yield at this angle is proportional to $B^{1/2}$, while the yield at 3.5° varies more slowly than $B^{1/2}$.

To summarize, we have reported the initial results of a beam survey of photoproduced K_L mesons. Total yields of 1.3×10^{-5} K^0/electron sr for $1.0<p_K<5.5$ GeV/c were obtained with $E_0=5.5$ GeV at 3.5° from a one-radiation-length aluminum target with an extremely clean beam which appears quite free of neutrons.[8] If we associate the peak in our difference spectrum with the decay of photoproduced φ mesons into K_SK_L, we obtain yields which are in agreement with those predicted from previously published DESY bubble-chamber results. If we use the upper limit of 0.46 μb obtained from the subtracted spectrum, it is possible to account for 84 % of the yield from the unsubtracted spectrum at $E_0=5.5$ GeV.

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†National Science Foundation Graduate Fellow.

‡Alfred P. Sloan Foundation Fellow.

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[5]S. D. Drell and M. Jacob, Phys. Rev. 138, B1312 (1965).

[6]German Bubble-Chamber Collaboration, reported at the International Conference on Electron and Photon Interactions at High Energies, Stanford, California, 1967 (to be published).

[7]This value of B is consistent with the observed angular distribution of charged K mesons from the φ in the DESY bubble chamber. (See Ref. 1.)

[8]Rough estimates from our data indicate that neutrons are fewer than several times the number of K_L, and there is no positive evidence for neutron background.

DIPS IN THE ω-EXCHANGE CONTRIBUTION TO $\pi N\to\rho N$

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In this note we consider a specific combination of the differential cross sections for $\pi^\pm p\to\rho^\pm p$ $(d\sigma_\pm/dt)$ and $\pi^-p\to\rho^0n$ $(d\sigma_0/dt)$ which, at high energy, isolates the contribution of the ω Regge trajectory. Usual Reggeization rules and Mandelstam analyticity requirements predict that this combination should exhibit pronounced dips at $t\simeq-0.5$ (GeV/c)^2 and $t\simeq0$. Analysis of the existing data at pion incident laboratory momentum $p_0=4$ and 8 GeV/c is found to support these predictions.

To begin with, let $T_\pm$ denote the amplitudes for $\pi^\pm p\to\rho^\pm p$ and T_0 the amplitude for $\pi^-p\to\rho^0n$. Then the following relation, due to the existence of only two isospin states $(I=\frac{3}{2},\frac{1}{2})$, is well known:

$$T_0=2^{-1/2}(T_+-T_-). \quad (1)$$

Next, at high energy, consider an analysis of

$T_\pm$ in terms of t-channel Regge-pole exchanges. Among the established trajectories only π, ω, A_1, and A_2 can be exchanged (adopting $J_{A_1}{}^{PJ}=1^{+-}$, $J_{A_2}{}^{PG}=2^{+-}$). If T_π denotes the contribution of the π Regge exchange, etc. $\cdots$, one has

$$T_\pm = \pm T_\pi + T_\omega \pm T_{A_1} \pm T_{A_2}. \tag{2}$$

The difference in the signs is due to the charge-conjugation quantum number C, which is $C=+1$ for π, A_1, and A_2 but $C=-1$ for ω (and ρ). From (1) and (2) one finds

$$|T_\omega|^2 = \tfrac{1}{2}(|T_+|^2 + |T_-|^2 - |T_0|^2). \tag{3}$$

Clearly, with this relation one can express the ω-exchange contribution in terms of the linear combination of differential cross sections[1]

$$X(s,t) = \frac{d\sigma_+}{dt} + \frac{d\sigma_-}{dt} - \frac{d\sigma_0}{dt}. \tag{4}$$

Then a number of observations and predictions can be made:

(A) Direct determination of the ω trajectory: At high energy $X(s,t)$ can be parametrized in terms of $\alpha_\omega(t)$ according to

$$X(s,t) = F(t)(s/s_0)^{2\alpha_\omega(t)-2}; \tag{5}$$

as usual, s_0 is a fixed constant with dimensions of mass squared. For two different values s_1 and s_2 one has

$$\frac{X(s_1,t)}{X(s_2,t)} = \left(\frac{s_1}{s_2}\right)^{2\alpha_\omega(t)-2}, \tag{6}$$

which allows a direct determination of $\alpha_\omega(t)$ at $t<0$ in terms of the experimentally measurable $X(s,t)$. The existing data do not allow, at present, an accurate determination; however, an ω trajectory roughly parallel to the ρ,

$$\alpha_\omega(t) \simeq 0.45 + 0.9t, \tag{7}$$

which is suggested by well-known arguments on the universality of slopes of Regge trajectories,[2] is consistent with an analysis of these data.[3] The form (7) is also in accord with a number of phenomenological analyses of nucleon-nucleon elastic scattering and pion photoproduction.

(B) Dip at $t \simeq -0.5$ (GeV/c)^2. Because of its spin and parity, the ω can couple to the $\pi\rho$ system only if the helicity of ρ is 1; thus, the ω-exchange contribution to $T_\pm$ is described by the following two (parity-conserving) combinations of helicity amplitudes:

$$F_+(s,t) = (\sin\theta_t)^{-1}[F_{10;\frac12\frac12}(s,t) + F_{-10;\frac12\frac12}(s,t)], \tag{8a}$$

$$F_-(s,t) = [\cos(\tfrac12\theta_t)]^{-2}F_{10;\frac12-\frac12}(s,t) - [\sin(\tfrac12\theta_t)]^{-2}F_{-10;\frac12-\frac12}(s,t). \tag{8b}$$

Here we use the notation $F_{\lambda_\rho\lambda_\pi;\lambda_N\lambda_{\bar N}}$ for the t-channel helicity states; θ_t is the scattering angle in the t-channel center-of-mass system. Standard rules of Reggeization lead to the following forms[4]:

$$F_+(s,t) = b_+\alpha\frac{1-e^{-i\pi\alpha}}{\sin\pi\alpha}\left(\frac{s}{s_0}\right)^{\alpha-1},$$

$$F_-(s,t) = b_-\alpha^2\frac{1-e^{-i\pi\alpha}}{\sin\pi\alpha}\left(\frac{s}{s_0}\right)^{\alpha-1}, \tag{9}$$

where $\alpha \equiv \alpha_\omega(t)$ and the functions $b_\pm = b_\pm(t)$ are smooth in the region[5] $t \simeq -0.5$ (GeV/c)^2. The presence of factors α and α^2 follows from the fact that the value $\alpha=0$ corresponds to a sense-nonsense transition for F_+ and to a nonsense-nonsense transition for F_-.[6] We conclude that at the value of t for which $\alpha(t)=0$, both $F_\pm$ vanish and lead to a pronounced dip in $X(s,t)$. From Eq. (7) we expect the dip to occur at $t\simeq -0.5$ (GeV/c)^2.

This prediction has been tested at $p_0 = 4$ GeV/c, where sufficient experimental information is available. Our analysis, presented in Fig. 1(a), does support the existence of a dip in the correct place.

Similar predictions hold for the process $\pi^\pm p \to \rho^\pm N^{*+}$ and $\pi^- p \to \rho^0 N^{*0}$, where N^* is an isobar with $I=\frac12$.

Note that, contrary to certain theoretical predictions, no similar dip is observed in $\pi^+ p \to \omega N^{*++}$ at $p_0 = 3.5$ and 8 GeV/c.[7] One possible explanation is that, apart from ρ exchange, the contribution of the B trajectory ($J_B{}^{PG}=1^{++}$) to $\pi^+ p \to \omega N^{*++}$ is important. Such a B meson, if established, is also expected to affect the dip predicted in $\pi^- p \to \omega n$ (Ref. 4); however, it does not contribute to the processes $\pi N \to \rho N$ and $\pi N \to \rho N^*$.

(C) Dip near the forward direction. Consider a decomposition of each of the amplitudes $T_\pm$ into the Mandelstam invariants $A_\pm{}^{(i)}(s,t)$ (for $\pi N \to \rho N$, $i = 1, 2, \cdots, 6$). From Eq. (2) it

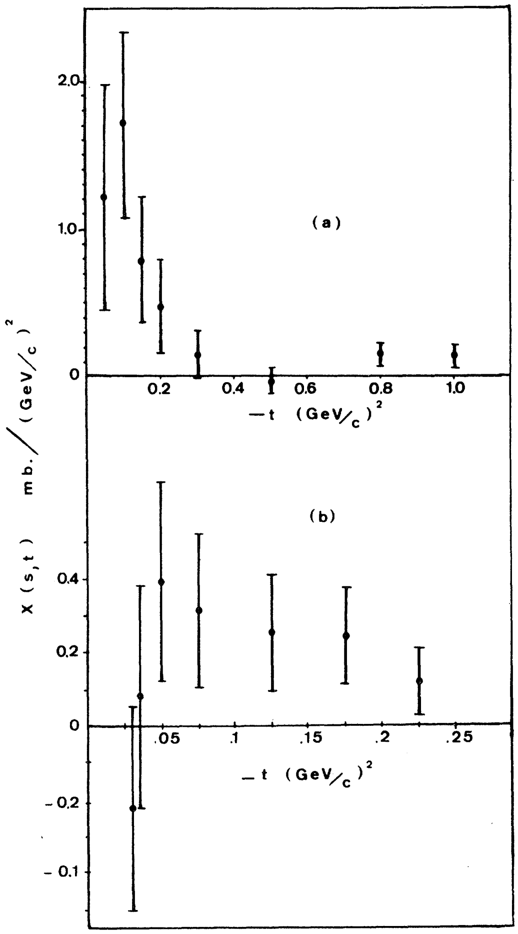

FIG. 1. Variation of $X(s,t) = d\sigma_+/dt + d\sigma_-/dt - d\sigma_0/dt$ as a function of t (a) at $p_0 = 4$ GeV/c and (b) at $p_0 = 8$ GeV/c. Data taken as in Ref. 3.

is clear that at high energy the sums $A_+^{(i)} + A_-^{(i)}$ receive contributions only from ω exchange. Then it can be shown[8] that the requirement that $A_\pm^{(i)}(s,t)$ be analytic at $t=0$ implies

$$F_-(s,t) \sim t^{1/2} \text{ (near } t=0). \qquad (10)$$

Hence, the contribution of the corresponding term to $|T_\omega|^2$ or to $X(s,t)$ contains a factor proportional to $|t|$.[9]

On the other hand, the contribution of F_+ to $X(s,t)$ is multiplied by a factor $\sin^2\theta_t$ (Ref. 9), which vanishes for $\theta_s = 0$ (i.e., forward scattering in the s channel). Because $m_\pi \neq m_\rho$, $\theta_s = 0$ corresponds to $t = t_{\min} < 0$. However, at $p_0 = 4$ GeV/c we find $t_{\min} = -5.5\times10^{-3}$ (GeV/c)^2; and at 8 GeV/c, $t_{\min} = -1.5\times10^{-3}$. We conclude that as $t \to t_{\min}$, $X(s,t)$ is expected to have a dip.

Now, the existing data at 8 GeV/c can be used to test this prediction; and our analysis [Fig. 1(b)] is in agreement with it. The data analysis at 4 GeV/c [Fig. 1(a)] is also consistent with $X(s,t)$ decreasing near $t=0$. However, at both 8 and 4 GeV/c improved statistics are clearly desirable.

(D) Implications on the analysis of the crossover effect. In certain phenomenological analyses the fact that, at a fixed energy, the differential cross sections for $pp\to pp$ and $p\bar{p}\to p\bar{p}$ cross at $t = t_0 \simeq -0.15$ (GeV/c)^2 (crossover effect) is attributed to a sign change of the ω contribution[10]; in these analyses all the ω residue functions contain factors vanishing at $t = t_0$. Then, by means of the factorization theorem, one should expect a dip in $X(s, t=t_0)$, as well.

Figure 1 gives no evidence for such a dip, either at 4 or at 8 GeV/c. If our conclusion is strengthened by further experimental information, the aforementioned analysis of the crossover will have to be reconsidered.

To conclude, it is desirable that the remarks and predictions of the present note be tested by improved experimental data, including also information at higher energy.

Useful discussions with Dr. L. Bertocchi, in particular concerning the prediction (C), and with Dr. K. Moriyasu are gratefully acknowledged. Two of us (A.P.C. and H.J.L.) are indebted to Professor Ph. Meyer and Professor A. Lagarrigue, respectively, for the hospitality extended to them at Orsay.

[1]This combination corresponds to the $I=0$ exchange contribution.

[2]G. F. Chew and S. C. Frautschi, Phys. Rev. Letters 8, 41 (1962).

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[4]Ling-Lie Wang, Phys. Rev. Letters 16, 756 (1966).

[5]Effects due to the presence of a third double-spec-

tral function are assumed to be negligible [see S. Mandelstam and Ling-Lie Wang, Phys. Rev. 160, 1490 (1967)].

[6]It is assumed that the ω couples to the sense-sense channels at $\alpha = 0$.

[7]D. R. O. Morrison, presented in the Proceedings of the International Conference on Elementary Particles, Heidelberg, Germany, 1967 (to be published).

[8]B. Diu and M. Le Bellac, to be published.

[9]The combination $X(s,t)$ can be written in a form identical to that of Eq. (14) of Ref. 4. This form contains correctly a factor $|t|$ in the contribution of F_-. The presence of this factor can also be concluded by means of the factorization theorem (Ling-Lie Wang, private communication quoted in Ref. 8).

[10]W. Rarita et al., University of California Radiation Laboratory Report No. UCRL-17523 (unpublished). This contains also further references.

EVIDENCE FOR A_1^0 PRODUCTION IN K^-p INTERACTIONS AT 4.6 AND 5.0 BeV/c*

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The A_1 effect has been reported previously only in the $I_3 = \pm 1$ states[1-12] decaying by $\rho^0\pi^\pm$. In those reactions in which it has been seen (mainly of the type $\pi N \rightarrow \pi\pi\pi N$ above 2.5 BeV/c), it is characteristically associated with events exhibiting very low four-momentum transfer from the target to the final-state proton. In reactions of this type at high momenta, the background contribution of the Deck effect[13-15] must be considered. In some cases the $\rho^0\pi^\pm$ mass distribution appears to require an additional resonance structure near 1080 MeV superposed on the Deck background. In other situations the Deck effect alone (possibly requiring both π and ρ exchange[16]) seems adequate to fit the data.

Evidence is presented in this report for the observation of a $\rho^\pm\pi^\mp$ enhancement at 1060 ± 15 MeV with a width of 120 ± 15 MeV in the reaction $K^-p \rightarrow K^-\pi^-\pi^+p\pi^0$ at incident K^- momenta of 4.6 and 5.0 BeV/c. This is interpreted as the A_1^0 on the basis of mass, width, and decay modes. Also, the experimentally determined spin and parity for this effect are consistent with previous investigations of the charged A_1.

Approximately 5800 measured four-prong events from 60 000 frames of K^- interactions in hydrogen in the Brookhaven National Laboratory 80-inch bubble chamber were processed to obtain a 1305-event sample for the reaction

$$K^-p \rightarrow K^-\pi^-\pi^+p\pi^0.$$

Kinematic fits to all constrained final states were tried. Events included in the sample were required to have an ionization-consistent fit to this reaction hypothesis with $\chi^2 < 5.0$. A 5-to-1 χ^2 probability ratio was used to choose among multiple fits satisfying the above criteria. Remaining ambiguous fits were included in the sample; however, comparison with a sample of unique fits indicates that possible contamination from incorrectly assigned fits does not affect the results presented here. Restrictions on missing mass and beam particle parameters were also imposed. The contamination from all sources is estimated at less than 18%.[17] The cross section for this reaction is 0.7 ± 0.1 mb.

In its general features this final state is rather complicated. There are strong signals for N^{*++} (15 ± 4%) and $\bar{K}^{*0}$ (22 ± 4%). Also, K^{*-} (9 ± 3%), N^{*+} (7 ± 2%), ρ^- (5.5 ± 2%), and ρ^+ (8 ± 3%) are evident. The gross $\pi^+\pi^-\pi^0$ distribution [Fig. 1(a)] indicates strong ω^0 production (17 ± 4%), some η^0 (3 ± 1.5%), and, of specific interest in this report, an enhancement in the region of 1060 MeV. This latter effect is not accounted for by the appropriate 3π phase space. Possible distortion in the background due to kinematic reflection of strong resonance production in other channels, specifically $K^-\pi^+$ and $p\pi^+$, has been examined by displaying the $\pi^+\pi^-\pi^0$ distribution for Monte-Carlo-generated phase-space events weighted on the experimental $K^-\pi^+$ and $p\pi^+$ mass distributions. In the case of the 3π spectrum there is no significant difference between the weighted and un-