Charged-particle ratios in $\pi^- p$ collisions and quark statistics

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Predictions based on a quark statistical model are compared with the recent Chicago-Princeton Collaboration results on the relative production of charged particles in $\pi^- p$ collisions. The model is seen to provide an adequate description of the data.

In recent years, experimental data on particle production at large transverse momentum have provided us with much information on the underlying dynamics of hard processes.[1] Specific models, such as the hard scattering of constituents of the hadron as initially suggested by Berman, Bjorken, and Kogut,[2] and the constituent-interchange model (CIM),[3] have been investigated as possible explanations for the experimental observation.

The recent Chicago-Princeton Collaboration results[4] on the measurements of the ratios of π, K, and p production at large values of transverse momentum in $\pi^- p$ collisions are extremely interesting. There is evidence that the charge ratios, for example π^-/π^+, K^-/K^+, and $\bar{p}/p$, are quite different from those observed in pp collisions. In addition, comparison with theoretical predictions seems to indicate that the CIM calculations fail to describe the data by a large factor, while a quantum-chromodynamics-based hard-scattering model is in better agreement. In this paper, we wish to point out that by using a quark statistical model[5] (i.e., the standard quark assumption together with Chao-Yang statistics[6]) it is possible to fit the magnitudes of all the charged-particle ratios in $\pi^- p$ collisions quite well.

Let us describe our model here briefly. Consider a collection of l quarks of types u, d, and s and their associated antiquarks $\bar{u}$, $\bar{d}$, and $\bar{s}$. (We neglect heavier flavors here.) We use (a,b,c) to describe the quantum states of the collection corresponding to a state of a u, b d, and c s quarks. The distribution function $N^l_{a,b,c}$ which is the number of possible ways of distributing the quantum number (a,b,c) over the l quarks, is taken to be the binomial distribution with the suppression factor γ for the strange quark:

$$\left(x+y+\gamma z+\frac{1}{x}+\frac{1}{y}+\gamma\frac{1}{z}\right)^l=\sum_{a,b,c} N^l_{a,b,c}x^a y^b z^c\,. \qquad (1)$$

Asymptotically, i.e., for large values of l, we have for $N^l_{a,b,c}$ the following expansion:

$$\begin{aligned}N^l_{a,b,c}=(4+2\gamma)^l\left(\frac{2+\gamma}{2\pi l}\right)^{3/2}\frac{1}{\sqrt{\gamma}}\Bigg(1-\frac{1}{4l}\left[(4+2\gamma)\left(a^2+b^2+\frac{c^2}{\gamma}\right)-\frac{\gamma^2-5\gamma+1}{\gamma}\right]\\+\frac{1}{128l^2}\left[(2+\gamma)^2\left(20+\frac{9}{\gamma^2}+\frac{4}{\gamma}\right)-70(2+\gamma)\left(2+\frac{1}{\gamma}\right)+385\right]\\+\frac{1}{48l^2}\Bigg\{(2+\gamma)^2\left[6\left(a^2+b^2+\frac{c^2}{\gamma}\right)^2-3\left(6a^2+6b^2+\frac{5c^2}{\gamma^2}+\frac{a^2+b^2+2c^2}{\gamma}\right)\right]\\+105(2+\gamma)\left(a^2+b^2+\frac{c^2}{\gamma}\right)\Bigg\}\Bigg).\end{aligned} \qquad (2)$$

The probability of finding k quarks in the final state is assumed to be

$$P_{q_1,q_2,\ldots,q_k}(l)=\frac{N^l_{a-\alpha,b-\beta,c-\delta}}{N^l_{a,b,c}}, \qquad (3)$$

where (α,β,δ) is the quantum state of the collection of k quarks with quantum numbers equivalent to α u quarks, β d quarks, and δ s quarks, and (a,b,c) is the initial state. It also seems reasonable to assume further that the probability of pro-

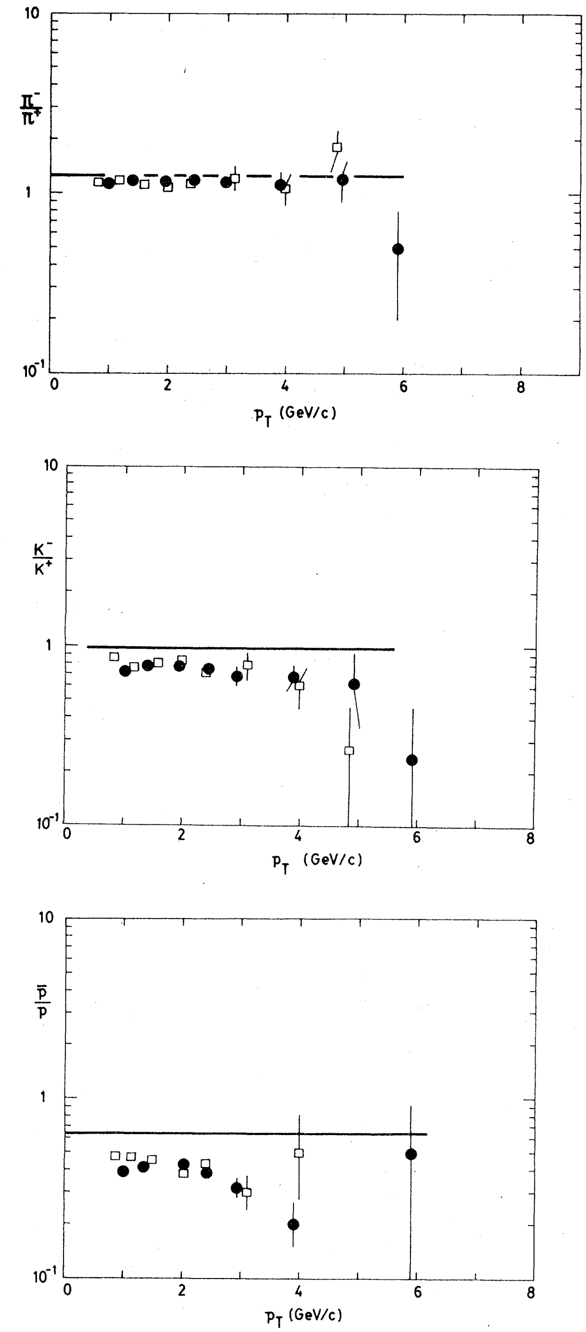

FIG. 1. The ratio of π^-/π^+, K^-/K^+, and $\bar{p}/p$ from the Chicago-Princeton data. The solid line is the quark-statistical-model result.

ducing a hadron h with quark contents $q_1, q_2, \ldots, q_k$ is proportional to this quark correlated probability $p_{q_1,q_2,\ldots,q_k}(l)$. We are then led to the following probabilities for the production of various particles in $\pi^- p$ collisions:

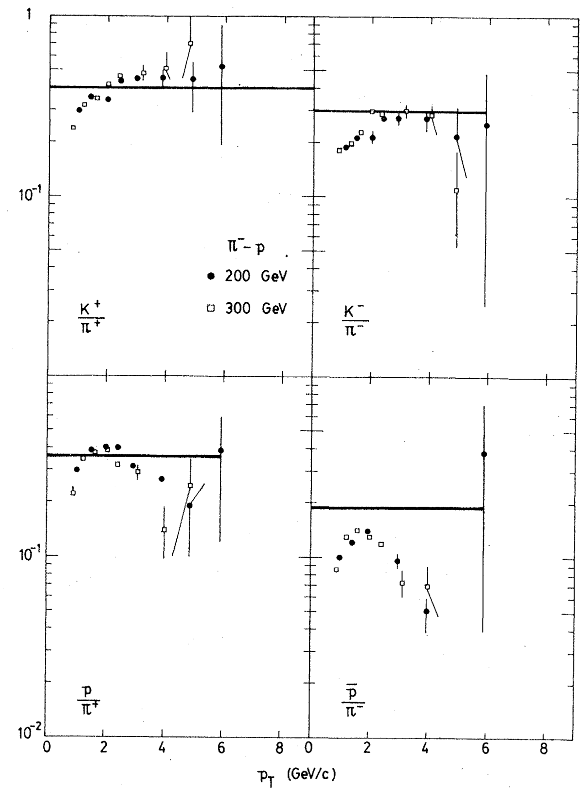

FIG. 2. The ratios of K and p to pions. The solid lines are the quark-statistical-model results.

$$
\begin{aligned}
\pi^+ &\propto N^{l-2}_{0,3,0}/N^{l}_{1,2,0}\,,\\
\pi^- &\propto N^{l-2}_{2,1,0}/N^{l}_{1,2,0}\,,\\
K^+ &\propto N^{l-2}_{0,2,1}/N^{l}_{1,2,0}\,,\\
K^- &\propto N^{l-2}_{2,2,-1}/N^{l}_{1,2,0}\,,\\
p &\propto N^{l-3}_{-1,1,0}/N^{l}_{1,2,0}\,,\\
\bar{p} &\propto N^{l-3}_{3,3,0}/N^{l}_{1,2,0}\,.
\end{aligned}
\qquad (4)
$$

We have evaluated the particle ratios with a strange-quark suppression factor of $\gamma = 0.1$ (extracted from the application of our model to hadron production at large p_T in pp collisions[5]), and an optimum value of $l = 20$. The results are

$$
\begin{aligned}
\pi^-/\pi^+ &\simeq 1.18\,,\\
K^-/K^+ &\simeq 1.00\,,\\
\bar{p}/p &\simeq 0.64\,,\\
K^+/\pi^+ &\simeq 0.40\,,\\
K^-/\pi^- &\simeq 0.30\,,\\
p/\pi^+ &\simeq 0.36\,,\\
\bar{p}/\pi^- &\simeq 0.19\,.
\end{aligned}
\qquad (5)
$$

Comparisons with the Chicago-Princeton data are shown in Figs. 1 and 2.

A few comments seem appropriate here. The p_T dependence of the various particle ratios is necessarily a manifestation of the dynamics of the underlying production mechanism. The quark statistical model used here, in contrast, by its intrinsic nature involving no dynamical assumption, gives only global (i.e., p_T-averaged) descriptions. Experimental results do indicate, however, that the invariant differential cross section falls sharply with p_T, and a realistic confrontation of our predictions with the data should really involve cross-section-weighted averages. Seen in this light, our model here seems to provide an adequate description of the data.

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