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QUARK FRAGMENTATION FUNCTIONS FROM NEUTRINO NUCLEUS INTERACTIONS

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Abstract

Quark fragmentation functions $D_u^{\pi^+}(z)$ and $D_u^{\pi^-}(z)$ are obtained from νNe and $\bar{\nu}$Ne interactions and compared with those obtained in ep interactions. Problems resulting from fast protons which are not identified are discussed.

1. Introduction

In this paper we present the fragmentation functions for both positive and negative particles obtained from ν ($\bar{\nu}$)Ne interactions and compare them to those obtained in ep interactions.

The fragmentation of quarks into hadrons is a subject which has received considerable phenomenological and experimental attention of late. It is generally believed that neutrino interactions are ideal for studying quark fragmentation functions since in the quark parton model the fundamental weak interaction results in a u (d) quark of energy

$$\nu = E_\nu - E_\mu \tag{1}$$

for ν ($\bar{\nu}$) interactions. This quark supposedly fragments into the final state hadrons and its fragmentation function is thought to depend only on the variable

$$z = p^h/p^q \tag{2}$$

which is the fraction of the momentum of the quark, q, which is given to a particular final state hadron, h. Experimentally the fragmentation functions are defined as the average multiplicity per unit Δz,

$$D_q^h \equiv \frac{1}{\sigma}\frac{d\sigma}{dz}, \text{ and} \tag{3}$$

by charge symmetry

$$D_u^{\pi^+} = D_d^{\pi^-} \text{ and } D_u^{\pi^-} = D_d^{\pi^+}. \tag{4}$$

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The difficulty in obtaining such functions from neutrino interactions is twofold. Firstly, most neutrino beams for which data are available are broad band beams and the resulting energy of the hadronic system is small; that is, W typically ranges from ~1 and ~10 GeV. Secondly, as we have reported earlier, there is an excess of minimum ionizing particles which are positively charged. This excess has been found by comparing charge symmetric states in ν and $\bar{\nu}$ interactions, and it has been concluded that these fast positive particles are very likely protons.[1] In addition, this positive excess is quantitatively similar to that observed in $\pi^{\pm}$ Ne interactions.

2. Data

The data come from a wide band beam exposure of the 15' Fermilab bubble chamber filled with a heavy NeH_2 mixture (64% atomic Ne). The condition of the experiment resulted in approximately comparable numbers of ν_μ and $\bar{\nu}_\mu$ charged current events. For each event, the momentum of the track identified by the EMI as a muon was required to be greater than 4 GeV/c, and the total visible energy $E_{vis} > 10$ GeV. We also require that each event have at least one fast, minimum ionizing hadron. The neutrino energy is reconstructed for each event from the measured momenta of charged secondaries where the missing hadronic energy is estimated from the empirical relation

$$E_h^M = E_h^S \cdot \frac{P_T^M}{\sum_i |P_T^i|} \tag{5}$$

where E_h^S is the energy of all observed charged hadrons and P_T^M is the missing transverse momentum in the plane perpendicular to the ν beam and P_T^i is the transverse momentum of the ith charged hadron.[2] Only the events with at least one minimum ionizing, non-muon track are included in the data sample. Since the operating conditions of the chamber provided for the identification of protons only below ~1GeV/c, the minimum ionizing secondaries, N_+, contain not only pions, but also fast protons, and kaons, while the negative tracks, N_-, consist of π^-'s mainly. In our study all minimum ionizing particles were assigned a pion mass. After all selection criteria are met, our sample consists of approximately 1200 ν_μ and 1200 $\bar{\nu}_\mu$ charged current events.

3. Results

From the average charged multiplicities of minimum ionizing positive and negative particles observed in ν $(\bar{\nu})$Ne given in Table 1 we note that

$$\langle N_+ \rangle_{\nu(\bar{\nu})\mathrm{Ne}} \tag{6}$$

is greater than

$$\langle N_-\rangle_{\bar{\nu}\,(\nu)\mathrm{Ne}} \tag{7}$$

whereas, by charge symmetry these quantities should be equal. Thus, the differences

$$\langle N_+\rangle_{\nu\,(\bar{\nu})\mathrm{Ne}} - \langle N_-\rangle_{\bar{\nu}\,(\nu)\mathrm{Ne}} \equiv \langle N_p^{\,f}\rangle \tag{8}$$

is a measure of the fast ($\gtrsim$1 GeV/c) protons in ν ($\bar{\nu}$)Ne interactions.† The differences all indicate that the fast positive excess is significant, and, as has been discussed in ref. 1), it is not possible to explain the magnitude of the excess as resulting from k meson production.

Table 1

Average Multiplicities of Charged Secondaries

Reaction	Energy (GeV)	$\langle N_+\rangle$	$\langle N_-\rangle$	$\langle N_p^{\,f}\rangle$	$\langle N_p^{\,f}\rangle/\langle N_+\rangle$
ν_μNe	$3 < W < 6$	2.61±0.05	1.37±0.04	0.68±0.06	26±2 %
π^+Ne	$\sqrt{s} = 4.4$	2.86±0.04	1.37±0.02	0.78±0.04	27±1 %
$\bar{\nu}$Ne	$3 < W < 6$	1.71±0.05	1.93±0.04	0.34±0.06	20±4 %
π^-Ne	$\sqrt{s} = 4.4$	1.83±0.02	2.08±0.02	0.46±0.03	25±2 %

It is this positive excess which presents potential difficulties in extracting fragmentation functions from neutrino nucleus interactions when using positive minimum ionizing particles observed in the bubble chamber.

In order to better understand how these protons are distributed in momentum we plot in figure 1 $(1/\sigma)$ $(d\sigma/dz)$ for neutrino interactions and $1/\sigma$ $(d\sigma/dX_F)$ for πNe interactions, where

$$X_F = P_L/P_{in} \tag{9}$$

(i.e., Feynman X in the lab.) and for z we use the "light-cone" variable in the laboratory frame,

$$z_+ \equiv (E+P_L)/(E_W+P_W), \tag{10}$$

† In Table 1 the neutrino interactions have a $3 < W < 6$ GeV cut in order to compare with $\pi^\pm$Ne interactions at 10 GeV ($\sqrt{s} = 4.4$).

where P_L is taken along the direction of the incident W. For large ν, $z_+ \approx E^h/\nu$. We note again the striking similarity between πNe and neutrino neon interactions and conclude that very likely these fast protons are a result of the nuclear target. We also note that this excess continues to approximately X_F or z equal to 0.5, or in the case of πNe interactions to approximately P_L = 5 GeV/c (which is similar for neutrino interactions since we have restricted ourselves to $3 < W < 6$ GeV. We conclude from these results that it is more prudent to use only the negative particles in studying fragmentation functions in neutrino nucleus interactions.

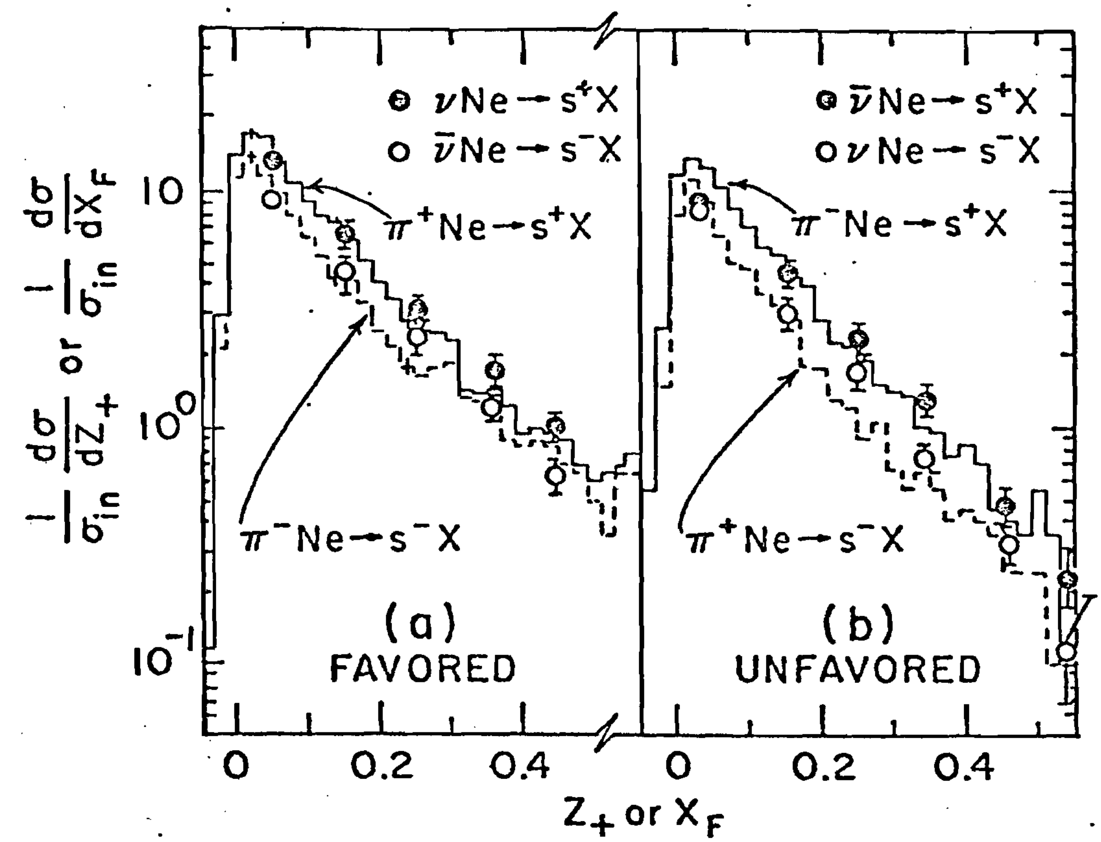

Fig (1) Comparison of the X_F^{lab} distributions from $\pi^\pm Ne \to s^\pm X$ ($\sqrt{s}$ = 4.4 GeV) with z distributions from ν ($\bar{\nu}$)$Ne \to s^\pm X$ ($3 < W < 6$ GeV), where $s^+(s^-)$ is the positive (negative) fast particle, for a) favored, b) unfavored particles.

In figure 2 we show the fragmentation functions

$$D_u^{\pi^+} \text{ and } D_u^{\pi^-} \text{ for } W > 2 \text{ GeV and } Q^2 > 2 \text{ (GeV/c)}^2$$

obtained from the minimum ionizing negative particles which have all been assigned a pion mass and compare that with the result obtained from electron proton interactions[3)] and also to the Field Feynman calculations.[4)] We note that there is rather good agreement over the entire range. We have also plotted on figure 2 the fragmentation functions obtained from the minimum ionizing positive particles which are assigned a pion mass, and we notice that in both cases there is an excess for $z < 0.5$. Thus, we emphasize that when obtaining fragmentation functions from the neutrino nucleus interactions one may have substantial contamination of protons in the positive charges and it is better to use the negative particles obtained in neutrino and anti-neutrino interactions. It is expected that as the primary neutrino beam energy increases there will be a corresponding increase in W which will very likely tend to reduce this effect since these protons should occupy a smaller fraction of phase space, if indeed they come from the nuclear target.

Acknowledgments

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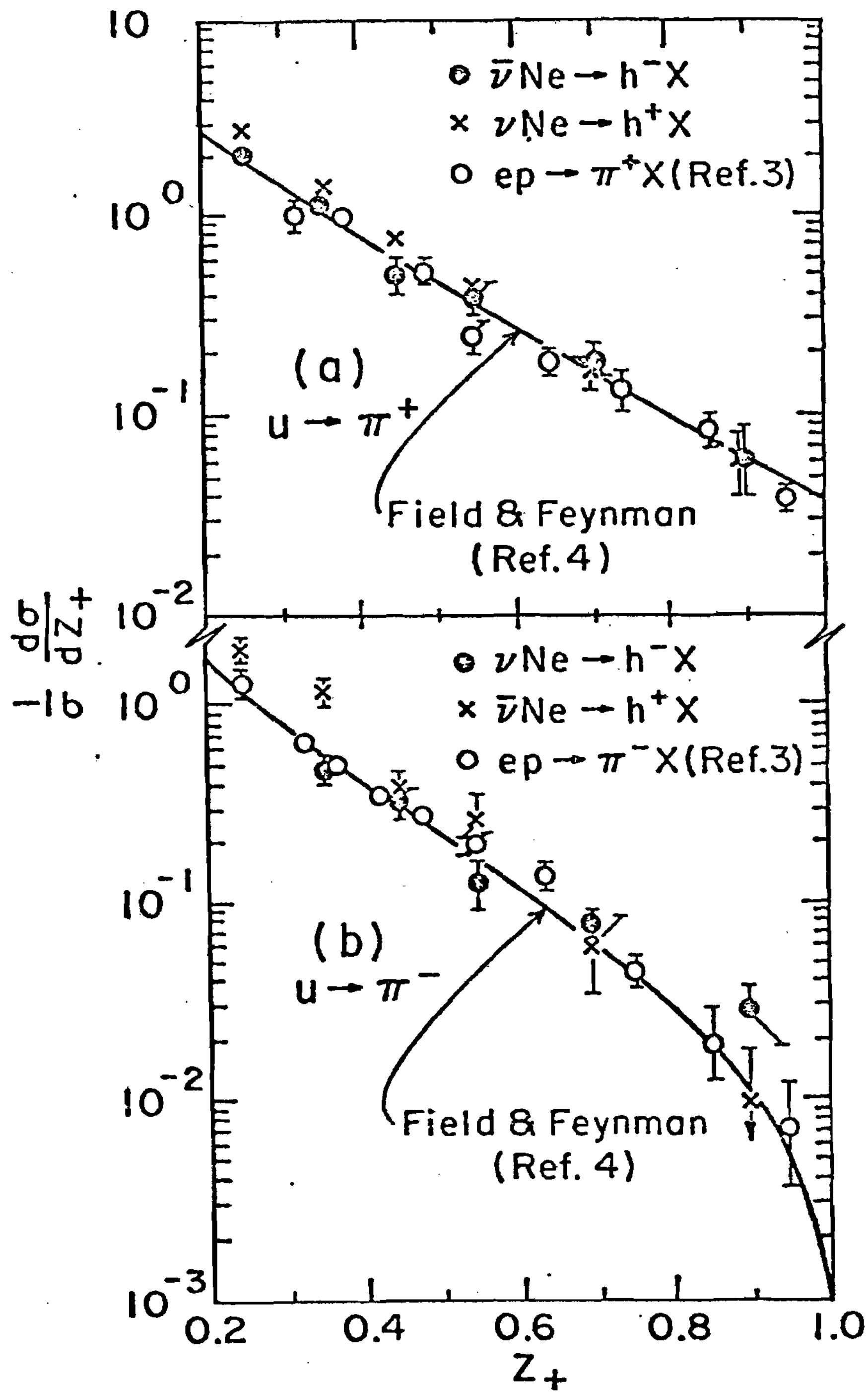

Fig (2) Fragmentation functions obtained in ν ($\bar{\nu}$)Ne interactions with W > 2 GeV and Q^2 > 2(GeV/c)^2 a) $D_u^{\pi^+}(z)$ and b) $D_u^{\pi^-}(z)$.