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Comments and Addenda

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Production of Resonances in the Rescattering Model

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The resonance (D) production process $A+B \to C+D$ can be regarded as a two-step process $A+B \to b+d \to C+D$, where the s-channel particles b and d are put on their mass shells in the rescattering square diagram. The corresponding absorptive part of the amplitude can be calculated by exploiting the pole in the amplitude for the process $b+d \to C+D$. The assumption that the absorptive part dominates then yields a production angular distribution for $N^{*-}(1236)$ and $Y_1^*(1385)$ in agreement with experiment, without any additional assumption regarding the production angle of the particle d.

1. INTRODUCTION

RECENTLY we have calculated[1,2] the contribution of the rescattering diagram to the production of $N^{*-}(1236)$ in π^--p scattering and of $Y^*(1385, 1520, 1660)$ in K^--p scattering, in order to understand the presence of both forward and backward peakings. In performing these calculations, we assumed the forward production of an intermediate d state (Fig. 1). The purpose of this paper is to investigate the changes in the result when this drastic assumption is not made, and the remaining two propagators in the coincident-pole-contribution amplitude are used to perform the angular integrations. An interesting situation is created by the fact that for the processes considered, one of the two propagators gives a pole in the physical region.

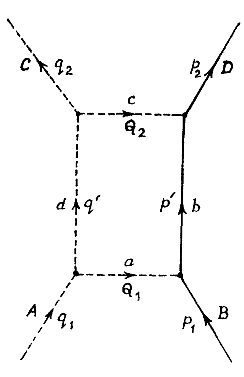

FIG. 1. Rescattering square diagram for the resonance (D) production in the process $A+B \to C+D$.

[1] C. P. Singh and B. K. Agarwal, Phys. Rev. **173**, 1611 (1968).
[2] C. P. Singh and B. K. Agarwal, Nuovo Cimento **54A**, 497 (1968).

2. METHOD OF CALCULATION

If the s-channel intermediate particles, i.e., b and d, are put on their mass shells, the absorptive part of the amplitude for the square diagram shown in Fig. 1 can be written[3] as

$$T_4=\int d\cos\theta'\, d\phi' \frac{|\mathbf{q}'|m_b}{16\pi^2 W}\bar{\psi}(p_2)\left(\frac{p_\sigma'}{m_c}\right)^{s-1/2}\Gamma\frac{g_{Dbc}g_{Ccd}}{Q_2^2+m_c^2}\times i(q_2-Q_2)_\nu\left(\delta_{\mu\nu}+\frac{q_\mu' q_\nu'}{m_d^2}\right)i(q_1+Q_1)_\mu\frac{g_{Bba}g_{Aad}}{Q_1^2+m_a^2}\times\frac{-i\gamma\cdot p'+m_b}{2m_b}\gamma_5 u(p_1)\,, \quad (1)$$

where $\cos\theta'=\hat{q}_1\cdot\hat{q}'$, ϕ' is the azimuth angle of $\mathbf{q}'$, s is the spin of the D particle, $\mathbf{q}'$ is the center-of-mass momentum of the intermediate particles, W is their center-of-mass total energy, $\bar{\psi}(p_2)$ is the Rarita-Schwinger [Dirac] wave function $U_\sigma(p_2)$ [$u(p_2)$] according as D has the spin $\frac{3}{2}$[$\frac{1}{2}$], and Γ is 1 [γ_5] for Y^* spin-parity $\frac{3}{2}^+$ [$\frac{3}{2}^-$] and $\frac{1}{2}^-$ [$\frac{1}{2}^+$]. To evaluate the integral in (1), we note that the function

$$F=1/(Q_1^2+m_a^2)(Q_2^2+m_c^2) \quad (2)$$

has a pole for $Q_2^2=-t''=-m_c^2$. This arises because of

[3] The normalization factors given in the present paper, Eq. (1), are correct and determine the cross-section magnitude without any arbitrariness. We regret that there was a mistake in the normalization in our earlier papers (Refs. 1 and 2); see Phys. Rev. **180**, 1616(E) (1969).

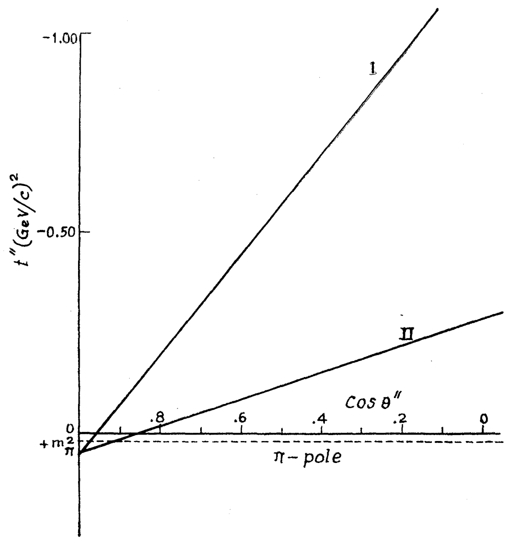

FIG. 2. Locations of the poles for the processes $\rho^0+n \to \pi^+ + N^{*-}$ (I) and $\rho^0+\Lambda \to \pi^+ + Y_1^{*-}$ (II) are shown in a plot of t'' versus $\cos\theta''$.

the fact that $t''_{\max}$, given by

$$t''_{\max} = -(1/W^2)(m_C^2-m_d^2)(m_D^2-m_b^2) - (1/W^2)(m_C^2+m_D^2-m_b^2-m_d^2) \times\left(\frac{m_C^2 m_D^2}{W^2-m_C^2-m_D^2}-\frac{m_b^2 m_d^2}{W^2-m_b^2-m_d^2}\right), \quad (3)$$

is usually negative or zero for elastic processes, but is positive for our cases, since

$$(m_C^2-m_d^2)(m_D^2-m_b^2)<0. \quad (4)$$

The situation may be compared with the pickup reactions of nuclear physics.

For the two-step process

$$A+B \to b+d \to C+D, \quad (5)$$

we are now getting a pole for the process $d+b \to C+D$. In Fig. 2, we have plotted t'' versus $\cos\theta''$ to show the position of the pole for the reactions $\rho^0+n \to \pi^+ + N^{*-}$ at $W=2.3099$ GeV and $\rho^0+\Lambda \to \pi^+ + Y_1^{*-}(1385)$ at $W=2.0067$ GeV.

To evaluate the integral in (1), we can do the ϕ' integration first and get[4]

$$T_4 = 2\int_{-1}^{+1} d\cos\theta'' \int_{z_-'}^{z_+'} d\cos\theta' [K(\cos\theta, \cos\theta', \cos\theta'')]^{-1/2} \times \frac{|\mathbf{q}'|m_b}{16\pi^2 W}\bar{\psi}(p_2)\left(\frac{p_\sigma'}{m_c}\right)^{s-1/2} \Gamma \frac{g_{Dbc}g_{Ccd}}{Q_2^2+m_c^2} i(q_2-Q_2)_\nu \times\left(\delta_{\mu\nu}+\frac{q_\mu' q_\nu'}{m_d^2}\right) i(q_1+Q_1)_\mu \frac{g_{Bba}g_{Aad}}{Q_1^2+m_a^2}\frac{-i\gamma\cdot p'+m_b}{2m_b} \times\gamma_5 u(p_1), \quad (6)$$

where

$$z_\pm' = \cos\theta\cos\theta'' \pm \sin\theta\sin\theta'',$$

$$\cos\theta'' = \hat{q}_2\cdot\hat{q}', \qquad \cos\theta = \hat{q}_1\cdot\hat{q}_2,$$

$$K(\cos\theta, \cos\theta', \cos\theta'') = 1-\cos^2\theta-\cos^2\theta'-\cos^2\theta'' + 2\cos\theta\cos\theta'\cos\theta''.$$

We perform the $\cos\theta''$ integration by the calculus of residues. The remaining integration, over $\cos\theta'$, can be done analytically by using the fact that

$$F' = \{[K(\cos\theta, \cos\theta', \cos\theta'')]^{1/2}(Q_1^2+m_a^2)\}^{-1} \quad (7)$$

is a rapidly varying function of $\cos\theta'$ and hence essentially determines the angular distribution. We substitute[5] in the rest of the integrand that value of $\cos\theta'$ for which the function F' is maximum (i.e., $\cos\theta'=1$). Equation (6) then takes the form

$$T_4 = \frac{4\pi^2 i|\mathbf{q}'|m_b}{4|\mathbf{q}_1||\mathbf{q}'|^2(-\beta)^{1/2}|\mathbf{q}_2|16_\pi{}^2 W}\bar{\psi}(p_2)\left(\frac{p_\sigma'}{m_c}\right)^{s-1/2} \times\Gamma g_{Dbc}g_{Ccd} i(q_2-Q_2)_\nu\left(\delta_{\mu\nu}+\frac{q_\mu' q_\nu'}{m_d^2}\right) i(q_1+Q_1)_\mu g_{Bba}g_{Aad} \times\frac{-i\gamma\cdot p'+m_b}{2m_b}\gamma_5 u(p_1), \quad (8)$$

where

$$\beta = 1-\cos^2\theta-\alpha_1^2-\alpha_2^2+2\alpha_1\alpha_2\cos\theta,$$

$$\alpha_1 = (2q_{10}q_0'-m_d^2)/2|\mathbf{q}_1||\mathbf{q}'|,$$

$$\alpha_2 = (2q_{20}q_0'-m_d^2)/2|\mathbf{q}_2||\mathbf{q}'|.$$

After performing the usual sum over the polarization and the spin states, we find the differential cross section to be

$$\frac{d\sigma}{d\Omega} = \frac{0.38935 m_B m_D \pi^2 g_{Dbc}^2 g_{Ccd}^2 g_{Bba}^2 g_{Aad}^2}{2048(2\pi W)^4(-\beta)|\mathbf{q}_2||\mathbf{q}'|^2|\mathbf{q}_1|^3} \times F_1F_2F_3^\pm \text{ mb/sr}, \quad (9)$$

where

$$F_1 = 16\left(q_2\cdot q_1 + \frac{q_2\cdot q' q_1\cdot q'}{m_d^2}\right)^2,$$

$$F_2 = \left[\frac{2}{3m_c^2}\left(p'^2+\frac{1}{m_D^2}(p'\cdot p_2)^2\right)\right]^{s-1/2},$$

$$F_3^\pm = \mp(2/m_B m_D)[(m_D m_b \mp p_2\cdot p')(m_B m_b + p_1\cdot p')].$$

Here F_3^+ corresponds to $J^P=\frac{3}{2}^+$, $\frac{1}{2}^-$ and F_3^- to $J^P=\frac{3}{2}^-$, $\frac{1}{2}^+$.

3. RESULTS AND DISCUSSION

Results from Eq. (9) are shown by the solid curves in Fig. 3 for N^{*-} production and in Fig. 4 for $Y_1^{*-}(1385)$

[4] A. O. Barut, *The Theory of the Scattering Matrix* (The Macmillan Co., New York, 1967), p. 99.

[5] L. Bertocchi and A. Capella, Nuovo Cimento **51A**, 369 (1967).

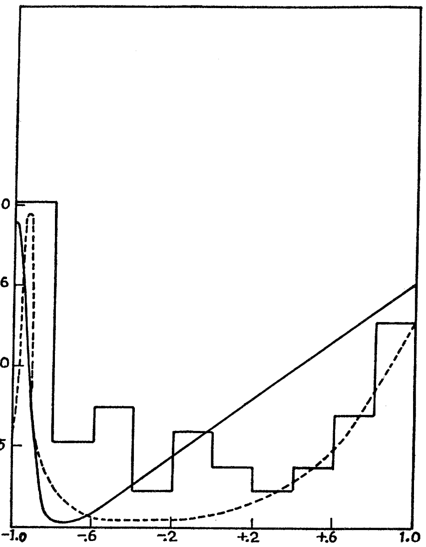

FIG. 3. Production angular distribution of the N^{*-} at a pion momentum of 2.36 GeV/c in the reaction $\pi^- + p \rightarrow \pi^+ + N^{*-}$ ($\cos\theta = \hat{N}^{*-}{}_{\text{out}} \cdot \hat{\pi}^-{}_{\text{in}}$). The present calculation from Eq. (9) is shown by the solid curve; the older calculation (Ref. 2), by the dashed curve. The histogram shows the experimental data of Huwe *et al.*, Phys. Letters **24**, 252 (1967).

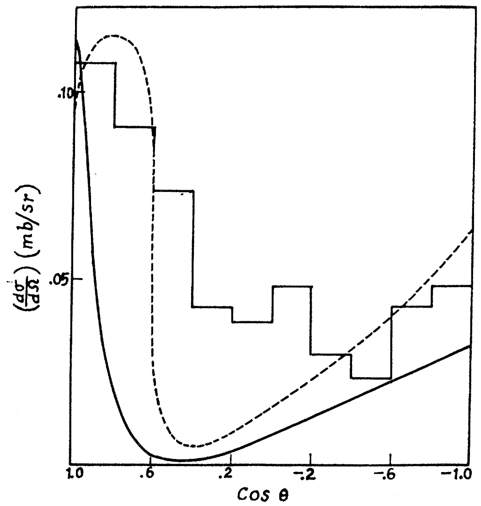

FIG. 4. Production angular distribution of Y_1^{*-} at a K^- momentum of 1.46 GeV/c in the reaction $K^- + p \rightarrow \pi^+ + Y_1^{*-}$ [$\cos\theta = \hat{Y}_1^{*-}{}_{\text{out}} \cdot \hat{p}_{\text{in}}$]. The present calculation from Eq. (9) is shown by the solid curve; the older calculation, by the dashed curve. The histogram shows the experimental data of Cooper *et al.*, in *Proceedings of the Sienna International Conference on Elementary Particles and High-Energy Physics, 1963*, edited by G. Bernardini and G. P. Puppi (Società Italiana di Fisica, Bologna, 1963), p. 160.

production. The dashed curves represent the results of our previous calculations. The main difference is that the fictitious fall in the forward direction which was present in the older calculation has disappeared. Both forward and backward peakings are still present, as required by the experiment.

In Fig. 4, the solid curve represents our prediction based on a $\frac{3}{2}^+$ spin-parity assignment for the $Y_1^*(1385)$. If we change the spin-parity assignment, Eq. (9) predicts a similar shape but different magnitudes. Thus, essentially, the curve is multiplied by a factor 2.77 for $\frac{3}{2}^-$, 1.57 for $\frac{1}{2}^+$, and 0.62 for $\frac{1}{2}^-$.

We hav eperformed the calculations for the production of $Y_0^*(1520)$ and $Y_1^*(1660)$ as well. Similar results are obtained in these cases also.

To conclude, we can say that the correct evaluation of the angular integral leaves our previous conclusions unchanged except for a slight modification in the detailed behavior in the forward direction.

ACKNOWLEDGMENT

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