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INCLUSIVE π^+ TO π^- RATIOS AND QUARK DISTRIBUTIONS OF PIONS AND NUCLEONS(*)

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Abstract

The ratio R of inclusive π^+/π^- production at low transverse momenta is measured in π^+n and pn interactions at 195 GeV/c. R (1/R) in the proton (neutron) fragmentation region increases with Feynman-x and is smaller than R from π^+ fragmentation. The results agree with a quark-quark scattering model originally proposed for "hard" processes and disagree with a modified version of the model which includes gluon scattering.

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Studies of inclusive pion production in pp and πp interactions are important for the understanding of constituent structure models of the nucleon. Field and Feynman[1] and Ochs[2] argued that a sensitive test of the models can be obtained by studying in hadron-hadron collisions the π^+/π^- ratio R, where phase space factors and details of the basic interaction cancel out. The u/d quark ratio, measured in deep-inelastic lepton scattering, is expected in certain models[2-3] to approach 5(1/5) for leading quarks fragmenting from a proton (neutron). Ochs[2] have shown that the π^+/π^- ratio R_p in the proton fragmentation region yields similar values at high and low transverse momenta (p_T) and follows the u/d ratio for all regions of x_R (x_R is the radial scaling variable, $2|p^*|/\sqrt{s}$, where p^* is the pion cms momentum and $\sqrt{s}$ the total cms energy).
Das and Hwa[4] have shown that meson production at low p_T and large x_R is inconsistent with the quark fragmentation mechanism[1]. They describe the data in terms of a quark-antiquark recombination model, where a fast valence quark combines with a slow anti-quark from the sea to produce the observed meson. However, for a sea quark distribution steeply falling with x_R, the ratio R_p is still behaving like the u/d ratio[5]. The π^+/π^- ratio in the fragmentation region of a π^+ meson (R_{π^+}) can be approximated by the ratio of the u quark decay functions $D_u^{\pi^+}(Z)/D_u^{\pi^-}(Z)$ in the notation of ref. 1. R_{π^+} is expected to become very large as $x_R \to 1$, since both quarks of a produced $\pi^+(u\bar{d})$ can be valence quarks from the incoming π^+, while in a produced $\pi^-(d\bar{u})$ none of them is a valence quark.

The π^+/π^- ratio has been previously measured in pp collisions both at high[6] and low[7-8] p_T regions at Fermilab and CERN ISR energies. Indeed, it was found[6-7] that R_p increases with x_R and becomes ~ 5 as $x_R \to 1$. Earlier attempts to determine R_{π^+} and $1/R_{\pi^-}$ from $\pi^\pm p$ data[9] yielded similar values in the pion fragmentation region ($x_R > 0.5$). No detailed study of R_n is available in the literature. The main purpose of our work is to present measurements of R at low p_T as a function of p_T and x_R in the proton, neutron and π^+ fragmentation regions and check if, for $x_R \gtrsim 0.5$, R_{π^+} is indeed larger than R_p or $1/R_n$, as expected from the above considerations.

The experiment was performed at Fermilab by exposing the 30" deuterium bubble chamber-PWC hybrid system[10] to a mixed π^+ and p beam at 195 GeV/c. By studying only odd prong events (and even prong events containing a backward visible spectator track) we obtain a pure sample of pn and π^+n interactions. From the analysis of the forward cms tracks we obtain mainly the π^+ and p fragmentations and the cms backward tracks yield the neutron fragmentation. Thus, in the same experiment we obtain and compare data concerning the fragmentation of several hadrons. The experimental details were described elsewhere[10-12]. The data presented here are derived from about 85,000 pictures and contains about 1100 π^+n interactions and 2700 pn interactions with ≥ 3 outgoing prongs. One and two prong events have not been included in our sample due to elastic contamination and poor scanning efficiency[11]. All events were measured several times yielding overall track efficiency of about 95% and 96% of the events are complete and charge-balanced. With the aid of the forward PWC

system[10] the momentum measurement of fast tracks is considerably better than in bare bubble chamber experiments[8].

All negative outgoing tracks are taken to be π^- mesons. Positive outgoing tracks can be identified as protons (1) by visible track ionization (slow protons, $p_{lab} < 1.4$ GeV/c); (2) when they are leading particles ($x_F = 2p_L/\sqrt{s} > 0.6$, where p_L is the longitudinal cms momentum) in pn interactions, since from pp work[8] we know that practically all leading particles with $x_F > 0.6$ are protons. The number of unidentified protons in each hemisphere is equal to the overall proton yield at that hemisphere, as determined[12] from the inclusive charge exchange probability at the nucleon vertex (~ 0.4), minus the number of protons identified as leading (forward hemisphere) or by track ionization (backward hemisphere). In this way we found[13-14] that $\sim 15\%$ of the apparent π^+ sample is due to unidentified protons. In order to obtain a cleaner π^+ sample, we have subtracted this contamination in a statistical way, as described in detail in ref. 14, and all the data presented in this work were corrected accordingly.

Our basic observations are presented in Fig. 1, where we show the ratio R as function of p_T, at various x_R intervals, in both the pn and π^+n experiments. In the forward cms hemisphere we show R, the π^+/π^- ratio, and in the backward cms hemisphere we show 1/R, namely the π^-/π^+ ratio. Several interesting features of the data are evident from inspection of Fig. 1: (1) in all 4 regions studied here, R seems to be constant with p_T for $p_T \leq 1$ GeV/c and to depend only on the appropriate x_R interval. (2) At equal x_R regions, R in Fig. 1a equals within errors to 1/R in Figs. 1b and 1d.

Thus $R_p=(R_n)^{-1}$ irrespective of the incoming particle. (3) R_{π^+} is usually higher for all x_R regions (Fig. 1c) than the corresponding R_p (or $1/R_n$). (4) The ratio R_p (or $1/R_n$) increases with increasing x_R. Thus experimentally we observe several of the features expected from the quark constituent models.†

In Fig. 2a we show R (1/R in the backward cms hemisphere) integrated over p_T as a function of x_R. The pn data is cut-off at $x_R=0.6$ since, as previously mentioned, all outgoing positive tracks with $x_R \sim x_F > 0.6$ have been assigned to be protons. The π^+n data is presented up to $x_R=0.95$. Above that region there are experimental losses due to the unmeasured 1-prong inelastic events. It is also not clear whether a comparison with a quark-scattering model is relevant for the highest x_R region, which is dominated by leading π^+ mesons (diffractive process with pomeron exchange). The R_{π^+} value for the last bin shown in fig. 2a ($0.7<x_R<0.95$) may have to be slightly reduced due to a small contamination of leading particles, but this is somewhat compensated by the absence of 1-prong inelastic events. For $x_R<0.7$ the effect of both leading π^+'s and tracks from 1-prong events is negligible.

The solid curve in fig. 2a is the calculated π^+/π^- ratio†† for 90° cms production (high p_T) in pp collisions assuming the quark-quark scattering model of ref. 1. In the proton fragmentation region, as was also noted by Johnson et al[7], we obtain good agreement with the model. In the neutron fragmentation region, the data of the π^+n and pn experiments agree with each other and both agree well with the calculated curves when one considers the π^-/π^+ ratio. The values of R_{π^+} seem to fall above the solid curve, and are in agreement with the ratio[1] $D_u^{\pi^+}/D_u^{\pi^-}$ (broken curve) as mentioned earlier†.

In fig. 2b we compare our averaged values of the π^-/π^+ ratio in the neutron fragmentation region in both the π^+n and pn experiments, with $R_{\pi^+}(\pi^+/\pi^-)$ obtained in our π^+n experiment, as function of $|x_F|$. In the same graph we also show $R_p(\pi^+/\pi^-)$ from an ISR experiment[16] and $R_{\pi^-}(\pi^-/\pi^+)$ obtained in a recent π^-p experiment[17] at 200 GeV/c. From fig. 2b we conclude: (1) Our $R_n(\pi^-/\pi^+)$ values agree with the $R_p(\pi^+/\pi^-)$ values of ref. 16 (also with those of refs. 7-8). (2) Our $R_{\pi^+}(\pi^+/\pi^-)$ agrees with $R_{\pi^-}(\pi^-/\pi^+)$ of ref. 17 over the whole $|x_F|$ range, and both show a clear tendency to be higher than $R_p(=1/R_n)$ above $x_F \approx 0.5$, as expected from quark fragmentation and recombination models. This conclusion is qualitatively compatible with a recent ISR observation[16] that at high x_F, the ratios

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†The equality between R_p and $1/R_n$ also follows from charge symmetry and the absence of long range correlations.

††As noted in ref. 1, the calculations are for prompt pion emission and thus one must substract from the data the contributions of resonances, mainly ρ^0. In practice for R near 1, ρ production is irrelevant. Only at $x_R \gtrsim 0.3$, when R becomes ~ 2, ρ production could distort the results significantly. However, experimentally we find a negligible ρ^0 signal at $x_R>0.3$ and thus our experimental values of R are essentially due to prompt pion production.

†Recent results of electroproduction of charged pions in the quark fragmentation region[15] yield inclusive $\pi^\pm$ distributions and fragmentation functions $D_u^{\pi^\pm}(Z)$ consistent with the calculations of ref. 1.

$\pi^+\pi^-/\pi^-\pi^-$ and K^+/K^- in pp collisions become much bigger than R_p. In the denominators of these ratios, as well as of R_{π^+}, none of the quarks in one of the outgoing particles is a valence quark, yielding very large R values expected for $x_F \to 1$.

The dashed-dotted curve in fig. 2a is a modification [18] of the quark-quark scattering model[1] which includes, within the framework of a QCD approach, also contributions from quark-gluon and gluon-gluon scattering. Contrary to the quark-quark model where the π^+/π^- ratio is independent of energy, there is some energy dependence in the modified model. The curve in fig. 2a is given for 200 GeV/c[18]. The values of R(1/R in backward cms) are smaller due to gluon decays, since gluons fragment into equal numbers of positives and negatives. Although high p_T data was found[18] to be consistent with both models, it is clear from fig. 2a as well as from other R_p results[7,17], that low p_T data is in good agreement with the quark-quark scattering model, but is in strong disagreement with the modified model. This observation indicates that gluon interactions are less important in low p_T hadron-hadron scattering than in "hard" processes, which may be due to the long time scale in low p_T processes compared to deep inelastic scattering, allowing most of the gluons to convert into sea $q\bar{q}$ pairs. This, in turn, justifies the basic assumptions of the recombination model, which yield[5] sea distributions strongly enhanced at low x_F compared to lepton experiments.

In conclusion we find that our low p_T data of the π^+/π^- ratio in the fragmentation regions of the proton, neutron and π^+ meson agree with the quark-quark scattering model[1], but not with the modified model[18] which includes gluon scattering. In particular we find that R at fixed x_R is independent of p_T and its value for the neutron for both p and π^+ projectiles equals 1/R of the proton. As expected from quark fragmentation and recombination models, R_π is larger than $R_p(1/R_n)$ above $x_F \sim 0.5$ for all low p_T data.

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Figure Captions.

Fig.1: The inclusive ratio R of π^+/π^- production as function of p_T at fixed x_R intervals in pn and π^+n interactions. Shown are several typical error bars. (a) and (c): R in p and π^+ fragmentation regions. (b) and (d): 1/R in n fragmentation region.

Fig.2: (a) R (or 1/R) as function of x_R in pn and π^+n interactions. Solid curves: quark scattering calculations[1] of R_p and $1/R_n$. Broken curve: expected R_{π^+} (see text). Dash-dotted curves: calculation[18] of $R_p(1/R_n)$ including gluon scattering. (b) R as function of $|x_F|$ for low p_T data from pn and π^+n (this experiment), pp (ref.16) and π^-p (ref. 17).

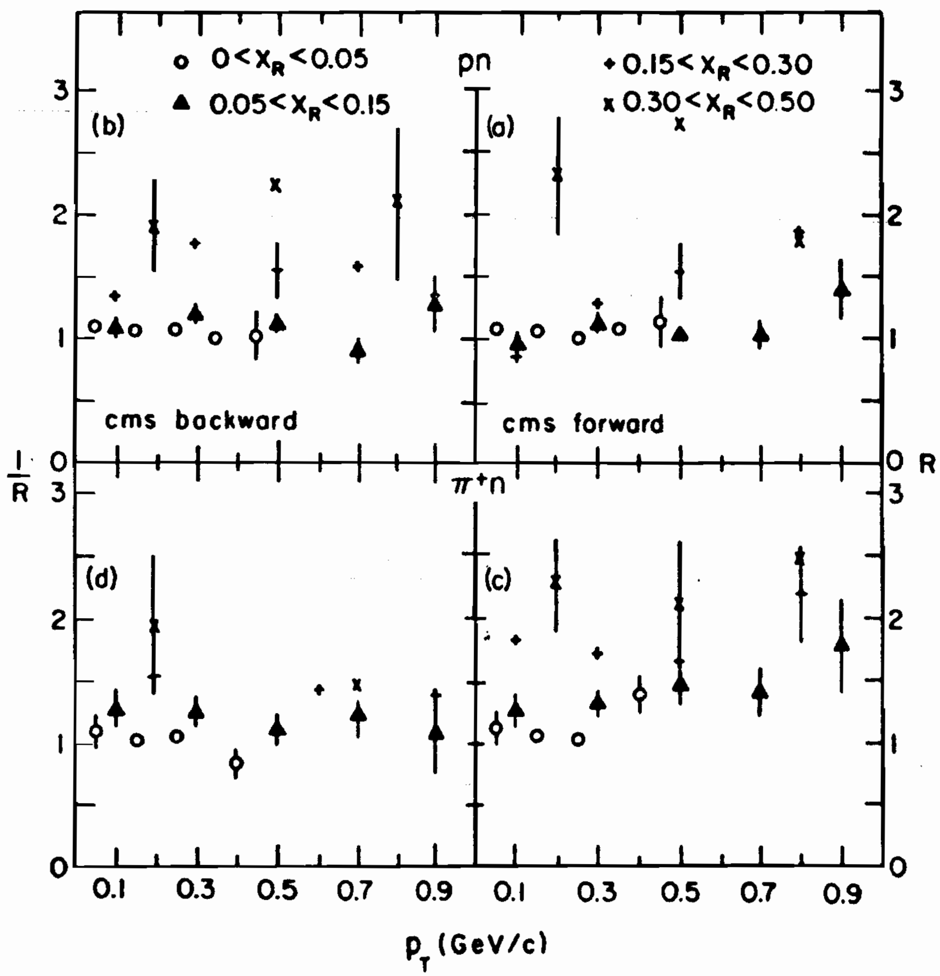
o 0<X_R<0.05
▲ 0.05<X_R<0.15
+ 0.15<X_R<0.30
x 0.30<X_R<0.50
pn
π⁺n
(a)
(b)
(c)
(d)
cms backward
cms forward
1/R
R
p_T (GeV/c)

Fig. 1

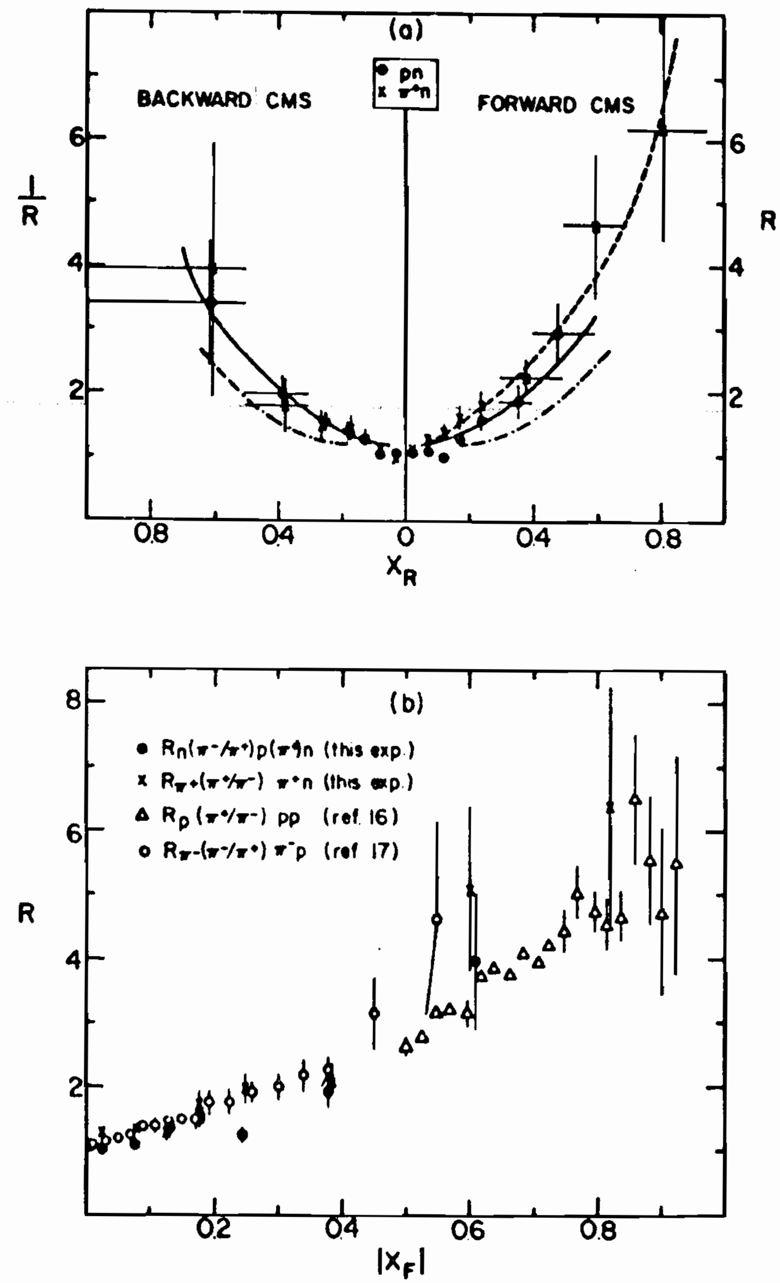
(a)
● pn
x π⁺n
BACKWARD CMS
FORWARD CMS
1/R
R
X_R
(b)
● R_n(π⁻/π⁺) p(π⁺)n (this exp.)
x R_π⁺(π⁺/π⁻) π⁺n (this exp.)
Δ R_p (π⁺/π⁻) pp (ref. 16)
o R_π⁻(π⁻/π⁺) π⁻p (ref. 17)
R
|X_F|

Fig. 2