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PHYSICAL REVIEW D VOLUME 4, NUMBER 7 1 OCTOBER 1971

$K^*(890)$ Production in the Charge-Exchange Reaction $K^+n \to K^+\pi^-p$ at 9 GeV/c*

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(Received 11 June 1971)

The energy dependence of the cross section for reactions $K^+n \to K^*(890)p$ and $K^-p \to K^*(890)n$ is compared over a wide range of incident momenta and found to be identical. This excludes odd C-parity exchanges in addition to the dominant π exchange. The conventional absorption model does not reproduce the rapid decrease of ρ_{00} as a function of the four-momentum transfer. The Reggeized π-A_2 model of Dass and Froggatt reproduces the t dependence of ρ_{00} and Reρ_{10}, but there is serious disagreement for ρ_{1-1} which may indicate the need to include A_1 exchange. The asymmetry in the decay angular distribution is interpreted as S-P wave interference.

I. INTRODUCTION

In this paper we present results from our analysis of the charge-exchange reaction

$$K^+n \to K^+\pi^-p \tag{1}$$

at 9 GeV/c. We obtained 4030 events of this type from approximately 280 000 pictures, taken in the Brookhaven 80-in. deuterium-filled bubble chamber exposed to an rf separated beam. This corresponds to a microbarn equivalent of 8 events/μb. For the subsequent analysis we use 3882 events since on part of the film, we measured only events with a recoil momentum less than 1 Gev/c.

The most dominantly produced meson resonances are the $K^*(890)$ and $K^*(1420)$, as can be seen in

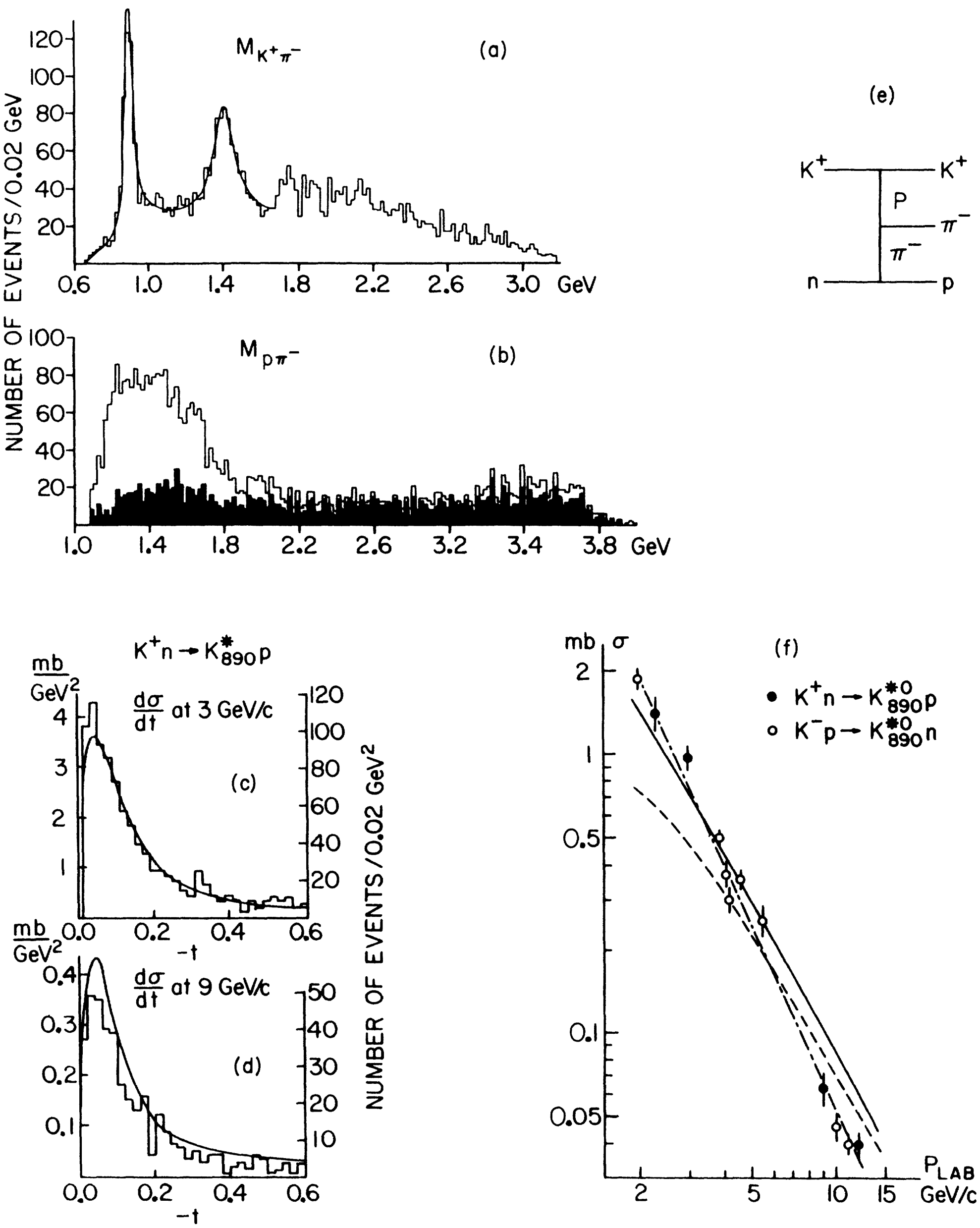

FIG. 1. (a) $K^+\pi^-$ mass distribution fitted with a superposition of two Breit-Wigner distributions and a smooth hand-drawn background for masses below 1.66 GeV. (b) $p\pi^-$ mass distribution for all events and, shaded, for events with $M_{K^+\pi^-} < 1.5$ GeV. (c) and (d) $d\sigma/dt$ for $K^+n \rightarrow K^*(890)p$ for 3 and 9 GeV/c, respectively (1116 and 435 events, respectively). The curves are absolute predictions of the absorption model of Jackson *et al.* (Ref. 2). (e) Double-Regge diagram including Pomeranchukon and pion exchange. (f) Total cross sections for reaction $K^+n \rightarrow K^*(890)p$ (full circles) at 2.3 GeV/c [Ref. 4(a)], 3.0 GeV/c [Ref. 4(b)], 9.0 GeV/c (this expt.), 12.0 GeV/c [Ref. 4(c)]; and reaction $K^-p \rightarrow \bar{K}^*(890)n$ (open circles) at 2.0 GeV/c [Ref. 5(a)], 3.9 GeV/c [Ref. 5(b)], 4.1 GeV/c [Ref. 5(c)], 4.2 GeV/c [Ref. 5(d)], 4.6 GeV/c [Ref. 5(b)], 5.5 GeV/c [Ref. 5(c)], 10.0 GeV/c [Ref. 5(e)], 11.2 GeV/c [Ref. 5(f)]. The full and dashed lines are the predictions of the absorption model for the first and second reaction, respectively. The dash-dotted line is the fitted function $\sigma(P) = 9.2(P_{\rm lab}/P_0)^{-2.24}$.

Fig. 1(a). The $K\pi$ mass distribution in Fig. 1(a) was fitted with a superposition of two Breit-Wigner distributions and a smooth, hand-drawn background, achieving a confidence level of 84%. The fit gave masses of 893 ± 2 and 1416 ± 6 MeV, widths of 53 ± 7 and 144 ± 22 MeV, and cross sections of 63 ± 10 and 77 ± 12 μb for the $K^*(890)$ and $K^*(1420)$, respectively. The cross sections contain a 5% correction due to the Glauber screening and the Pauli principle, but no corrections for unseen decay modes. Figure 1(b) shows the $p\pi^-$ mass distribution (unshaded for all events). From the shaded $p\pi$ mass distribution in Fig. 1(b) ($M_{K\pi} < 1.5$ GeV), it seems likely that baryon resonances, if present, constitute only a small background under the K^* peaks.

II. $K^*(890)$ PRODUCTION IN CHARGE-EXCHANGE REACTIONS

The production mechanism of $K^*(890)$ can be studied by investigating the energy dependence of the charge-exchange reactions

$$K^+n \to K^{*0}(890)p \qquad (2)$$

$$K^-p \to \overline{K}^{*0}(890)p \qquad (3)$$

and by analyzing their decay angular distributions.

A. Energy Dependence

We have compared the predictions of the absorption model[1,2] with the $K^*(890)$ data. The absorption-model predictions were calculated within the formalism given by Jackson and collaborators[1,2] using basically their prescription for selecting the parameters.[3] The absorption parameters vary with the type of reaction and with energy. Figures 1(c) and 1(d) show the differential cross sections for the 3-GeV/c CERN data[4(b)] of reaction (2) and our data at 9 GeV/c for the same reaction. Events with a $K\pi$ mass between 0.84 and 0.94 GeV have been selected. Not only the shape of the t distributions is reproduced correctly, but also the change in the cross section by an order of magnitude is accounted for. The energy dependence of both charge-exchange reactions (2) and (3) is further illustrated in Fig. 1(f), where we present a compilation[4,5] of cross sections for various incident momenta (uncorrected for unseen decay modes). The full and dashed curves are the absorption-corrected π-exchange calculations for reactions (2) and (3), respectively. Since the total cross section is higher for K^-p than for K^+n collisions, the absorption effect is stronger for reaction (3), and consequently the predictions for reaction (3) in Fig. 1(f) (dashed line) lie below the predictions for reaction (2) (solid line). However, for incident momenta above 5 GeV/c, this effect is of the order of or smaller than the errors in the experimental cross sections. We observe a rough agreement between the experimental data and the model calculations. This agreement leads us to conclude that π exchange is the main characteristic of the production mechanism for reactions (2) and (3).

The decrease of the absorption-model-predicted cross section with increasing incident momentum is slower than $P_{\rm lab}^{-2}$, expected for unmodified π exchange. The data show, on the contrary, a somewhat faster decrease than $P_{\rm lab}^{-2}$, and consequently support a Reggeized parametrization for π exchange. Since there is no apparent distinction in the behavior of reactions (2) and (3), we fitted all experimental cross sections in Fig. 1(f) with the function $\sigma = A(P_{\rm lab}/P_0)^{-n}$, where $P_0 = 1$ GeV/c. Assuming 15% experimental errors in all cases, the fit gave $A = 9.2 \pm 0.8$ mb and $n = 2.24 \pm 0.15$ with a confidence level of 46% [see dash-dotted line in Fig. 1(f)]. The observation that the cross sections for reactions (2) and (3) are equal within the present experimental errors, excludes any major contribution from odd C-parity exchanges, like ρ exchange, in a model-independent way.[6]

B. Production Density Matrix

For the $K^*(890)$ with spin-parity 1^-, the decay angular distribution is determined by the production density matrix. The density-matrix elements have been calculated in the Jackson frame using the method of moments. Events were taken having a $K\pi$ effective mass between 0.84 and 0.94 GeV. In Fig. 2 the density-matrix elements are presented as a function of the momentum transfer squared, $-t$, and compared to the absorption-model calculations, discussed in Sec. II A (solid line). The experimental values for ρ_{00} decrease much faster than the absorption-model prediction and show a peak rather than a dip for small momentum transfers. The agreement for ${\rm Re}\rho_{10}$ is fair, and again some disagreement is observed for ρ_{1-1} at $|t|$ values above 0.1 GeV^2.

In addition, these density-matrix elements have been compared to the Reggeized π-exchange calculations of Dass and Froggatt,[7] who include A_2 exchange as well. The dashed and dash-dotted curves in Fig. 2 represent the evasive and conspiratorial solutions, respectively. The t dependence of ρ_{00} is much better reproduced by these Regge-model calculations than by the absorption model, and the agreement for ${\rm Re}\rho_{10}$ is comparable in both cases. Judging from the peaking of the experimental ρ_{00} distribution at small momentum transfers and from the zero value for the experimental ${\rm Re}\rho_{10}$ point in the lowest bin, the evasive solution seems to be slightly preferred.[8] But such a distinction is far from being definite at the present stage of experimental accuracy.

There is a surprisingly large discrepancy for ρ_{1-1} between the Regge-model calculations and the data, in particular, for $|t|$ values above 0.2 GeV^2. The fact that the experimental values of ρ_{1-1} are compatible with zero over the t range considered, implies that natural- and unnatural-parity exchanges, contributing to the production of helicity-1 states, have to occur in equal amounts.[9] Therefore, this discrepancy may give a hint that in addition to A_2 exchange, some unnatural parity exchanged with spin equal to or larger than 1 has to be included. A_1 exchange may be a suitable choice.[10] This point should be the subject of further investigation.

III. INTERFERENCE TERMS IN THE $K^*(890)$ DECAY CORRELATIONS

After having discussed the production mechanism of the $K^*(890)$, one can turn to the detailed structure of the decay angular distribution. Both models discussed in Sec. II predict a symmetric decay angular distribution. But this symmetry is not observed experimentally, as has been reported earlier.[4(a),4(b)] In Fig. 3 we present the Jackson and Treiman-Yang angular distributions of the $K\pi$ system in reaction (1) for the $K^*(890)$ region and for two adjacent control regions. The distributions in the $K^*(890)$ region show a strong forward peaking in $\cos\theta_{K\pi}$ and a strong deviation from isotropy in $\phi_{K\pi}$. A tentative explanation of this behavior would be a double-Regge mechanism consisting of Pomeranchuk and π exchange as illustrated by the diagram in Fig. 1(e). According to a conjecture of Harari,[11] this diagram may provide a general-type background for the $K\pi$ system. Calculations along this line performed by Fu,[12] for the reaction $K^+p \to K^+\pi^-\Delta^{++}(1236)$ at 9 GeV/c, show that a distinctive feature of this type of background is a forward peaking in the Jackson-angle distribution and an anisotropic Treiman-Yang angle distribution.

Just these characteristics are observed in the $K^*(890)$ region. But to be sure about the origin of these effects one has to look at adjacent control regions as well. The lower region has only few events and the upper control region shows a backward peaking in $\cos\theta_{K\pi}$ and isotropy in $\phi_{K\pi}$, just the opposite expected from the double-Regge exchange. One might still argue that constructive interference changes to destructive interference as the mass of the $K\pi$ system increases. But it is hard to see how the strong anisotropy in $\phi_{K\pi}$ should vanish at higher $K\pi$ masses, where the double-Regge exchange is thought to become increasingly important. We therefore rule out the interference of $K^*(890)$ production with the double-Regge mechanism as very unlikely.

In fact, the double-Regge-type background is

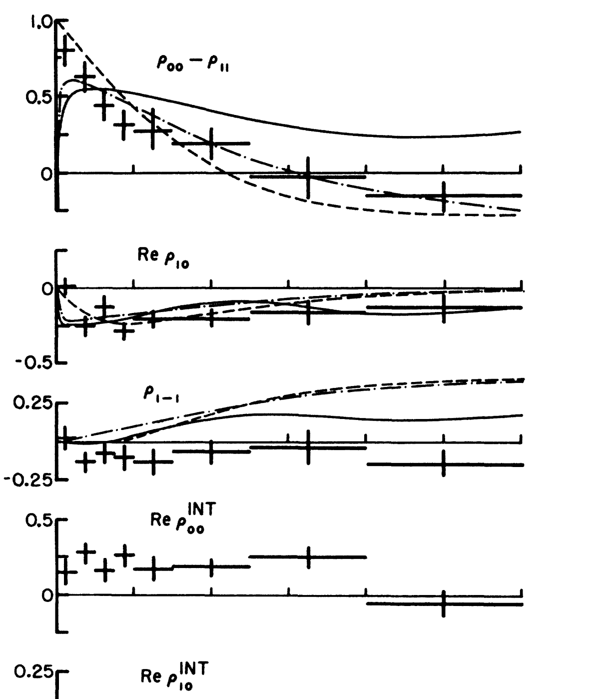

FIG. 2. Density-matrix elements for $K^+n \to K^*(890)p$ at 9 GeV/c. The full curves are absorption-model predictions of Jackson *et al.* (Ref. 2). The dashed and dash-dotted curves are Regge-model predictions of Dass and Froggatt representing the evasive and conspiratorial solutions, respectively. The S-wave interference, represented by $\mathrm{Re}\rho_{00}^{\mathrm{int}}$ and $\mathrm{Re}\rho_{10}^{\mathrm{int}}$, is not taken into account by the model calculations.

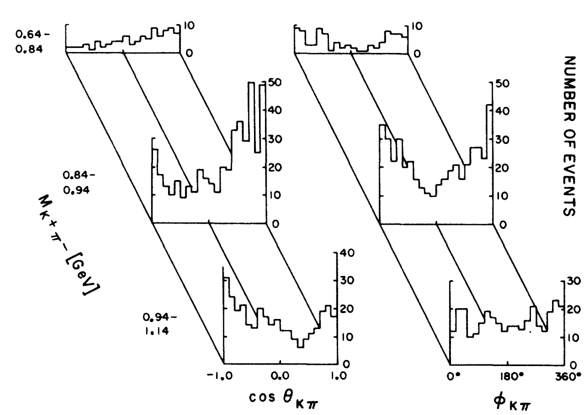

FIG. 3. Jackson and Treiman-Yang angular distributions in the $K^*(890)$ region and in two control regions.

probably negligible in the $K\pi$ mass range below 1.5 GeV. In Fig. 1(b) the $p\pi$ mass distribution for events with $M_{K\pi} \leq 1.5$ GeV is shown as the shaded histogram. No excessive low-$p\pi$-mass enhancement, characteristic of double-Regge exchange, is observed in the shaded histogram. This mechanism may be of some minor importance in the $K^*(1420)$ region and certainly dominates for $K\pi$ masses above 2 GeV.

In order to explain the asymmetry in the $K^*(890)$ decay angular distribution, we turn to the traditional approach assuming an interference of the P wave with an S-wave background. We use a parametrization of this interference applied earlier to ρ^0 production[13] in $\pi^- p \to \rho^0 n$ and $K^*(890)$ production in reaction (3).[5(b)] In addition to the density-matrix elements in Sec. II, $\mathrm{Re}\rho_{00}^{\mathrm{int}}$ and $\mathrm{Re}\rho_{10}^{\mathrm{int}}$ are introduced; they represent the interference terms between S and P waves. Since $\mathrm{Re}\rho_{00}^{\mathrm{int}}$ is the coefficient of the $\cos\theta$ term in the angular distribution, it accounts for the asymmetry in the Jackson-angle distribution. Similarly, $\mathrm{Re}\rho_{10}^{\mathrm{int}}$ accounts for part of the anisotropy in $\phi_{K\pi}$. In Fig. 2 we present in addition to the density-matrix elements, discussed in Sec. II, the S-P-wave-interference density-matrix elements. The interference terms are definitely different from zero in the $|t|$ range from 0–0.4 GeV^2 and do not show strong variation.

IV. CONCLUSIONS

We want to conclude with the remark that the energy dependence of reactions (2) and (3) by itself does not establish π exchange as the exclusive production mechanism. The observation that within experimental errors the energy dependence is identical for both reactions excludes contributions from odd C-parity exchanges. The conventional π-exchange model with absorption does not reproduce the rapid decrease of ρ_{00} as a function of the four-momentum transfer. The Reggeized π-A_2 model of Dass and Froggatt reproduces the t dependence of ρ_{00} and ρ_{10}, but there is serious disagreement for ρ_{1-1}. When A_2 exchange is included we see the need for additional unnatural-parity exchange, like A_1 exchange, since ρ_{1-1} is zero experimentally. The asymmetry in the decay angular distribution is interpreted as S-P wave interference.

ACKNOWLEDGMENTS

We wish to thank the physicists and technicians at Brookhaven National Laboratory for their assistance during the exposure. We also thank Professor L. J. Gutay for helpful discussions, in particular for pointing out the implication of ρ_{1-1} being zero experimentally.

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*Work supported in part by the U. S. Atomic Energy Commission.

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$$\frac{g_{K^{*0}K^+\pi^-}{}^2}{4\pi} = 1.5\ \mathrm{GeV}^{-2}, \quad \frac{g_{np\pi^-}{}^2}{4\pi} = 29.2\ \mathrm{GeV}^{-2}.$$

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