/.
We use the matrix element for the $X^0 \to \eta\pi^+\pi^-$ decay with mixing coefficient for the amplitudes $\ell_\eta = 0$, $\ell_{\pi\pi} = 2$ and $\ell_\eta = 2$, $\ell_{\pi\pi} = 0$ equal to $K = -4$ /3/:

$$M_{2^-}(X^0 \to \eta\pi^+\pi^-) \sim X_{ij} P_i^+ P_j^- \sim X_{ij}(q_i q_j - 4 q_i' q_j'),\ q' = \tfrac{1}{2}(p^+ - p^-), \quad (10)$$

where $\vec{q}$ is the η meson momentum in the X^0 meson rest system, $\vec{q}'$ is the relative momentum of pions. The matrix element (I0) is well consistent with the existing asymmetry on the Dalitz plot for the $X^0 \to \eta\pi^+\pi^-$ decay /6,7/ and also satisfies the Adler's selfconsistency condition /3,8/.

For the angular distributions $W_{1,2,3}$, after phase volume integration we obtain:

$$W_1(\varphi) \sim \tfrac{4}{5}A_1 - B_1\left(\rho_{22}^{(2)} - \tfrac{1}{5}\right)(3\cos^2\varphi - 1),$$

$$W_2(\psi) \sim \tfrac{4}{5}A_1 + B_1\left(\rho_{22}^{(2)} + \rho_{00}^{(1)} - \tfrac{2}{5}\right)(3\cos^2\psi - 1),$$

$$W_3(\chi) \sim \tfrac{6}{5}A_1\left\{\sin^2\chi + \rho_{00}^{(1)}(3\cos^2\chi - 1)\right\}, \quad (11)$$

$$A_1 : B_1 = 1{,}7 : 1, \qquad |K| = \frac{|M(\ell_\eta = 0, \ell_{\pi\pi} = 2)|}{|M(\ell_\eta = 2, \ell_{\pi\pi} = 0)|} = 4.$$

2/We take into account only amplitudes $\ell_\eta, \ell_{\pi\pi} = 0{,}2$ and $\ell_\eta, \ell_{\pi\pi} = 2{,}0$. It means that the momentum $\vec{q}'$ can be changed by the momentum of the π^+ - meson in ($\pi^+\pi^-$) rest frame.

Here the angular variables are determined by the formulae (6) where $\vec{q}$ is in this case the momentum of η meson. Let us determine the angles φ' and ψ' in the following way: $\cos\varphi' = \frac{(\vec{q}'\cdot\vec{k})}{|\vec{q}'||\vec{k}|}$ $\cos\psi' = \frac{(\vec{q}'\cdot\vec{p})}{|\vec{q}'||\vec{p}|}$. Then for the $W_1'(\varphi')$ and $W_2'(\psi')$ we obtain

$$W_1'(\varphi') \sim \frac{4}{5}A_1 - (2A_1 - B_1)(\rho_{22}^{(2)} - \frac{1}{5})(3\cos^2\varphi' - 1), \tag{I2}$$
$$W_2'(\psi') \sim \frac{4}{5}A_1 + (2A_1 - B_1)(\rho_{22}^{(2)} + \rho_{00}^{(1)} - \frac{2}{5})(3\cos^2\psi' - 1),$$
$$A_1 : B_1 = 1,7 : 1 .$$

3. If $X^0(960)$ meson is pseudoscalar, then for all the decay modes the angular distributions $W_{1,2,3}$ are alike: $W_3 \sim \sin^2\varkappa$, $W_{1,2}(W'_{1,2})$ are isotropic:

$$W_1(\varphi) = W_2(\psi) = 1$$
$$W_3(\varkappa) = \frac{3}{2}\sin^2\varkappa \tag{I3}$$
$$W_1'(\varphi') = W_2'(\psi') = 1$$

The deviations of the angular correlations from the relation (I3) is incompatible with the X^0 meson pseudoscalarity.

A similar analysis can be performed for the reaction $p\bar{p} \to X^0\pi\pi$ as it has been done for instance in /9/ for the reaction $p\bar{p} \to E\pi\pi$. In this case it is possible also annihilation from ${}^1S_0$ state. Any deviations of $W_1(W_1')$ and $W_2(W_2')$ distributions from the isotropical ones for annihilations both from the triplet and singlet states would be an evidence for the $J^P(X^0) = 2^-$ hypothesis. The result for the $W_3(\varkappa)$ distribution, even for $J^P(X^0) = 0^-$ is ambiguous and depends upon the contribution of the higher orbital moments of the $\pi\pi$ system which can not be neglected because of the high q value in the reaction

$p\bar{p} \to X^0\pi\pi$.

Thus the experimental observation of the X^0 meson in the reaction $p\bar{p} \to X^0\rho^0 (X^0\pi\pi)$ and the study of the distribution $W_{I,2,3}$ ($W'_{1,2}$) will permit to determine the spin of the $X^0(960)$ meson.

The advantage of this method for determining the X^0 spin parity is that all the available statistics of the events can be used. Analogous correlation effects in meson baryon collisions depend upon the momentum transfer, and due to the selection of the events with low momentum transfer the statistics becomes poorer /4/.

4. More attention must be paid to the 2^- hypothesis for the X^0 meson in connection with the existence of another candidate for the ninth pseudoscalar meson, namely E(I420) meson /I,9/. At present the following classification of mesons /I,I0/ is very probable: π, K, η, E(I420) for the 0^- nonet and π_A (I640), K_A(I775), η_A(I830), $X^0(960)$ for the 2^- nonet.

We hope that with the help of additional experimental data the problem of the quantum numbers of the $X^0(960)$ will be solved in the near future.

The authors are grateful to T.L. Asatiani, S.B. Gerasimov, S.H. Matinian, B.N. Valuev and especially V.I. Ogievetsky and V. Tybor for useful discussions.

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Received by Publishing Department
on November 29, 1971