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Dynamical and symmetry effects in the K/π ratio in the central plateau

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Produced-mass and internal-mass effects are used along with symmetry considerations in a general peripheral structure to account for the K/π ratio in the central plateau with no free parameters. The increase of the ratio with increasing $q_\perp$ is accounted for.

A general peripheral structure for the inclusive single-particle spectrum in the central plateau region has recently been used[1,2] to fit the pion's $q_\perp$ spectra at the highest CERN ISR energy.[3] This peripheral structure, Fig. 1(a), leads to the inclusive single-particle cross section as a forward 3-3 absorptive part, Fig. 1(b). This structure has the proper 3-3 Regge analytic behavior and results in the Mueller-type diagram Fig. 1(c).

In this model we utilize SU(3), quark-model symmetry, and the dynamical effects of the masses of the produced particle and the exchanged particles to calculate the production of kaons versus pions. For c a pion or kaon we then follow ABFST (Amati-Bertocchi-Fubini-Stanghellini-Tonin)[4] and take the t_l exchange to be a pseudoscalar meson (P) and t_r to be an effective vector (V) or tensor (T) exchange. In this dynamical model we can apply the SU(3) assumptions on the g_{PPV}, g_{PPT}, and Pomeron couplings and treat the π, K mass effects independently.

One mass-dependent effect is that the exchange of a pion pole in t_l gives an enhancement over other exchanges and this occurs more often in pion than kaon production. This effect persists even at large $q_\perp$.

The other effect is that the mass of the produced particle c kinematically limits the missing-mass phase space. This suppresses the production of heavier-mass particles at small $q_\perp$ (Refs. 5, 6) but has no effect at very large $q_\perp$.

The assumption of pure quark-model symmetry is supplemented by the inclusion of a small u_8 octet part to the predominantly unitary singlet Pomeron to include the effective πp-Kp cross-section difference. We also relate the strengths of the vector and tensor exchanges experimentally. The decay $K_S^0 \to \pi^+\pi^-$ was calculated and found to be a small correction to the K^+/π^+ ratio.

The conclusion of our study is that the mass-dependent effects with the corrections from the other three effects lowers the K/π ratio in the central plateau to about 0.20 at $q_\perp = 0.4$ GeV/c. The ISR experiments at $q_\perp = 0.4$ find the ratio to be 0.12 $\pm$ 0.03.

We also demonstrate that at large $q_\perp$ the production of kaons becomes closer to that of pions and should approach about 0.7 at large $q_\perp > 4$ GeV/c.

First we examine the mass-dependent effects. For the internal damping factors of Fig. 1(a) we use the product of a propagator (or effective propagator) and a form factor:

$$\beta_l(t_l) = \frac{1}{(t_l - m_P{}^2)(t_l - a^2)},$$

$$\beta_r(t_r) = \frac{1}{(t_r - a^2)^2}.$$

In β_l, for pion exchanges we take $m_P{}^2 = m_\pi{}^2$ to get the pion-pole-exchange effect while for kaon or other exchanges we take $m_P{}^2 = a^2$. We parametrize the other effective form factors and propagators by one parameter a^2, which is determined by fitting to the pion spectrum. The fit with $a^2 = 0.36$ GeV^2 is virtually identical to that of Ref. 2 where all four "masses" were taken to be the same.[7]

The external-mass dependence occurs through[8] $\eta = q_\pi{}^2 + m^2$ and in $e^{m^2\Omega}$ in Eq. (2.12) of Ref. 2. At large $q_\perp$, we find $e^{m^2\Omega} \approx 1$, $\eta \approx q_\perp{}^2$, and the effect of the external mass disappears. At small $q_\perp$, we find that the approximation[9] of m^2 entering only through η is good up to a factor of 2.

In Table I we show the effects in the spectrum of pion exchange versus other exchanges in β_l and the effects of the pion or kaon external masses. The numbers are normalized to the pion exchange in pion production, column 2, for easy comparison. We see that the exchange-mass and produced-mass effects are independent since their results are approximately multiplicative. Also the exchanged-mass effect persists at large $q_\perp$ but the produced mass has no effect at large $q_\perp$.

For the symmetry effects[10] we consider all allowed (P, V) and (P, T) exchanges in Fig. 1(c) for

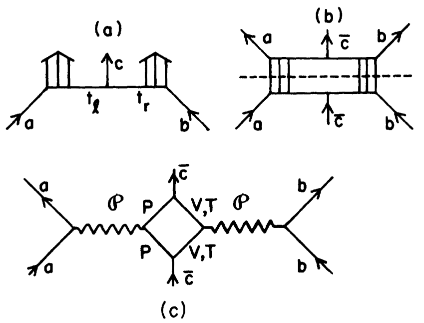

FIG. 1. (a) Peripheral production amplitude for the central plateau region. (b) Inclusive single-particle cross section as an absorptive part. (c) The resulting Mueller double-Regge behavior.

producing a π^+ or K^+. We eliminate other exchanges in the spirit of ABFST.[4] We also do not consider V- or T-resonance production in order to avoid double counting. The relative strengths of the couplings for vector nonet exchanges are calculated from U(3) and similarly for tensor nonet exchanges.[11] Using the quark model, we assume that the exchanged Pomerons couple with the same strength to the vector and tensor nonets.

Initially we assume that the Pomeron is a pure unitary singlet, and that the V and T couplings are equal by exchange degeneracy. From Fig. 1(c) we see that we need the squares of the coupling constants, and these are given in Table II under the above assumptions.

The important point to note is that the dynamically enhanced π exchanges occur with twice as much total coupling in π production as in K production. Combining the strengths of π exchange versus other pseudoscalar exchanges from Table II with the dynamical mass effects from Table I we obtain the result for full symmetry:

$$\frac{\rho_{K^+}(q_\perp)}{\rho_{\pi^+}(q_\perp)} = 0.30 \quad \text{at } q_\pi = 0.4\ \text{GeV}/c\,.$$

Since this is larger than the experimental results, we will introduce the observed[12] breaking of exchange degeneracy by taking $g_{PPT} = 0.6\, g_{PPV}$ for

TABLE I. Dynamic effects of pion exchange versus other exchanges, and of pion and kaon external masses. The numbers are normalized to the pion exchange in pion production.

	π produced Exchanged		K produced Exchanged	
$q_\perp$ (GeV/c)	π	Other	π	Other
0.4	1.0	0.20	0.44	0.094
2.0	1.0	0.54	0.94	0.50
9.0	1.0	0.59	1.00	0.59

TABLE II. Relative squares of the coupling constants.

π^+ produced Exchanged				K^+ produced Exchanged			
V		T		V		T	
$\rho^0\pi^+$	4	$A_2^0\pi^+$	0	ρ^0K^+	1	$A_2^0K^+$	1
$\rho^+\pi^0$	4	$A_2^+\pi^0$	0	ρ^+K^0	2	$A_2^+K^0$	2
$\bar{K}^{*0}K^+$	2	$\bar{K}_N^0K^+$	2	$K^{*0}\pi^+$	2	$K_N^0\pi^+$	2
$K^{*+}\bar{K}^0$	2	$K_N^+\bar{K}^0$	2	$K^{*+}\pi^0$	1	$K_N^+\pi^0$	1
$\rho^+\eta_8$	0	$A_2^+\eta_8$	$\frac{4}{3}$	$K^{*+}\eta_8$	3	$K_N^+\eta_8$	$\frac{1}{3}$
$\rho^+\eta_0$	0	$A_2^+\eta_0$	$\frac{8}{3}$	$K^{*+}\eta_0$	0	$K_N^+\eta_0$	$\frac{8}{3}$
$\omega_8\pi^+$	0	$f_8\pi^+$	$\frac{4}{3}$	ω_8K^+	3	f_8K^+	$\frac{1}{3}$
$\omega_0\pi^+$	0	$f_0\pi^+$	$\frac{8}{3}$	ω_0K^+	0	f_0K^+	$\frac{8}{3}$

the reduced matrix elements. To account for the difference in πp and Kp cross sections we include an f_8 part of the Pomeron $\mathcal{P}$. This changes $g_{\pi\pi\mathcal{P}} = g_{KK\mathcal{P}} = g_{\eta_8\eta_8\mathcal{P}} = g_{\eta_0\eta_0\mathcal{P}}$ to the effective couplings

$$g_{KK\mathcal{P}} = 0.83\, g_{\pi\pi\mathcal{P}}\,,$$

$$g_{\eta_8\eta_8\pi} = 0.89\, g_{\pi\pi\mathcal{P}}\,,$$

$$g_{\eta_0\eta_0\mathcal{P}} = 0.78\, g_{\pi\pi\mathcal{P}}\,.$$

Equivalent results obtain for the vector and tensor nonets.

The result of combining the above effects is

$$\frac{\rho_K(q_\perp)}{\rho_\pi(q_\perp)} = \frac{0.37c_4 + 0.96c_5}{1 + 0.54c_3}\,,$$

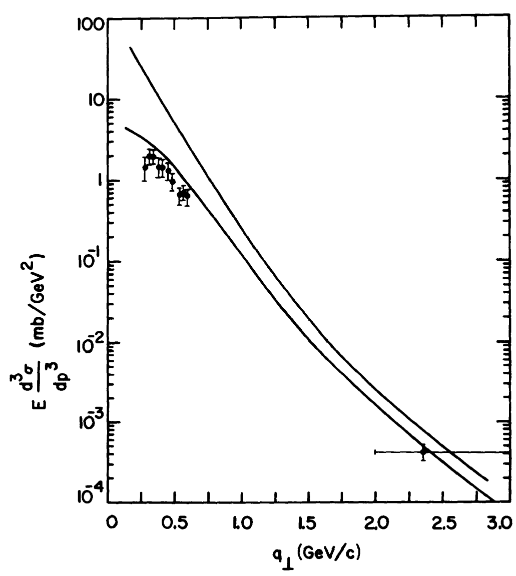

FIG. 2. The single-particle spectrum at $x \approx 0$ and $\sqrt{s} = 53$ GeV. The experimental π^+ spectrum is indicated by the upper line. The K^+ data and our fit are shown below it. The point at large $q_\perp$ was for $\sqrt{s} = 44$ GeV.

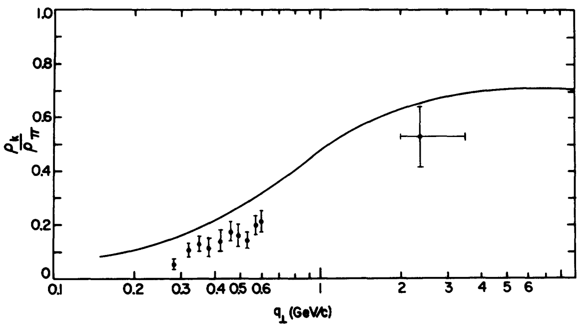

FIG. 3. The K^+/π^+ ratio of the inclusive spectra at $x \approx 0$ and $\sqrt{s} = 52$ GeV and our fit.

where c_3, c_4, and c_5 are the functions of $q_\perp$ given in Table I in columns 3, 4, and 5.

At $q_\perp = 0.4$ GeV/c we now find a K/π ratio of 0.23.

The present experimental data for π^+ may be partly contaminated with π^+ from the decays of the other produced pseudoscalars K_S^0, η', and η. These decays give, respectively, 0.7, 1.2, and 0.3 π^+ per produced pseudoscalar. These pions are more concentrated at small $q_\perp$ than their parents. The spectra of π^+ from $K_S^0 \to \pi^+\pi^-$ decay was calculated exactly for decay in a central plateau[13] and was found to lower the observed K^+/π^+ ratio by about 0.02 at $q_\perp = 0.4$ GeV/c from 0.23 to 0.21. The calculations of the decay spectra of η and η' are more difficult, and since they would have at most half the effect of the K_S^0, we have ignored them. However, at $q_\perp < 0.2$ GeV/c the contributions of K_S^0, η, and η' are greater and would have to be considered.

The preliminary results of the British-Scandinavian Collaboration[14,15] for the $K^\pm$ spectra at $x = 0$ and $\sqrt{s} = 53$ GeV is shown in Fig. 2. At $q_\perp = 0.4$ GeV/c the K^+/π^+ ratio is 0.12 ± 0.03. With the effects described we can now calculate the entire K^+ spectrum with no free parameters (using the magnitude and a^2 that fit the π spectrum). This is shown in Fig. 2. The point at large $q_\perp$ was found using the K^+/π^+ ratio of Ref. 16 for the bin $2.0 < q_\perp < 3.5$ GeV/c. The point was positioned at the average (over the spectrum) value of $q_\perp$ in the interval. In Fig. 3 we show the K/π ratio as a function of $q_\perp$.

At very large $q_\perp$, the spectra approach the limiting ratio $\rho_K/\rho_\pi \to 0.7$. The experimental observation of $K^\pm$ at large $q_\perp$ will be important since it probes the internal structure with the external-mass effect eliminated.

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