ON THE DETERMINATION OF THE $X^0(960)$ MESON SPIN-PARITY IN THE POLARIZATION EXPERIMENT

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To establish the $X^0(960)$ meson spin-parity it is suggested to study the forward production of X^0 in the reaction $K^-p \to X^0\Lambda$ with the polarized proton.

The analysis of the experimental data [1, 2, 3] on the $X^0(960)$ meson allows to draw the following conclusions:
— at present, the $X^0(960)$ meson spin-parity J^P has not been firmly established;
— the most likely J^P assignments for $X^0(960)$ are 0^- and 2^-;
— new methods for determining the X^0 meson spin are desirable [4].

In this paper we draw attention to the possibility of making use of polarized targets to establish the $X^0(960)$ meson spin-parity. We suggest to study the forward production of X^0 in the reaction $K^-p \to X^0\Lambda$ with the polarized proton.

In the forward reaction, the amplitude for $0^-\frac{1}{2}^+ \to 0^-\frac{1}{2}^+$ differs from the one for $0^-\frac{1}{2}^+ \to 2^-\frac{1}{2}^+$ since in the latter care the baryon spin flip is possible. Indeed: — if the $X^0(960)$ meson spin-parity is 0^-, then the matrix element for scattering under consideration is

$$M \sim \bar{\psi}_\Lambda \psi_p \bar{X} \Phi_K \tag{1}$$

where ψ_Λ, ψ_p, Φ_K and X describe Λ, p, K and X particles respectively; — if the $X^0(960)$ meson spin parity is 2^-, then

$$M = \bar{\psi}_\Lambda(\alpha n_i n_j + \beta n_i(\vec{\sigma}\times\vec{n})_j)\psi_p \bar{X}_{ij}\Phi_K \tag{2}$$

where X_{ij} is the polarization tensor for the spin 2^-, $\vec{n}$ is the unit vector in the direction of the reaction, α and β being the baryon non flip and spin flip amplitudes respectively[1].

Let us study the forward scattering $K^-p \to X^0\Lambda$ if the spin-parity of X^0 is 2^-. One obtains from (2):

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[1] In general (not collinear) case there are ten independent amplitudes.

1) the change of the baryon polarization. Indeed, the polarization $\vec{P}^{\Lambda}$ of the Λ hyperon is

$$\sigma_0 \vec{P}^{\Lambda} = \tfrac{2}{3}|\alpha|^2 \vec{P}^p_{\perp} + (\tfrac{2}{3}|\alpha|^2 - |\beta|^2)\vec{P}^p_{||} \tag{3}$$

where $\sigma_0 = \frac{2}{3}|\alpha|^2 + |\beta|^2$ and the proton polarization is

$$\vec{P}^p = \vec{P}^p_{\perp} + \vec{P}^p_{||} \qquad (\vec{P}^p_{\perp} \perp \vec{n},\ \vec{P}^p_{||} || \vec{n});$$

2) the following elements of the spin density matrix of the produced $X^0(960)$ meson:

$$\sigma_0\varrho_{00} = \tfrac{2}{3}|\alpha|^2, \qquad \sigma_0\varrho_{11} = \tfrac{1}{2}|\beta|^2(1+P_{||}), \qquad \sigma_0\varrho_{-1-1} = \tfrac{1}{2}|\beta|^2(1-P_{||}), \tag{4}$$

$$\sigma_0\varrho_{10} = \sigma_0\varrho_{-10} = \sigma_0\varrho^*_{01} = \sigma_0\varrho^*_{0-1} = \frac{i}{\sqrt{6}}\alpha^*\beta P_{\perp},$$

with all other elements vanishing, where $\vec{P}^p = (P_{\perp}, 0, P_{||})$ and $\vec{n} = (0, 0, 1)$. We can expect the dependence of the X^0 decay on the azimuthal angle since not all non diagonal matrix elements vanish (if α, β do not vanish). Some examples of the decay angular distributions are given in the Appendix.

From the experimental point of view it is interesting to give the upper limit of the accepted production angles ϑ in the suggested method. It seems that the usually applied criterion [6] $\vartheta < \frac{1}{r_0 k}$ (r_0 is the range of the interaction and k is the outgoing momentum in the production process) is plausible.

Other problem is the value of the ratio $|\beta|/|\alpha|$, because only for not too small $|\beta|/|\alpha|$ the unambiguous determination of the spin of the X^0 is possible. However, we have no suggestions on the order of magnitude of this number.

So, the experiment with the polarized target allows, in principle, to establish the spin-parity of the $X^0(960)$ meson. The experiment is very difficult but we should like to stress once again the importance of the unambigous determination of the quantum numbers of the $X^0(960)$ meson.

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APPENDIX

a. $X^0 \to 2\gamma$

The decay matrix element in the X^0 rest system is of the form [4]

$$X_{ij}k_ik_j(\vec{k}\cdot\vec{e}_1\times\vec{e}_2) \tag{A.1}$$

where $\vec{k}$ is the relative momentum of the photons, $\vec{e}_1$ and $\vec{e}_2$ being the polarization vectors of the photons. The angular distribution is

$$W(\theta,\varphi) = \frac{15}{8\pi}\left\{\frac{3}{2}\varrho_{00}\left(\cos^2\theta - \frac{1}{3}\right)^2 + (1-\varrho_{00})\cos^2\theta\sin^2\theta + \right.$$

$$\left. +2\sqrt{6}\,\mathrm{Im}\,\varrho_{10}\cos\theta\sin\theta\left(\cos^2\theta - \frac{1}{3}\right)\sin\varphi\right\}, \tag{A.2}$$

where

$\cos\theta = \left(\vec{n}\cdot\frac{\vec{k}}{k}\right)$ and the azimuthal angle φ is read from $\vec{P}^p_\perp$ $[\vec{P}^p = (P^p_\perp, 0, P^p_\parallel), \vec{n} = (0, 0, 1)]$.

b. $X^0 \to \varrho\gamma$

There are three decay matrix elements [4]

$$\{g_1\varrho_i[\vec{k}\times\vec{e}]_j + g_2 e_i[\vec{k}\times\vec{\varrho}]_j + f k_i k_j(\vec{k}\cdot\vec{e}\times\vec{\varrho})\}X_{ij}, \tag{A.3}$$

where $\vec{\varrho}$ is the polarization vector of the ϱ meson. The angular distribution of the photon or of the ϱ meson is:

$$W(\theta,\varphi) \sim C_1 + C_2\left\{1 - \frac{1}{3}\varrho_{00} + (1+\varrho_{00})\cos^2\theta + \frac{8}{\sqrt{6}}\,\mathrm{Im}\,\varrho_{10}\cos\theta\,\sin\theta\,\sin\varphi\right\} +$$
$$+ C_3\left\{\frac{3}{2}\varrho_{00}\left(\cos^2\theta - \frac{1}{3}\right)^2 + (1-\varrho_{00})\cos^2\theta\,\sin^2\theta +\right.$$
$$\left. + 2\sqrt{6}\,\mathrm{Im}\,\varrho_{10}\cos\theta\,\sin\theta\left(\cos^2\theta - \frac{1}{3}\right)\sin\varphi\right\}, \tag{A.4}$$

where

$$C_1 = (g_1+g_2)^2, \quad C_2 = \frac{1}{4}[2g_2^2 - (g_1+2g_2)^2], \quad C_3 = g_2^2 + 2k^4f^2 + 2k^2f(g_2-g_1).$$

c. $X^0 \to \eta\pi^+\pi^-$

We use the decay matrix element of the form [5]

$$X_{ij}p_i^+p_j^- \tag{A.5}$$

where $\vec{p}^+$ and $\vec{p}^-$ are the momenta of π^+ and π^- respectively. The matrix element (A.5) satisfies the Adler self-consistency condition and gives the correct η-energy asymmetry in the decay $X \to \eta 2\pi$ [5]. For example, the angular distributions of the normal to the decay plane and the angular distribution of the η particles are of the form:

$$W(\theta,\varphi) \sim B_0\left\{\frac{9}{4}\varrho_{00}\left(\cos^2\theta - \frac{1}{3}\right)^2 + \frac{3}{2}(1-\varrho_{00})\sin^2\theta\,\cos^2\theta +\right.$$
$$\left. + 3\sqrt{6}\,\mathrm{Im}\,\varrho_{10}\left(\cos^2\theta - \frac{1}{3}\right)\cos\theta\,\sin\theta\,\sin\varphi\right\} +$$
$$+ B_1\{3\varrho_{00}\sin^2\theta\,\cos^2\theta + (1-\varrho_{00})[(2\cos^2\theta - 1)^2 + \cos^2\theta] -$$
$$- 2\sqrt{6}\,\mathrm{Im}\,\varrho_{10}(2\cos^2\theta - 1)\cos\theta\,\sin\theta\,\sin\varphi\} +$$
$$+ B_2\left\{\frac{3}{4}\varrho_{00}\sin^4\theta + \frac{1}{2}(1-\varrho_{00})(1-\cos^4\theta) - \sqrt{6}\,\mathrm{Im}\,\varrho_{10}\cos\theta\,\sin^3\theta\,\sin\varphi\right\}. \tag{A.6}$$

The ratio $B_0 : B_1 : B_2$ is:

1 : 0 : 3.72 for the distribution of the normal,

1 : 0.38 : 0.34 for the distribution of the η particle.

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