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Charged-particle ratios and large-transverse-momentum-dependent quark statistics

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The concept of "leading quarks" is developed and incorporated into the quark statistics. This gives the quark statistical model large-p_T-dependent characteristics and is able to explain the variation of the ratios of charged particles emitted over a wide range of large p_T during violent collisions. This feature is clearly manifested when the data obtained by the Chicago-Princeton Collaboration for $\pi^- p$, pp, and p"n" collisions at 300 and 400 GeV in the p_T range of 0.77 to 6.91 GeV/c are analyzed.

The plots for the ratios π^-/π^+, K^-/K^+, and $\bar{p}/p$ obtained from the Chicago-Princeton Collaboration's data[1,2] are analyzed in detail. The reactions studied are $\pi^- p$, pp, and p"n" collisions at 300 and 400 GeV over a wide p_T range of 0.77 to 6.91 GeV/c. The most striking feature observed from these plots is that they are all almost straight lines at lower p_T and then curve downwards at larger p_T except for the π^-/π^+ ratio which curves upwards in $\pi^- p$ collisions.

In order to account for the curvature in the plots the momentum of the quarks that participated in the reaction has to be considered during the analysis. This is done with the incorporation of the "leading-quarks" concept into the quark statistics.[3,4,5]

To introduce the leading-quarks concept into the quark statistics let us look at the $\pi^- p$ collision in more detail. When a π^- ($\bar{u}d$) approaches a stationary p (uud), the quark contents of both particles will spread out violently on impact. All the energy and momentum of the projectile particle are transferred to the exploding system with the five quarks forming the outer rim of the explosion. However according to quantum chromodynamics these quarks will not be freed. Instead, the original out-spreading quarks from the two colliding particles will cause more quark and antiquark pairs to materialize. These created quark and antiquark pairs will also spread outwards. The number of such pairs created will depend on the energy and momentum of the colliding particles.

In such a collision the momentum associated with the outermost quarks is the largest and this decreases rather rapidly with those nearer towards the center of the points of impact. The momentum associated with the created quarks is relatively lower because they have to be created first and then being drawn along by their "creators." This modified model therefore indicates to us the group of quarks that are participating most actively in the collisions. Besides it also tells us that the process which is taking place in the core of the exploding system can be viewed as purely statistical.

When the p_T under analysis is now increased, the momentum associated with the quarks in the exploding system will also increase. However the increase is not equally distributed among all the quarks involved but depends on their existing momenta. Those quarks with larger momentum will have a larger increase. Therefore the quarks with the largest increase are those at the outer rim of the exploding system, which are the original contents of the two colliding particles. These quarks will be called the leading quarks.

To substantiate the leading-quarks concept, the ratios of π^-/π^+, K^-/K^+, and $\bar{p}/p$ are dealt with quantitatively. The leading quarks associated with all the particles involved are placed in parentheses against them as shown in Table I for the three collisions under consideration. By comparing the difference in the number of such quarks associated with these particles the following relationships are predicted:

$$(1-\pi^-/\pi^+)_{pp} > (\pi^-/\pi^+ - 1)_{\pi^- p} > (1-\pi^-/\pi^+)_{pn} , \quad (1)$$

TABLE I. The difference in the number of leading quarks associated with each ratio and the computed charged-particle ratios for $l=60$ and $\gamma=0.1$.

Charged-particle ratios \ Types of collisions	$\pi^- p$	pp	p"n"
π^-/π^+	$\pi^-(3)>\pi^+(2)$ $\Delta L=+1$ $\pi^-/\pi^+>1$ (1.07)	$\pi^-(2)<\pi^+(4)$ $\Delta L=-2$ $\pi^-/\pi^+<1$ (0.89)	$\pi^-(3)=\pi^+(3)$ $\Delta L=0$ $\pi^-/\pi^+\sim 1$ (1.00)
K^-/K^+	$K^-(1)<K^+(2)$ $\Delta L=-1$ $K^-/K^+<1$ (0.93)	$K^-(0)<K^+(4)$ $\Delta l=-4$ $K^-/K^+<1$ (0.81)	$K^-(0)<K^+(3)$ $\Delta L=-3$ $K^-/K^+<1$ (0.85)
$\bar{p}/p$	$\bar{p}(1)<p(4)$ $\Delta L=-3$ $\bar{p}/p<1$ (0.76)	$\bar{p}(0)<p(6)$ $\Delta L=-6$ $\bar{p}/p<1$ (0.58)	$\bar{p}(0)<p(6)$ $\Delta L=-6$ $\bar{p}/p<1$ (0.60)

$$(1-K^-/K^+)_{pp}>(1-K^-/K^+)_{pn}>(1-K^-/K^+)_{\pi^-p}\,, \tag{2}$$

$$(1-\bar{p}/p)_{pp}\sim(1-\bar{p}/p)_{pn}>(1-\bar{p}/p)_{\pi^-p}\,. \tag{3}$$

To confirm the above predictions the distribution function obtained by the existing quark statistics for large values of l is used. The function[4] is

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

The particle ratios are then computed using this function with a strange-quark suppression factor of $\gamma=0.1$ and an optimum value of $l=60$.[6] The ratios calculated for the various particles are listed in Table I in parentheses.

Basing on the computed values, the three predic-

TABLE II. Confirmation of predictions made by the leading-quarks concept.

Charged-particle ratios	Relationships predicted by leading-quarks concept and values obtained by p_T-independent quark statistics				
π^-/π^+	$(1-\pi^-/\pi^+)_{pp}$	$>$	$(\pi^-/\pi^+-1)_{\pi^-p}$	$>$	$(1-\pi^-/\pi^+)_{pn}$
	0.11	$>$	0.07	$>$	0
K^-/K^+	$(1-K^-/K^+)_{pp}$	$>$	$(1-K^-/K^+)_{pn}$	$>$	$(1-K^-/K^+)_{\pi^-p}$
	0.19	$>$	0.15	$>$	0.07
$\bar{p}/p$	$(1-\bar{p}/p)_{pp}$	$\sim$	$(1-\bar{p}/p)_{pn}$	$>$	$(1-\bar{p}/p)_{\pi^-p}$
	0.42	$\sim$	0.40	$>$	0.24

tions made earlier are evaluated and all the relationships agreed precisely as expected. This result strongly indicates that the leading-quarks concept is the dynamics behind the quark statistics. In order to give a more explicit view of the result, the predictions as well as the calculated values are listed in Table II for comparison.

Having known the characteristics exhibited by the plots as well as the momentum variation of the quarks in the central region, it is found that the variation of the particle ratios are exponential functions of p_T and the difference in the number of leading quarks. The ratios of particles A and B may therefore be represented symbolically by

$$\frac{A}{B}=Re\frac{\Delta L\, p_T}{N}\,, \tag{5}$$

where R is the charged-particle ratio computed by the existing quark statistics, ΔL is the difference in the number of leading quarks between A and B, and N is a constant is common for the same ratio for all collisions.

The values of R and ΔL have already been computed and are listed in Table I. In this study the value of N is calibrated with p_T at 3.85 GeV/c. This value is chosen because it is midway between the p_T range of 0.77 to 6.91 GeV/c under consideration. It is found that the values of N are 41, 18, and 13 GeV/c for π^-/π^+, K^-/K^+, and $\bar{p}/p$, respectively, for all the three collisions. Having known these values the charged particle ratios at different values of p_T could then be computed. The charged particle ratio functions for π^-/π^+, K^-/K^+, and $\bar{p}/p$ are listed in Table III and the

TABLE III. Charged-particle ratio functions (p_T in GeV/c).

Charged-particle ratios \ Collisions	π^-p	pp	p"n"
π^-/π^+	$1.07e^{p_T/41}$	$0.89e^{-2p_T/41}$	$1.00e^{-0p_T/41}$
K^-/K^+	$0.93e^{-p_T/18}$	$0.81e^{-4p_T/18}$	$0.85e^{-3p_T/18}$
$\bar{p}/p$	$0.76e^{-3p_T/13}$	$0.58e^{-6p_T/13}$	$0.60e^{-6p_T/13}$

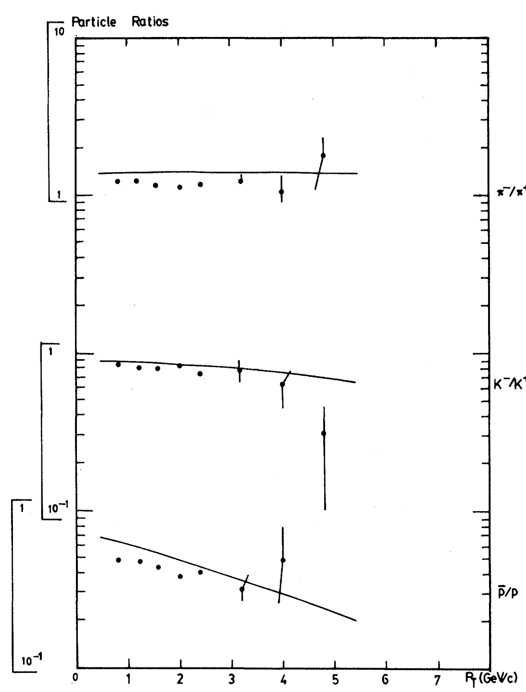

FIG. 1. Plots showing how π^-/π^+, K^-/K^+, and $\bar{p}/p$ vary with large p_T for π^-p collisions at 300 GeV, where the solid lines are the theoretical curves.

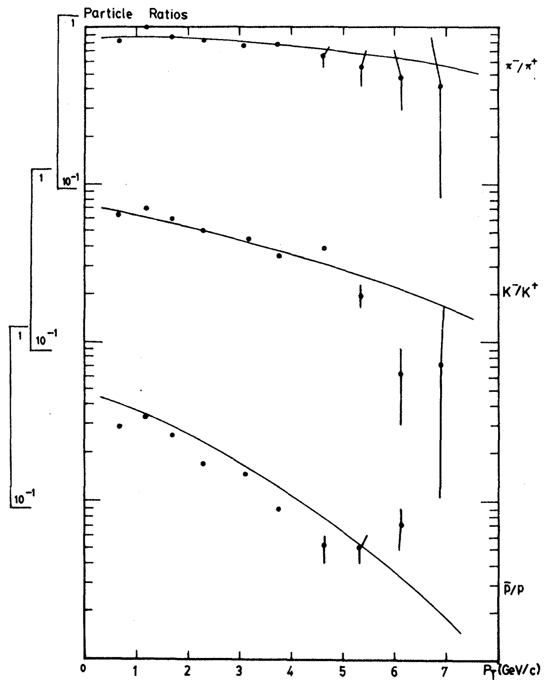

FIG. 2. Plots showing how π^-/π^+, K^-/K^+, and $\bar{p}/p$ vary with large p_T for pp collisions at 400 GeV, where the solid lines are the theoretical curves.

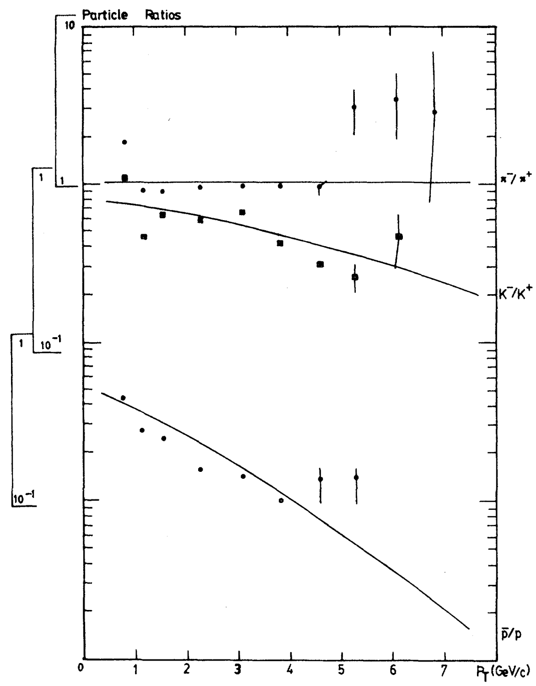

FIG. 3. Plots showing how π^-/π^+, K^-/K^+, and $\bar{p}/p$ vary with large p_T for p"n" collisions at 400 GeV, where the solid lines are the theoretical curves.

detail variation of these ratios with p_T for the three collisions are shown in Figs. 1 to 3.

Having investigated the variation of π^-/π^+, K^-/K^+, and $\bar{p}/p$ with large p_T, it is found that with the incorporation of the leading-quarks concept into the quark statistics, the large-p_T-dependent characteristic of charged-particle ratios could now be accounted for by the model. This study indicates that the leading-quarks mechanism is the underlying dynamics of the quark statistics and it also confirmed that the charged-particle ratios vary as an exponential function of large p_T and the difference in the number of leading quarks in the two particles concerned.

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[6]The number of quarks in the state $l=60$ is arbitrary and it depends on the energy of the bombarding particles. If l varies, it will slightly affect the charged-particle ratios and so long as a large value is maintained, the overall pattern will remain the same.