NOTAS DE FÍSICA

VOLUME VIII

Nº 12

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RIO DE JANEIRO

1961

Notas de Física - Volume VIII - Nº 12

ON THE PRODUCTION AND SPIN OF THE K^* RESONANCE *, **

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(Received November 6, 1961)

In this letter we examine the production of the K^* resonance in the reactions:

$$K^- + p \longrightarrow K^{*-} + p \qquad \text{(A)}$$

$$K^{*-} \rightarrow \bar{K}^0 + \pi^- \qquad \text{(A')}$$

$$K^{*-} \rightarrow K^- + \pi^0 \qquad \text{(A")}$$

* Submitted for publication in Physical Review Letters.

** Work partially supported by the Conselho Nacional de Pesquisas, Brazil.

$$K^- + p \longrightarrow \overline{K}^{*o} + n \qquad \text{(B)}$$

$$\searrow K^- + \pi^+ \qquad \text{(B')}$$

as related, in particular, to the question of the K^* spin. Our analysis is based on measurements by M. Alston *et al.*[1], with incident K^- of momentum 1.15 Gev/c. We first give a summary of their results:

1) The resonance energy is 885 MeV with a full width of 16 MeV.

2) The branching ratio $R = \dfrac{K^{*-} \longrightarrow K^- + \pi^o}{K^{*-} \longrightarrow \overline{K}^o + \pi^-} = 0.75 \pm 0.35$ strongly favours isotopic spin $T = \frac{1}{2}$ for K^*.

3) The branching ratio for reactions (A') and (B') is about one. If $T = \frac{1}{2}$ this branching ratio is the same as for the reactions (A) and (B).

4) The total cross section for $\overline{K}^o \pi^-$ production is (2.0 ± 0.3)mb. From a total number of 48 $\overline{K}^o \pi^-$ events, 21 have been classified as coming from an intermediate K^*. Hence, the cross section for reaction (A), assuming $T = 1/2$ is (1.31 ± 0.35)mb.

5) The proton angular distribution is roughly isotropic.

6) Let θ be the angle between the direction of the outgoing $\overline{K}^o$ in the K^* rest system and the direction of the incoming K^-. The mean value of $\cos^2\theta$ is 0.275. If K^* has spin zero one should obtain $\langle \cos^2\theta \rangle = 1/3$, with a standard deviation of $\pm$ 0.066. For spin one the value of $\langle \cos^2\theta \rangle$ could range from 0.2 to 0.6. Under certain plausible assumptions higher spins can be excluded.

Reaction (A) has been investigated by several authors[2] assuming that it is produced mainly through the eschange of a single pion as shown in the diagram of Fig. 1. Such a model leads to certain results which have been considered as evidence in favour of spin 1 for K^*. Indeed, if $S = 1$, the proton angular distribution is essentially flat and the total cross section is in agreement with the experimental value. On the other hand, if $S = 0$, the model predicts the angular distribution strongly peaked backwards, and the total cross section smaller than the experimental value by a factor of 9. However, the predictions of the model for items 3) and 6) above, have been overlooked. Assuming $S = 1$ for K^* the value of $\langle \cos^2\theta \rangle$, according to the model, would be very close to the threshold value $\langle \cos^2\theta \rangle = 0.6$, in complete disagreement with the experimental result. In fact the amplitude for graph 1 is proportional to $\cos\theta' = \cos\theta \cos\delta + \sin\theta \sin\delta \cos\phi$ where θ' is the angle between the incoming and outgoing K-mesons in the rest system of K^* and δ is the angle between the directions of the incident K^--meson in the center of mass system and in the rest system of K^*. (See Fig. 2) Hence $d\sigma/d\cos\theta \sim \langle \cos^2\delta \rangle \cos^2\theta + \frac{1}{2} \langle \sin^2\delta \rangle \sin^2\theta$. Near the threshold $\delta \approx 0$, thence $d\sigma/d\cos\theta \approx \cos^2\theta$. Moreover, the model gives 1/4 for the branching ratio of reactions (A') and (B'). This again is inconsistent with the experimental estimate. It is then clear that although the amplitude as given by the diagram of Fig. 1 has the right order of magnitude for $S = 1$, the production mechanism cannot be explained in terms of that diagram alone. Consequently, the argument claimed in favour of $S = 1$ is not entirely consistent.

We shall start our analysis, by observing that the reported experiment has been done at an energy which falls within the width of the resonance Y_4^* of the K^-p system[3] (m_4 = 1812 MeV; Γ_4 = = 120 MeV). The isotopic spin of Y_4^* is already known to be T = 0. From unitarity one can put a lower limit on the spin of Y_4^*. The condition $\sigma_{res}(T = 0) \leqslant 4\pi\ (J + \frac{1}{2})\ q^2_{res}$ gives $J \geqslant 3/2$. Let us suppose that J = 3/2. Then, if K^* is scalar either the $p_{3/2}$ or $d_{3/2}$ wave of the $K^{*-}p$ system would be affected by the resonance Y_4^* depending on its parity. On the other hand, if K^* is vector, the s-wave would be affected, provided that the resonance Y_4^* occurs in the $d_{3/2}$-state of the K^-p system. Since the experiment was performed close to the threshold for K^* production and the proton distribution is nearly isotropic one can assume that s-waves are dominant. Therefore, a strong influence of the resonance Y_4^* in the production of K^* is to be expected if S = 1, but not much if S = 0. Let us assume that Y_4^* is a $d_{3/2}$ resonance of the K^-p-system and K^* a p-wave resonance of the $K\pi$-system. Then, the amplitudes for transitions in which the state of the incoming particles is $d_{3/2}$, T = 0, might be given by the diagram of Fig. 3 (isobar model). We shall examine the production processes (A) and (B) under the foregoing conditions[4].

The general form of the angular correlation $d\sigma/d\cos\theta$ is:

$$\frac{d\sigma}{d\cos\theta} = 2\pi\ (|a|^2 \cos^2\theta + \frac{1}{2}\ |b|^2 \sin^2\theta). \qquad (1)$$

The assymptotic wave function in this channel will then be given by $\psi_\lambda \approx \left[(\exp.\ iq'r)/r\right] \phi_\lambda$ with:

$$\phi_\lambda = \sqrt{4\pi}\,(f_{1/2}\, Y^{\lambda}_{1/2;1,1/2} + \sqrt{2}\, f_{3/2}\, Y^{\lambda}_{3/2;1,1/2}), \tag{2}$$

where λ is the helicity of the incoming proton, $Y^{\lambda}_{J;S_1,S_2}$ are the normalized eigenstates of the total angular momentum $\vec{J} = \vec{S}_1 + \vec{S}_2$ with $J_z = \lambda$; $f_{1/2}$ and $f_{3/2}$ are the transition amplitudes $s_{1/2} \longrightarrow s_{1/2}$ and $d_{3/2} \longrightarrow s_{3/2}$ respectively. They are functions of the total energy only.

We have:

$$\begin{aligned} Y^{\frac{1}{2}}_{3/2;1,1/2} &= \sqrt{\tfrac{2}{3}}\, Y^{0}_{1}\, \chi_{\frac{1}{2}} + \sqrt{\tfrac{1}{3}}\, Y^{1}_{1}\, \chi_{-\frac{1}{2}}\,, \\ Y^{\frac{1}{2}}_{1/2;1,1/2} &= -\sqrt{\tfrac{1}{3}}\, Y^{0}_{1}\, \chi_{\frac{1}{2}} + \sqrt{\tfrac{2}{3}}\, Y^{1}_{1}\, \chi_{-\frac{1}{2}}\,, \end{aligned} \tag{3}$$

with similar expressions for $\lambda = -1/2$.

If the initial proton is unpolarized the angular correlation will be given by:

$$\frac{d\sigma}{d\cos\theta} = 2\pi \times \frac{1}{2} \sum_{\lambda} \phi^{\dagger}_{\lambda}\, \phi_{\lambda} = \frac{8\pi^2}{3} \Big\{ |2\, f_{3/2} - f_{1/2}|^2 |Y^{0}_{1}|^2 + |\sqrt{2}\,(f_{3/2} + f_{1/2})|^2\, |Y^{1}_{1}|^2 \Big\}. \tag{4}$$

Hence, in the expression (1) we have:

$$\begin{aligned} a &= 2\, f_{3/2} - f_{1/2}\,, \\ b &= \sqrt{2}\,(f_{3/2} + f_{1/2}). \end{aligned} \tag{5}$$

Here θ is the angle defined in item 6).

We shall take into account only those transitions leading to s-states of the $K^* p$ - system. This approximation is justified by the arguments given before. Therefore, the total cross section for reactions (A) or (B), and the mean value of $\cos^2\theta$ are given by:

$$\sigma = \frac{4\pi}{3}(|a|^2 + |b|^2) = 4\pi(2|f_{3/2}|^2 + |f_{1/2}|^2), \qquad (6)$$

and

$$\langle \cos^2\theta \rangle =$$

$$= \frac{1}{15}(14|f_{3/2}|^2 + 5|f_{1/2}|^2 - 8 \text{ Re } f_{3/2} f^*_{1/2})/(2|f_{3/2}|^2 + |f_{1/2}|^2). \qquad (7)$$

Since the diagram of Fig. 1 gives $\langle \cos^2\theta \rangle \approx 0.6$, the partial amplitudes obtained therefrom would approximately satisfy the relation $f_{1/2} + f_{3/2} = 0$.

The amplitudes for reactions (A) and (B) may be expressed in terms of transition amplitudes f^T in states of definite isotopic spin $T = 0$ and $T = 1$. One obtains:

$$f^A = \frac{1}{2}(f^1 + f^o), \qquad f^B = \frac{1}{2}(f^1 - f^o). \qquad (8)$$

The isotopic spin dependence of graph 1 is contained in the factor $\vec{\tau}_1 \cdot \vec{\tau}_2 = P_1 - 3 P_o$, where P_1 and P_o are the projection operators for the respective isotopic states. Thus, for that graph, $f^o = -3f^1$. Now, according to our basic hypothesis, $f^o_{3/2}$ will be obtained from graph 3 and has the form $f^o_{3/2} = \rho_o e^{i\varphi}$, where $\text{tg } \varphi = \Gamma_4 m_4 / (m_4^2 - E^2) = -1.15$. The other amplitudes will be taken from graph 1, and can all be expressed in terms of $f^1_{3/2} = - \rho_1$. The total cross section for reaction (A) calculated from the diagram 1 is $\sigma_A = 4.70\ \mathrm{GeV}^{-2} = 12\pi\rho_1^2$, wherefrom one finds $|\rho_1| = 0.353\ \mathrm{GeV}^{-1}$. Collecting all these pieces together we obtain the following set of partial amplitudes:

Reaction (A):

$$f^A_{3/2} = \frac{1}{2}\left(-\rho_1 + \rho_o\, e^{i\varphi}\right) \qquad (9)$$

$$f^A_{1/2} = -\rho_1$$

Reaction (B):

$$f^B_{3/2} = \frac{1}{2}\left(-\rho_1 - \rho_o\, e^{i\varphi}\right) \qquad (10)$$

$$f^B_{1/2} = 2\rho_1 .$$

The results for the total cross section and $\langle\cos^2\theta\rangle$ for both reactions (A) and (B) using these amplitudes are shown in Fig. 4, as function of the parameter ρ_o. The best fit to the experimental data in reaction (A) is obtained with ρ_o/ρ_1 in the range 0.8 to 1.0. The total cross section for reaction (B) is still too large by a factor of about two; this however, should not be considered as a serious drawback, in view of the rough nature of the experimental estimate. On the other hand, the model itself must be considered as a first approach. The main objection to it, is that s-wave interactions depend on short range forces and are usually not well reproduced by Born terms, like the diagram 1 . We remark that, fixing ρ_o/ρ_1 within the range (0.8 —— 1.0) and changing the amplitude $f^o_{1/2}$ by as much as 20 to 30% one can reduce the cross section for reaction (B) and, at the same time, slightly improve the results for reaction (A). We give in Table I a summary of theoretical results for $\rho_o/\rho_1 = 0.9$ and different values of $f^o_{1/2}$. We would like to point out

TABLE I

λ	σ_A(mb)	σ_B(mb)	σ_B/σ_A	$\langle\cos^2\theta\rangle_A$	$\langle\cos^2\theta\rangle_B$
0.70	1.21	1.96	1.61	0.284	0.289
0.75	1.26	2.06	1.64	0.276	0.290
0.80	1.31	2.17	1.66	0.268	0.291

TABLE I. The parameter λ is defined by $f^o_{1/2} = -3\lambda\rho_1$.

that this model predicts for $\langle\cos^2\theta\rangle$ in the reaction (B), a value around 0.29. It would be interesting to check this prediction. If this model is correct it is rather unfortunate that one cannot use this test to identify the spin of K^*. At higher energies, however, and for events with relatively small momentum transfer it is reasonable to expect a preponderance of peripheral collisions. Under such conditions the angular correlation (1), will distinguish between spins S = 0 and S = 1. For S = 0 one should still obtain $\langle\cos^2\theta\rangle = 1/3$ and for S = 1, $\langle\cos^2\theta\rangle =$ $= 0.6 - O(\beta^2)$ where β is the ratio of the velocities of K^* and the incoming K-meson, in the center of mass system. Actually, it is better to measure the angle θ' instead of θ, because then the angular correlation for S = 1, would simply become $\cos^2\theta'$ ($\langle\cos^2\theta'\rangle = 0.6$) if the scattering amplitude is given by diagram 1.

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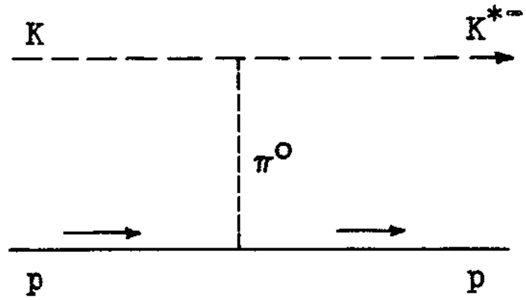

Fig. 1 - Production of K^* through the exchange of a π-meson.

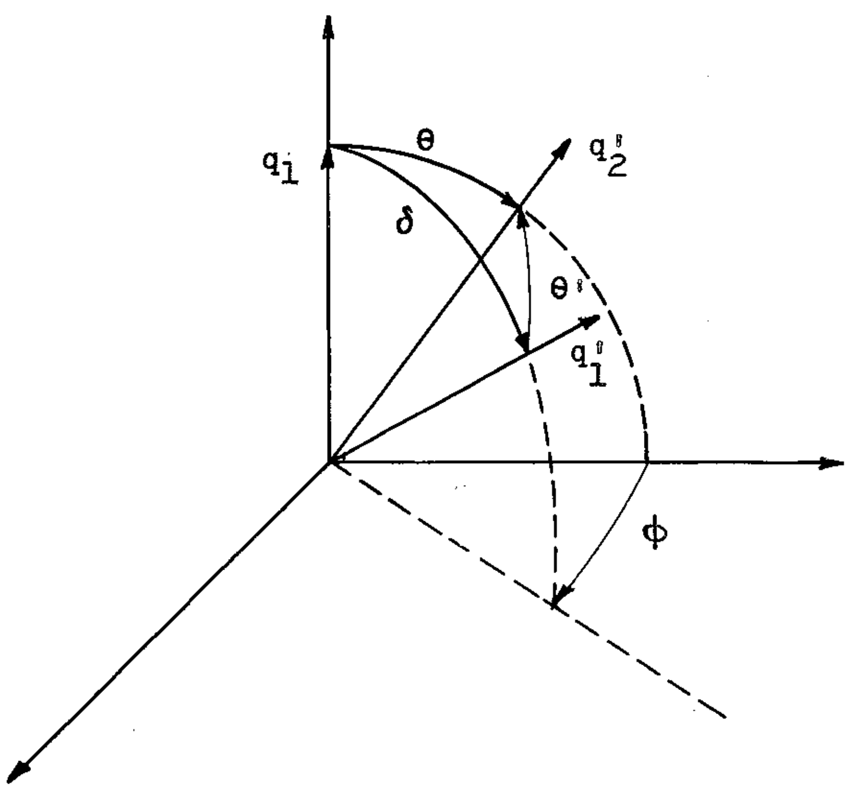

Fig. 2 - Configuration of the K-momenta:

q_1 incident momentum of K^- in the Lab. system;
q_1' incident momentum of K^- in the rest system of K^*;
q_2' outgoing momentum of $\overline{K^o}$ in the rest system of K^*.

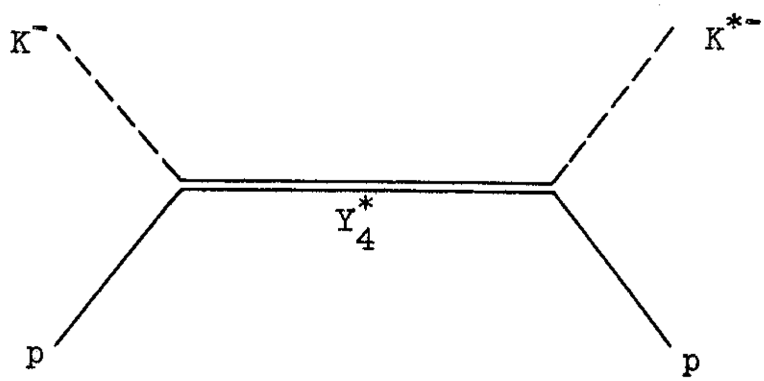

Fig. 3 - Production of K^* through the resonance Y_4^*.

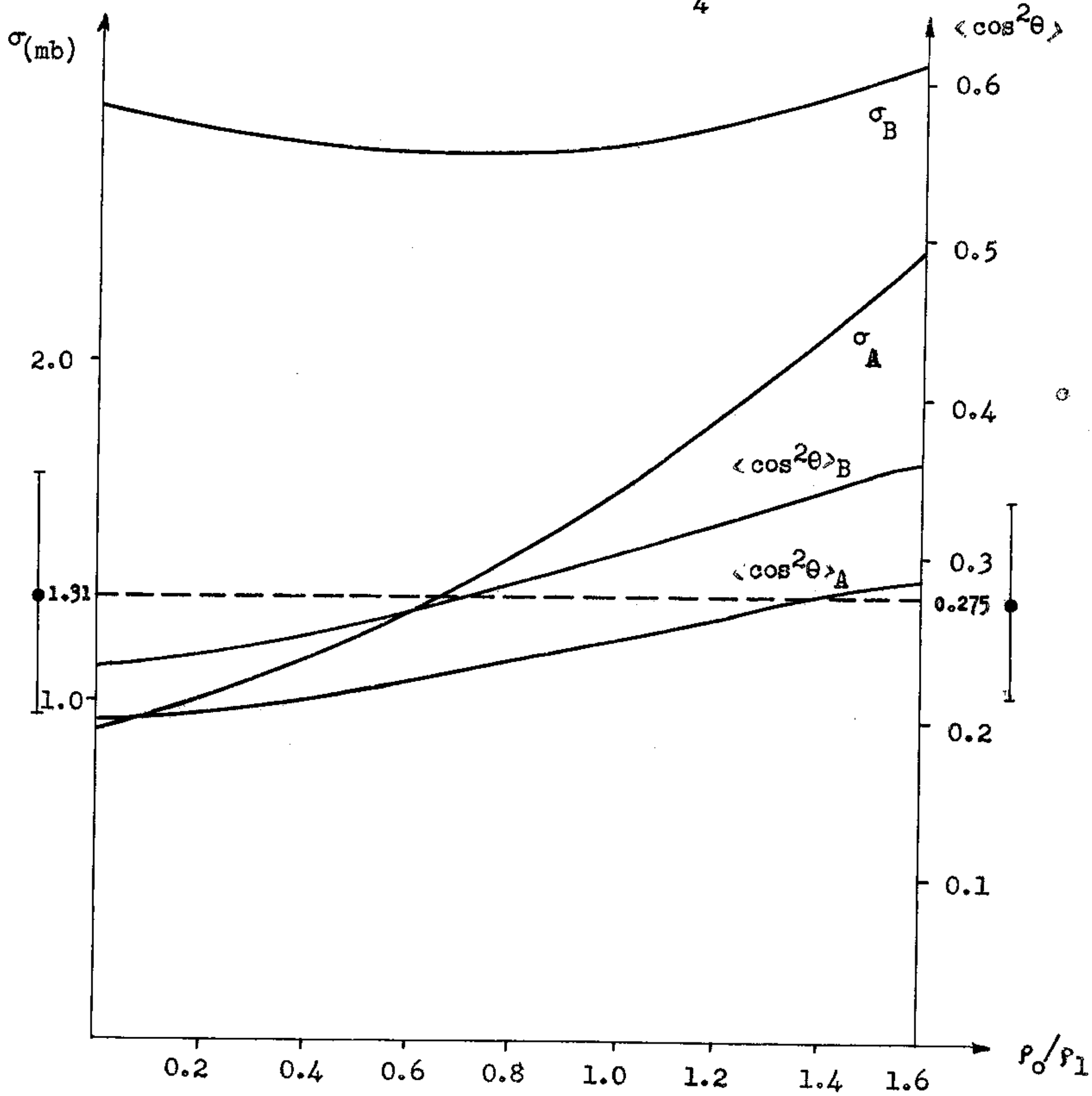

Fig. 4 - Theoretical curves for the total cross section and mean value of $\cos^2\theta$ for processes A and B at 1.15 GeV/c momentum of the K^- meson, as function of the parameter ρ_o/ρ_1. The experimental value (dashed line) is shown for σ_A and $\langle\cos^2\theta\rangle_A$ with the statistical error on the margin. Actually the standard deviation of $\langle\cos^2\theta\rangle_A$ is not constant but increases slowly with $\langle\cos^2\theta\rangle$.