Symmetric π^- Production from $K^+ + p \rightarrow \pi^- +$ Anything at 12 GeV/c*

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The longitudinal momentum distribution of π^- meson from the reaction $K^+ + p \rightarrow \pi^- +$ anything at 11.8 GeV/c is examined in various reference frames. A forward-backward symmetry is found in that frame corresponding to a simple quark model. The frame of symmetry is dependent on the charged-particle multiplicity, however, which reduces the appeal of that model in explaining the present data.

Much thought is being devoted these days toward the search for a "correct" reference frame in which to view the interactions of hadrons. The "limiting-fragmentation" model, "parton" model, and so on, all involve the choice of a reference frame wherein to display best the eseential features of the model or to attempt to simplify the characteristics of the interaction in order to aid our limited intuition as we try to perceive what nature is actually doing in strong interactions.

We are probably not amiss, then, in reporting on reference frames that display forward-backward symmetry in the distribution of longitudinal momentum P_L of *produced* particles. Although such symmetry carries no *guarantee* of relevance, attempts to explain such symmetry *may* lead to instructive new models of the interaction. Furthermore, the more general the symmetry is with respect to the various kinds of strong interactions, the more likely it is to have some relevance, and the symmetry discussed here is found to exist in both K^+p and π^-p interactions and at quite different energies.[1]

The events discussed here were produced in the Stanford Linear Accelerator Center 82-in. hydrogen bubble chamber during an exposure to 11.8-GeV/c K^+ mesons. The events examined in this study constitute about 9.5% of the total exposure and correspond to 2.8 ± 0.2 events per microbarn. They yielded almost 30 000 negative pions.

In studying the reaction

$$K^+ + p \rightarrow \pi^- + \text{anything}, \tag{1}$$

we examined all four-, six-, and eight-prong events. Two-prong events cannot produce a negative particle, and events with ten or more prongs constitute only ~0.5% of the total cross section. Therefore we do not feel that these omissions introduce a significant bias. No kinematic fitting was done on any events, and events both with and without associated "vees" were used. The measured momentum of each negative track was used, and every negative track was assumed to be a pion. The K^- and antiproton contamination introduced by this procedure is probably about 1%.[2]

Reaction (1) is particularly well suited to a study of *produced* particles since (i) the production of negative particles ($K^-, \bar{p}$) other than pions is small, making the purity of the π^- sample rather good; and (ii) neither of the incident particles (K^+, p) can be mistaken for the produced pions, so all pion distributions are relatively free from "leading-particle" effects.[3] Such effects are known to produce asymmetries in the longitudinal-momentum distribution since each incident particle has a unique and large momentum that seems to carry over to the final state.

Turning now to the data, we show in Fig. 1 the center-of-mass longitudinal-momentum distribu-

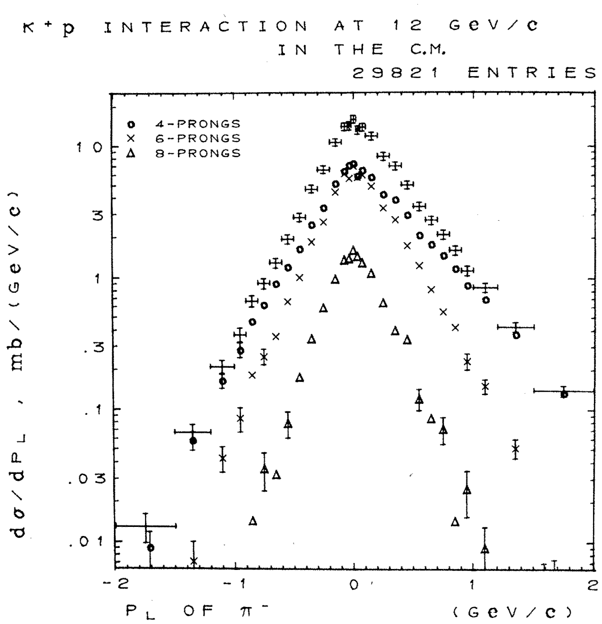

FIG. 1. The differential cross section for π^- production as a function of P_L, the longitudinal momentum in the center of mass. The distributions for events with four, six, and eight prongs are shown separately as well as their sum.

tion of all negative pions, summed over all values of transverse momentum. Each prong multiplicity is shown separately as well as their sum. We speak here of the usual overall center of mass, where the target momentum $\vec{P}_p$ is equal and opposite to the projectile momentum $\vec{P}_K$. This semilogarithmic plot demonstrates that the distribution follows a simple exponential form rather well, even all the way out to the kinematic limits of P_L. The exponential slope parameter thus provides a convenient measure of the distribution's shape. We have found that the P_L distribution (summed over P_T) can approximately be described by a simple exponential in any of the frames to which we have transformed, therefore we will describe asymmetries by comparing the values of the forward and backward slope parameters.

The distribution in Fig. 1 exhibits forward-backward asymmetry, the forward slope parameter being 2.9 ± 0.3 $(\text{GeV}/c)^{-1}$ and the backward one 4.4 ± 0.4 $(\text{GeV}/c)^{-1}$. The values were obtained from a fit of the form

$$d\sigma/dP_L = \begin{cases} ce^{-aP_L}, & P_L > 0 \\ ce^{bP_L}, & P_L < 0 \end{cases}. \tag{2}$$

We have made fits of this form to the longitudinal-momentum distribution as seen in a number of reference frames boosted from the laboratory frame with the velocity $\beta = 11.8 \times (11.8 + 0.9383 P_K/P_p)^{-1}$. The coefficients a and b are shown in Fig. 2, for each of the reference frames. These distributions are labeled "SUM" in the figure. The frames are identified by the ratio P_p/P_K, the ratio of the incident proton momentum to the incident kaon momentum. The value -1.0 identifies the overall center of mass. We see that a and b become equal when $P_p/P_K = 1.55 \pm 0.15$. This value is very near to the value -1.5 that would apply to a quark-quark center of mass, assuming all quarks to have the same effective mass. The effect would be more suggestive if all quarks in the K^+ and p were *identical,* for then a quark-quark interaction would be *required* to be symmetric in the center of mass of the two quarks. Nevertheless, the quark model has had success[4] in relating πN and NN cross sections by comparing them at equivalent total energies in the quark-quark system as defined above, so any symmetries in that frame are worthy of notice.

The longitudinal-momentum distribution obtained by a boost to the q-q system ($P_p/P_K = -1.50$) is shown in Fig. 3. The distribution is quite nicely symmetric. A fit of the form (2) gives al-

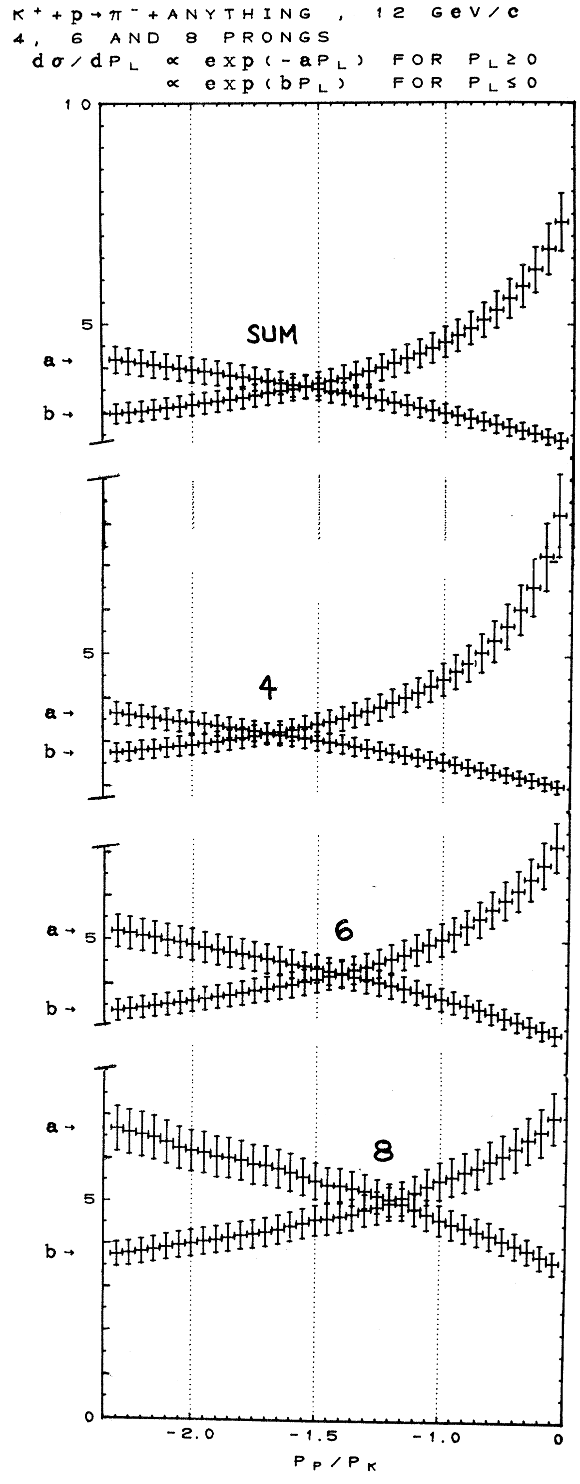

FIG. 2. The coefficients a and b in various rest frames. The rest frames are identified by the value of P_p/P_K. The coefficients are obtained from a fit to $d\sigma/dP_L \propto \exp(-aP_L)$ and $\exp(bP_L)$ for $P_L > 0$ and $P_L < 0$, respectively. The values obtained using only four-, six-, or eight-prong events are shown separately as well as those obtained using all the events together.

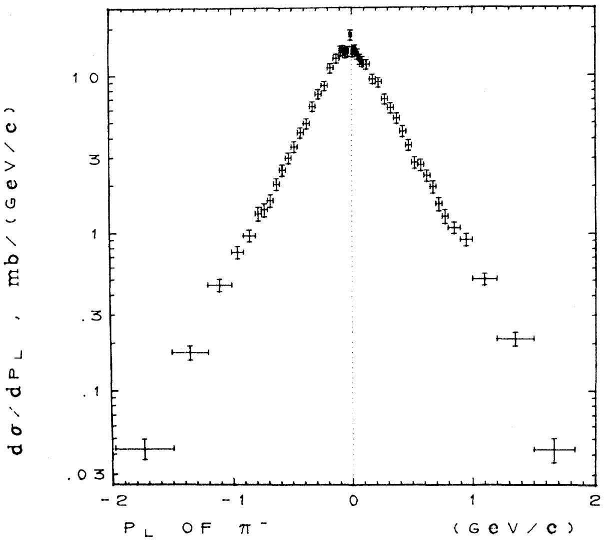

FIG. 3. Same as Fig. 1 for all the events, but in the rest frame where $P_p/P_K = -1.5$.

most equal slope parameters, namely 3.6 (GeV/c)$^{-1}$.

The effect persists at any value of P_T, the transverse momentum of the pion, as can be seen in Fig. 4, where the slopes are plotted for events with selected values of P_T. In the q-q system the corresponding slopes are seen in Fig. 4 to be equal, except for very large values of P_T.

The system of symmetry is not, however, independent of the charged-particle multiplicity. In the above analysis, all negative pions were used. If, instead, we analyze only the four-prong events, we find the slope parameters vary with the boost in a manner shown in Fig. 2 as the distributions labeled "4." we see that the ratio of P_p/P_K takes on the value -1.70 ± 0.15 when the slope parameters are equal. Similar distributions for six- and eight-prong events are also shown in Fig. 2. A systematic trend is evident, the magnitude of P_p/P_K decreasing as the prong multiplicity increases. The effect is very similar to that observed with π^- mesons incident on protons at 25 GeV/c.[1] There the four-, six-, and eight-prong events yield symmetric distributions when the ratio P_p/P_K is ~2.2, ~1.4, and ~1.3, respectively. In our own data, the corresponding ratios are 1.7 ± 0.15, 1.4 ± 0.15, and 1.2 ± 0.15.

Thus these two features, the symmetrization of the total pion distribution near $P_p/P_K = 1.5$ and the variation with prong number, seem to be general features of hadron interactions in that they occur for both 12-GeV/c K^+p collisions and 25-GeV/c π^-p collisions.

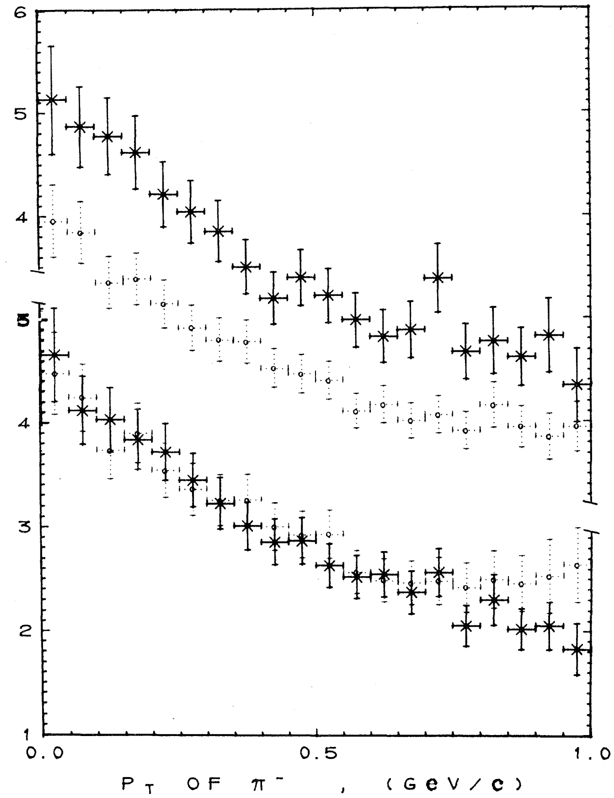

FIG. 4. A plot of the slope parameters obtained from fits of the form $d^2\sigma/dP_T dP_L \propto \exp(-aP_L)$ and $\propto \exp(bP_L)$ for the forward ($P_L > 0$) and backward ($P_L < 0$) pions, respectively. The values are plotted against the value of P_T. The upper two distributions relate to the center of mass and the lower two to the rest frame where $P_p/P_K = -1.5$.

Their interpretation in terms of a simple quark model is not at all clear, however.[5] The prong effect destroys the simplicity of the quark-quark interpretation. Specific mechanisms designed to explain this effect in the quark-quark center of mass may be no more appealing than similar mechanisms in the overall center of mass. Any model must accommodate the fact that the effect is produced by kaons as well as pions.

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[1]A forward-backward symmetry in the longitudinal-momentum distribution of produced pions in a particular reference frame has been observed recently in $\pi^- p$ interactions at an incident momenta of 25 GeV/c: J. W. Elbert, A. R. Erwin, and W. D. Walker, to be published. That interaction, however, contains inherent difficulties that might raise doubts about the validity of the results. For example, although a matter of symmetry is under discussion, and one might like to examine the distribution of a single kind of meson, the actual analysis had to be done by using negative pions for the backward distribution and positive pions for the forward distribution. The procedure is necessary in order to reduce the contribution from the incident particles (π^-,p) but it is difficult to know *a priori* how well the procedure works. These authors were, of course, aware of the problems inherent in their analysis. The virtue of the present $K^+ + p$ study is that it establishes the effect by using negative pions only, which are free of the ambiguities in the $\pi^- p$ data. In doing so, it justifies the πp analysis and demonstrates that the effect is the same in both πp and Kp collisions.

[2]Lawrence Radiation Laboratory Particle Data Group, Report No. UCRL 20 000 K^+N, 1969 (unpublished).

[3]We mean by "leading" particles those particles that produce a nearly uniform $d\sigma/dP_L$ distribution over a broad range of forward values of P_L in the center of mass. Generally, $d\sigma/dP_L$ falls roughly exponentially from a peak at $P_L \sim 0$. If leading particles are present, the distribution then flattens at some intermediate value of P_L and remains roughly constant out to the elastic peak. Our $d\sigma/dP_L$ distribution falls essentially exponentially at all values of P_L out to the kinematic limit. We take this to mean that leading particles are not numerous in our data.

[4]H. Satz, Phys. Rev. Lett. 19, 1453 (1967), and references therein.

[5]We are told, in fact, that an adequate fit to the separate distributions for four-, six-, and eight-prong data is possible without explicit reference to the quark model. Within the context of the multiperipheral model, the proton-meson (π or K) mass difference and the greater peripherality of the meson-proton vertex compared to the meson-meson vertex combine to produce the observed asymmetries in the center of mass. Dr. J. Friedman and Dr. C. Risk, private communication.

Phenomenology of the Background in the Resonance-Production Region*

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On the basis of the Harari-Freund hypothesis that the background in the two-body reactions can be identified with the Pomeranchuk contribution, we point out that an analysis of the background in the resonance region of inclusive reactions gives the triple Reggeon couplings involving the Pomeranchukon. This is feasible at presently available energy. Combining this with the hypothesis that the triple Pomeranchukon coupling is extremely small, we arrive at the conclusion that the background cannot be produced diffractively. This can be used to define resonances such as A_1.

The resonances have long been the focus of attention in missing-mass experiments, with the background underneath treated as somewhat of a nuisance. In this Letter we suggest that the analysis of the background in the resonance-production region at high energies can give us very important physical information.

When the c.m. energy squared, s, is much greater than the missing-mass squared, s', the scattering process $p_a + p_b \to p_c + k_1 + \cdots + k_n$, where $k_1, k_2, \cdots, k_n$ are the momenta of the particles in the missing mass, can be described by a Reggeized quasi two-body amplitude corresponding to $p_a + p_b \to p_c + p_d$, $p_d = k_1 + \cdots + k_n$ and $s' \equiv p_d^2$:

$$T_n(s,t,s',k_1,\cdots,k_n) \approx \sum_i \beta_i(t)(s/s')^{\alpha_i(t)} \gamma_i^{(n)}(t,s',k_1,\cdots,k_n), \tag{1}$$

where $\beta_i(t)$ is the normal Regge coupling between the particles a and c and the trajectory $\alpha_i(t)$, and $\gamma_i^{(n)}(t, s'; k_1, \cdots, k_n)$ is the Regge coupling between the particle b and quasiparticle d and the trajectory $\alpha_i(t)$. Alternatively, γ_i is the amplitude for the particle b and the trajectory $\alpha_i(t)$ going to the particles $k_1, k_2, \cdots, k_n$. The signature factor is absorbed in $\beta_i(t)$.