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DETERMINATION OF THE π AND K MESON STRUCTURE FUNCTIONS FROM MASSIVE DIMUONS PRODUCED AT 150 AND 200 GeV.

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ABSTRACT

We have studied high statistics samples of dimuon events ($\sim 3 \times 10^4$) produced from $\pi^\pm$ and K^- on platinum nucleus in the mass interval $4.1 \leqslant M_{\mu\mu} \leqslant 8.5$ GeV at 150 and 200 GeV. The data are obtained in the CERN-NA3 experiment using an high intensity hadron beam (up to $5\text{x}10^7$ particles/burst) instrumented with high resolution Cerenkov counters for K identification. The π structure function is obtained by a fit of $d^2\sigma/dx_1dx_2$ to the π^+ and π^- data at 200 GeV as well as using the high statistics data ($\sim 2.2\text{x}10^4$ events) at 150 GeV. The simultaneous use of π^+ and π^- data allows a separate determination of the valence and sea structure functions of the π. Furthermore the 150 GeV π^- data allows accurate determination of the shape of the valence structure function. The kaon valence structure function $\bar{u}_K(x_1)$ is then determined relative to the pion valence structure function $\bar{u}_\pi(x_1)$ by the ratio $R(x_1) = \bar{u}_K(x_1)/\bar{u}_\pi(x_1)$ which is approximately equal to the ratio of experimental x_1 distribution obtained with K^- and π^- beams.

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We have shown in a separate paper presented at this conference(1) that the nucleon structure functions obtained by the analysis of $\mu^+\mu^-$ pairs produced in $\bar{p}p$ or pp collision have the same shape as the one measured by deep inelastic scattering of ν or μ. The absolute value of the cross section obtained is however higher by a factor K = 2.3 ± 0.4 when compared to the prediction from a leading log Drell-Yan computation. Such a correction of the cross section by a nearly constant factor is predicted by perturbative QCD first order non leading log terms(2). Within the assumption of a constant K factor we will use our data to extract the kaon and pion structure functions from our $\mu^+\mu^-$ data obtained with a high energy π beam containing few percent of kaons.

1. EXPERIMENTAL DATA

Our experimental set up at the CERN SPS has been described previously(3). The muon pairs are produced in a 6 cm platinum target placed 40 cm upstream of a 1.5 m hadron absorber. The muons are analysed by our multiwire proportional chamber magnet spectrometer. To exclude the resonance region (J/ψ, ψ', Υ) a mass selection was applied in the range 4.1 to 8.5 GeV. We present here the final analysis of our 200 GeV π^- and π^+ data(4) and our 150 GeV π^- and K^- data (Table 1). The K^- in the negative beam are identified by a differential Cerenkov counter (Cedar) and the relative K^-/π^- luminosity, obtained by the Cedar calibration, is known to ≃10%. For the positive beam the π^+, p, K^+ separation is performed by Cedar and threshold Cerenkov counters. The relative π^+/π^- luminosity is monitored by the J/ψ events collected simultaneously with the dimuon continuum. The J/ψ production cross sections by π^+ and π^- beams on a platinum target were measured to be equal within ±1%*). The π^+/π^- relative luminosity is thus known to ±2%.

The spectrometer acceptance is calculated as a function of the variables x_1, x_2 assuming a $1+\cos^2\theta$ decay angular distribution and a gaussian

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*) J/ψ production cross sections from π^+ and π^- are identical on a (I=0) target. For a platinum target a correction factor of 1.003 ± 0.011 comes from the neutron excess in the nucleus (Z/A = 0.4). Such a correction is estimated by a comparison of the production cross section on hydrogen and platinum(5).

transverse momentum distribution, both distributions being compatible with the one observed in our experiment$^{(5)}$. The acceptance being approximately independant of p_T it does not critically depend on the specific form of the assumed p_T distribution.

2. THE QUARK ANNIHILATION MODEL

The muon pair momentum $p_{\mu\mu}$ and the invariant mass $M_{\mu\mu}$ determine the kinematical variables of the annihilating $\bar{q}q$ pair :

$$M^2_{\mu\mu} = x_1 x_2 s; \; x_{//} = x_1 - x_2; \; x_{//} = 2P^*_{\mu\mu//} / \sqrt{s};$$

where x_1 and x_2 are the fractional momenta of the quark in the beam and target particle respectively, the transverse momenta of the dimuon being assumed to be negligible. In the Drell-Yan model the cross section is written as :

$$\frac{d^2\sigma}{dx_1 dx_2} = \frac{\sigma^0}{3x_1{}^2 x_2{}^2} \sum_i Q_i{}^2 \left[f_i(x_1)\, \bar{g}_i(x_2) + \bar{f}_i(x_1)\, g_i(x_2) \right] \qquad (1)$$

where the sum is over the different quark flavours; f_i, $\bar{f}_i$, g_i, $\bar{g}_i$ are the quark and antiquark structure functions of the incident and target particle respectively. Q_i is the quark charge (2/3, 1/3) and

$$\sigma^0 = \frac{4\pi\alpha^2}{3s}$$

The $\pi^-(\pi^+)$ structure function contains a valence part :

$$V(x_1) = \bar{u}_v{}^{\pi^-} = d_v{}^{\pi^-} = \bar{d}_v{}^{\pi^+} = u_v{}^{\pi^+}$$

and a sea part $s_\pi(x_1)$ identical for π^+ and π^-. The nucleon has also a valence part $u(x_2)$, $d(x_2)$ and a sea part $s_n(x_2)$. It is easily seen that, by isospin invariance, the valence-sea, sea-valence and sea-sea terms are the same for π^- and π^+ nucleon interactions. On the other hand the valence-valence terms are different (roughly in the ratio $(2/3)^2$ to $(1/3)^2$ for π^- and π^+ respectively). A global fit to π^- and π^+ data thus allows a determination of both the valence and sea structure functions.

3. PARAMETRIZATION METHOD

We assume for the structure function the following simple x-dependence for the various structure functions, similar to the Buras and Gaemers parametrization for the nucleon :

$$V(x) = Ax^{\alpha}(1-x)^{\beta}$$

$$s_{\pi}(x) = B(1-x)^{n}$$

$$u(x) = A'_{u}x^{\alpha'}(1-x)^{\beta'}$$

$$d(x) = A'_{d}x^{\alpha'}(1-x)^{\beta'+1}$$

$$s_{n}(x) = B'(1-x)^{n'}$$

The choice of $\alpha'_u = \alpha'_d$ and $\beta'_d = \beta'_u+1$ is the result of theoretical prejudices. The parameters A, A'_u, A'_d are fixed in terms of α and β by the normalization condition to the number of valence quarks

$$\int \frac{V(x_1)dx_1}{x_1} = 1; \quad \int \frac{u(x_2)dx_2}{x_2} = 2 ; \int \frac{d(x_2)dx_2}{x_2} = 1$$

Because of our large acceptance in x_1 and x_2 an almost complete x_1 distribution is obtained for different value of x_2, in consequence the $f^i(x_1)$ and $g^i(x_2)$ structure functions obtained are not strongly correlated. A global χ^2 analysis to our x_1x_2 distribution can be used to test factorozation of the Drell-Yan cross section.

Table 2 gives the result of a global fit of the 200 GeV π^+ and π^- data. As in the $\bar{p}N$ data(1) the nucleon structure functions obtained are in good agreement with the results of the ν deep inelastic scattering experiment(7). To improve the accuracy on the pion structure function we fix the nucleon parameters $\alpha' = 0.5$ and $\beta' = 2.8$ compatible to the values given by the CDHS fit; we obtain the result given in table 3.

To analyse the 150 GeV π^- data we impose the π sea taken from our 200 GeV $\pi^+\pi^-$ fit and we use the nucleon valence and sea from the CDHS fit, the results are given in table 4.

4. PROJECTION METHOD

By projecting the content of the x_1, x_2 array on the two axes we get the distribution dN/dx_1 and dN/dx_2. If L is the integrated luminosity calculated from the integrated beam intensity and from the useful number of target nucleons assuming a linear A dependence(6) of the cross section, we can get from equation (1) an expression where only the variable x_1 appears :

$$F_\pi(x_1) \equiv \frac{dN/dx_1}{\frac{\sigma_0}{3}\,\frac{L}{{x_1}^2}\,I(x_1)} = K\left[V(x_1) + \frac{J(x_1)}{I(x_1)}\,s_\pi(x_1)\right] \qquad (2)$$

In this equation the quantities $I(x_1)$ and $J(x_1)$ are integrals involving the effective nucleon structure functions $G(x_2)$ and $H(x_2)$ and the calculated acceptance of the apparatus $A(x_1,\ x_2)$:

$$I(x_1) = \int \frac{G(x_2)}{{x_2}^2}\ A(x_1,\ x_2)dx_2, \quad J(x_1) = \int \frac{H(x_2)}{{x_2}^2}\ A(x_1,\ x_2)dx_2\ .$$

K is the cross section normalization factor assumed to be constant in the present analysis. For platinum target (Z/A = 0.4) the nucleon functions $G(x_2)$ and $H(x_2)$ take the following forms :

$G = 1/9(1.6u + 2.4d + 5s_n)$ for incident π^-;

$G = 1/9(0.6u + 0.4d + 5s_n)$ for incident π^+;

$H = 1/9(2.2u + 2.8d + 11s_n)$ for incident $\pi^\pm$.

We use for u and d the results of CDHS parametrization(7) (which are consistent with the u and d shape from our fits either in πp as explained above or in pp and $\bar{p}p$ interactions)(1).

In fig.1a,b we present the values of $F_\pi(x_1)$ thus obtained respectively at 200 and 150 GeV together with the curves calculated from our fit $x^\alpha(1-x)^\beta$.

Following the suggestion of Berger et al(8) we have attempted to fit our π structure function at $x > 0.5$ with a form $\sqrt{x}\,((1-x)^2 + (2/9)\cdot\langle {K_T}^2\rangle/{M_{\mu\mu}}^2)$ with $\langle {K_T}^2\rangle = 1$. The result of this parametrization (distorted by experimental error) is shown in fig. 2. Our data are not compatible with a $(1-x)^2$ shape at $x < 0.7$.

The structure function $F_N(x_2)$ can be expressed as a function of dN/dx_2 in a form similar to the one of $F_\pi(x_1)$ in equation (2), by using as input the pion structure functions $V(x_1)$ and $s_\pi(x_1)$ taken from our fit. $F_N(x_2)$ is shown in fig.1a,b together with the effective nucleon structure function calculated using the valence and sea quark parametrization given by the CDHS collaboration.

By assuming in equation (2) the K factor to be independent of x_1, we can derive its value after integration of $F_\pi(x_1)$ over x_1:

$$K = \frac{\int F_\pi(x_1)dx_1}{\int \left[V(x_1) + \frac{J(x_1)}{I(x_1)} S_\pi(x_1)\right] dx_1}$$

At 200 GeV we obtain $K = 2.05 \pm 0.4$ and at 150 GeV we obtain $K = 2.4 \pm 0.4$. Thus the experimental cross section for production of massive μ pairs is larger than the prediction of the simple Drell-Yan model computation by this K factor of ∼2.2. We recall that in the case of pN and $\bar{p}$N collisions we had found $K_{pN} = 2.3 \pm 0.4^{(9)}$ and $K_{\bar{p}N} = 2.3 \pm .4^{(1)}$. In trying to identify the origin of the K factor, further analysis of our $\pi^\pm$ data allows us to exclude two hypotetical contributions :

a) By analysing the $\pi^- - \pi^+$ data at 200 GeV we find $K = 2.2 \pm 0.4^{(9)}$. Thus the increase in μμ pair production can not be due to the decay of high mass resonances or simultaneous leptonic decays of heavy mesons (D,B), since these effects cancel out in first order in the $\pi^- - \pi^+$ data.

b) We also collected μ pairs production by pions on a hydrogen target$^{(6)}$. The analysis of these data gives $K = 2.4 \pm 0.4$. Thus the increase in cross section cannot be due to coherent nuclear effects on platinum.

It is therefore most probable that the K factor implies a fundamental correction to the leading log Drell-Yan computation. Such a correction, non leading log first order in QCD, has been calculated to give $K \sim 1.8^{(2)}$, in the $\tau = M_{\mu\mu}/\sqrt{s}$ interval ∼0.2 to ∼0.4 where our experimental data are available.

5. THE K^- STRUCTURE FUNCTION

At 150 GeV/c we have collected simultaneously μ pairs produced by K^- and π^- and we have obtained 700 $\mu^+\mu^-$ pairs with mass between 4.1 and 8.5 GeV produced by K^-.

Using a formalism similar to the projection method described above we can obtain a $F_K(x_1)$ and $F_\pi(x_1)$. In this case (since the K^- data are at values of x_1 larger than 0.2 and their statistical accuracy is limited) we neglected contributions of the meson sea. Up to an accuracy of ~10% in the ratio $\bar{u}_K(x_1)/\bar{u}_\pi(x_1)$, we can also neglect terms corresponding to the annihilation of the charge −1/3 valence quark of the pion or kaon (d or s) with sea quarks of the nucleon ($\bar{d}$ or $\bar{s}$).

The only terms left are from the annihilation of the valence meson antiquark $\bar{u}$ with the valence quark of the nucleon :

$$\left.\frac{dN}{dx_1}\right|_\pi = K_\pi \frac{\sigma_0 L_\pi}{3x_1^2} \bar{u}_\pi(x_1)\cdot I(x_1)$$

$$\left.\frac{dN}{dx_1}\right|_K = K_K \frac{\sigma_0 L_K}{3x_1^2} \bar{u}_K(x_1)\cdot I(x_1)$$

where $I(x_1)$ is an effective nucleon structure function integrated over experimental acceptance.

For a platinum target (Z/A = 0.4) :

$$I(x_1) = \int \frac{1}{9x_2^2} \left[1.6u\,(x_2) + 2.4d\,(x_2) + 4s_n(x_2)\right] A(x_1,\, x_2)dx_2$$

- $L_\pi(L_K)$ is the integrated luminosity for pions (kaons)
- K_π, K_K are the ratios of the measured cross section of the reactions :

$$\left.\begin{matrix} K^- \\ \pi^- \end{matrix}\right\} + \text{Nucleus} \rightarrow \mu^+\mu^- + x$$

to their predicted value by the Drell-Yan model. K_π and K_K are assumed to be identical in value.

If these K factors are due to QCD non leading log corrections, they are predicted to be nearly constant for π nucleon reaction in our x_1, x_2 range$^{(2)}$ and should be the same for incident π or K.

We thus obtain the result (fig.2) :

$$\frac{\bar{u}_K(x_1)}{\bar{u}_\pi(x_1)} = \frac{L_\pi}{L_K} \frac{dN/dx_1|_K}{dN/dx_1|_\pi} \qquad (3)$$

this ratio is independent of experimental acceptance and trigger efficiency due to simultaneous K and π data collection in our experiment.

The K^- are identified by a Cedar, the contamination of π's in the K Cedar signature as measured by a pressure curve is less than 1%. The only background left is thus due to random coincidences (~20%) which were subtracted out in the data analysis.

From fig.3 it appears that for values of $x_1 > 0.7$ the momentum spectrum of the $\bar{u}$ quark in the kaon decreases faster than the corresponding one for the $\bar{u}$ in the pion. This can also be expressed by parametrizing the data with the analytic form $R(1-x)^A$, giving $A = 0.18 \pm 0.07$.

In fig.3, we compare our data with the theoretical models based on Regge considerations, proposed by P.V. Chliapnikov et al.$^{(10)}$ and A. El Hassouni et al.$^{(11)}$. These models limit the value of A in the range 1/8 to 1/2. Recently a non relativistic calculation$^{(12)}$ of the pion and kaon structure function in the framework of QCD has been performed assuming for the quark mass ratio m_s/m_u the value : 540/336. The corresponding $\bar{u}_K/\bar{u}_\pi$ ratio can be deduced from this model and be compared to our experimental data. This is shown in fig.3 by the solid curve which seems to agree satisfactorily with the data.

TABLE 1

Number of dimuon events collected at 150 and 200 GeV on two targets : 6 cm platinum and 30 cm hydrogen, in the mass interval 4.1 to 8.5 GeV.

Beam Energy	Incident beam particle	Platinum target	Hydrogen target
-200 GeV	π^-	4996	138
	K^-	80	-
	$\bar{p}$	30	-
+200 GeV	π^+	1770	40
	K^+	170	-
	p	1080	-
-150 GeV	π^-	21200	540
	K^-	700	-
	$\bar{p}$	275	-

TABLE 2

Result of a global fit of the π^+ and π^- 200 GeV data.

Pion structure functions	Nucleon structure functions
$\alpha = 0.4 \pm 0.15$	$\alpha' = 0.49 \pm 0.2$
$\beta = 1.07 \pm 0.12$	$\beta' = 3.3 \pm 0.5$
$B = 0.32 \pm 0.2$	$B' = 0.25 \pm 0.1$
$n = 6.9 \pm 2.9$	$n' = 7.7 \pm 1.4$
$A = 0.57$	$A'_u = 2.2$
	$A'_d = 1.22$

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TABLE 3

Improved fit of the pion structure functions at 200 GeV.

Pion structure functions	Nucleon structure functions from CDHS fit
$\alpha = 0.45 \pm 0.1$	$\alpha' = 0.52$
$\beta = 1.04 \pm 0.1$	$\beta' = 2.8$
$B = 0.25 \pm 0.15$	$B' = 0.27$
$n = 5.4 \pm 2.0$	$n' = 8$
$A = 0.66$	$A'_u = 2.27$
	$A'_d = 1.29$

TABLE 4

Result of the fit of the 150 GeV data : we have imposed the π sea and the nucleon valence and sea as displayed in table 2.

Pion structure function :

$\alpha = 0.40 \pm 0.1$

$\beta = 0.90 \pm 0.1$

$A = 0.55$

FIGURE CAPTIONS

Fig. 1 (a) The data points represent $F_{\pi}(x_1)$ as defined by eq.(2) using nucleon structure function from CDHS fit;

i) dashed curves represent the valence structure function of pion obtained from our fit,

ii) solid curves represent the (valence+sea) pion structure function as defined by eq (2).

The curves have been scaled up by a factor K :

$K = 2.05$ for 200 GeV data; $K = 2.4$ for 150 GeV data.

(b) The data points represent $F_N(x_2)$ as defined in section 4

- dashed curves represent the valence part of the nucleon structure function : $1.6u(x_2) + 2.4d(x_2)$ for π^- ,
- solid curves represent (valence+sea) nucleon structure function as defined in section 4.

The curves have been scaled up by a factor K :

$K = 2.05$ for 200 GeV data; $K = 2.4$ for 150 GeV data.

Fig. 2 - Data points represent $F_{\pi}(x_1)$ at $x_1 > 0.5$ as defined by eq. (2) using CDHS nucleon structure function from CDHS fit,

- curve represent pion structure function parametrized with the form(8) : $\sqrt{x}\ ((1 - x)^2 + (2/9)\cdot\langle K_T^{\,2}\rangle/M_{\mu\mu}^{\;2})$,
- curve is normalized to the data points at $0.85 < x_1 < 1$.

Fig. 3 The data points represent

$$\frac{L_{\pi}\left.\frac{dN}{dx_1}\right|_K}{L_K\left.\frac{dN}{dx_1}\right|_{\pi}} \quad \text{as defined by equation (3)}$$

The dashed curves represent the limits of this ratio using $\bar{u}_K/\bar{u}_{\pi}$ and $s_K/\bar{u}_K$ from ref.(10). The upper (lower) curve corresponds to $A = 1/8$ ($A = 1/2$).

The dotted and solid curves represent $\bar{u}_K/\bar{u}_{\pi}$ ratio from ref.(11) and (12) respectively.

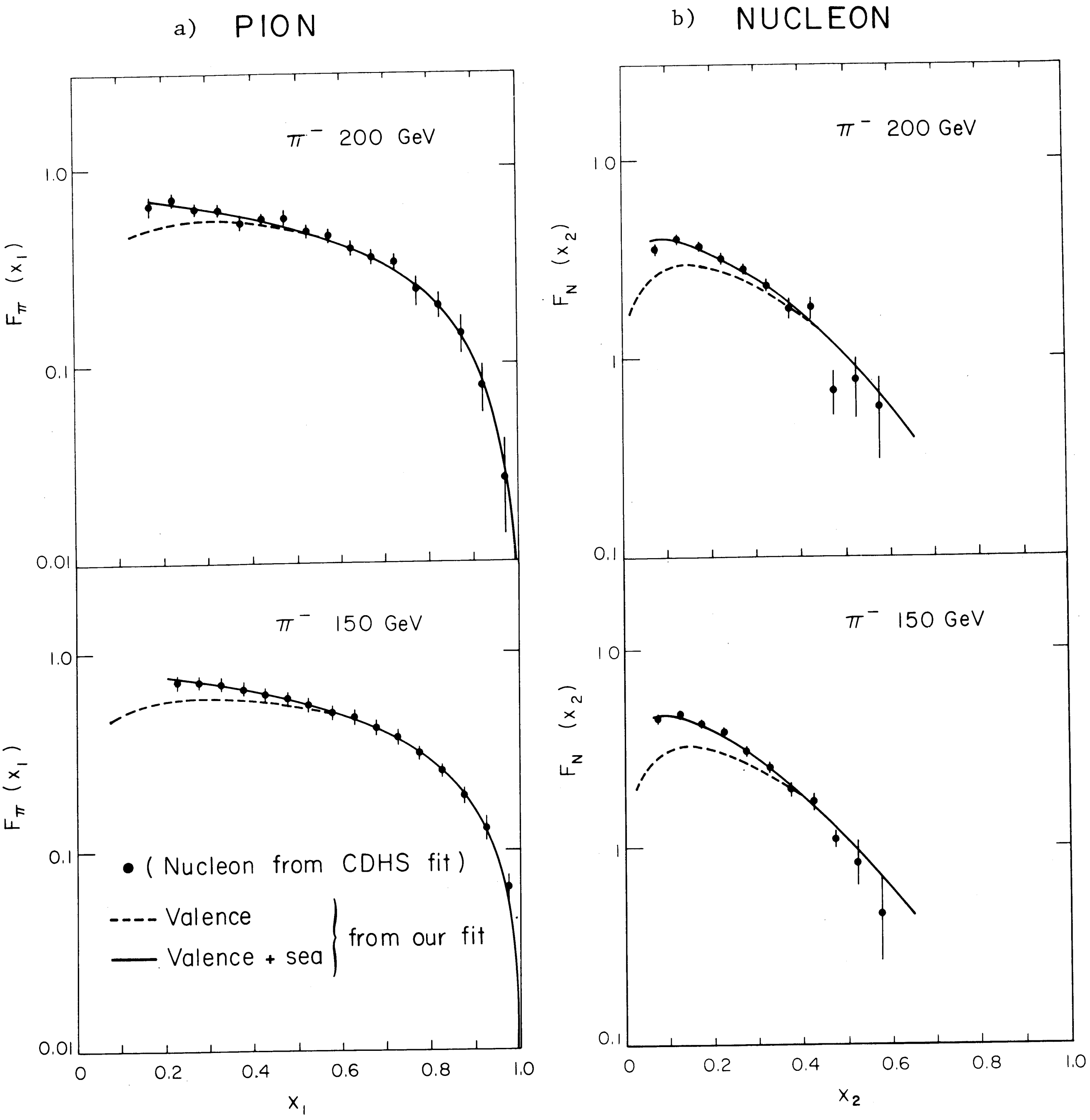

a) PION
b) NUCLEON
π⁻ 200 GeV
π⁻ 150 GeV
π⁻ 200 GeV
π⁻ 150 GeV
F_π (x_1)
F_N (x_2)
1.0
0.1
0.01
10
1
0.1
0
0.2
0.4
0.6
0.8
1.0
x_1
x_2
● (Nucleon from CDHS fit)
---- Valence
—— Valence + sea
from our fit

FIG. 1

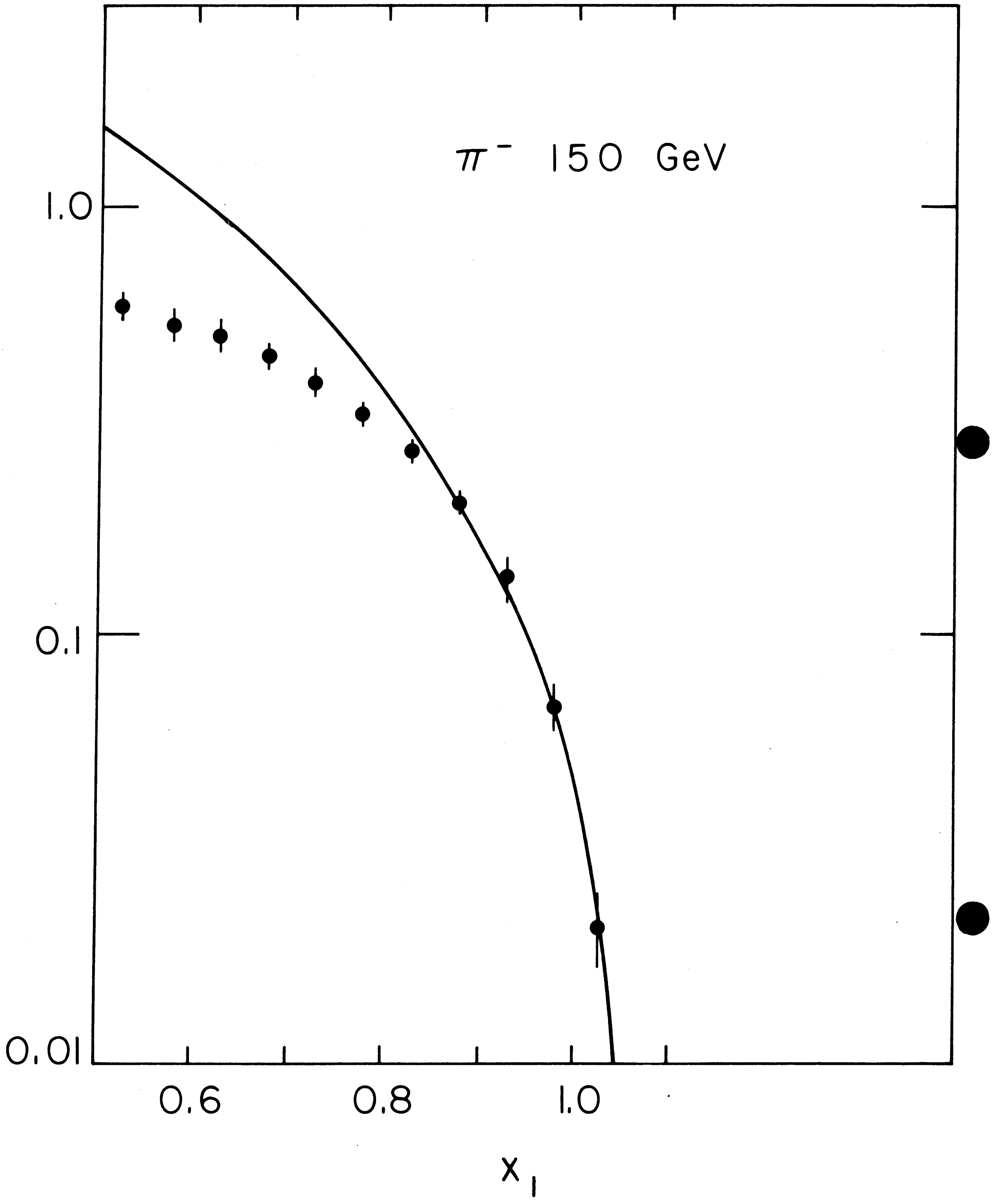
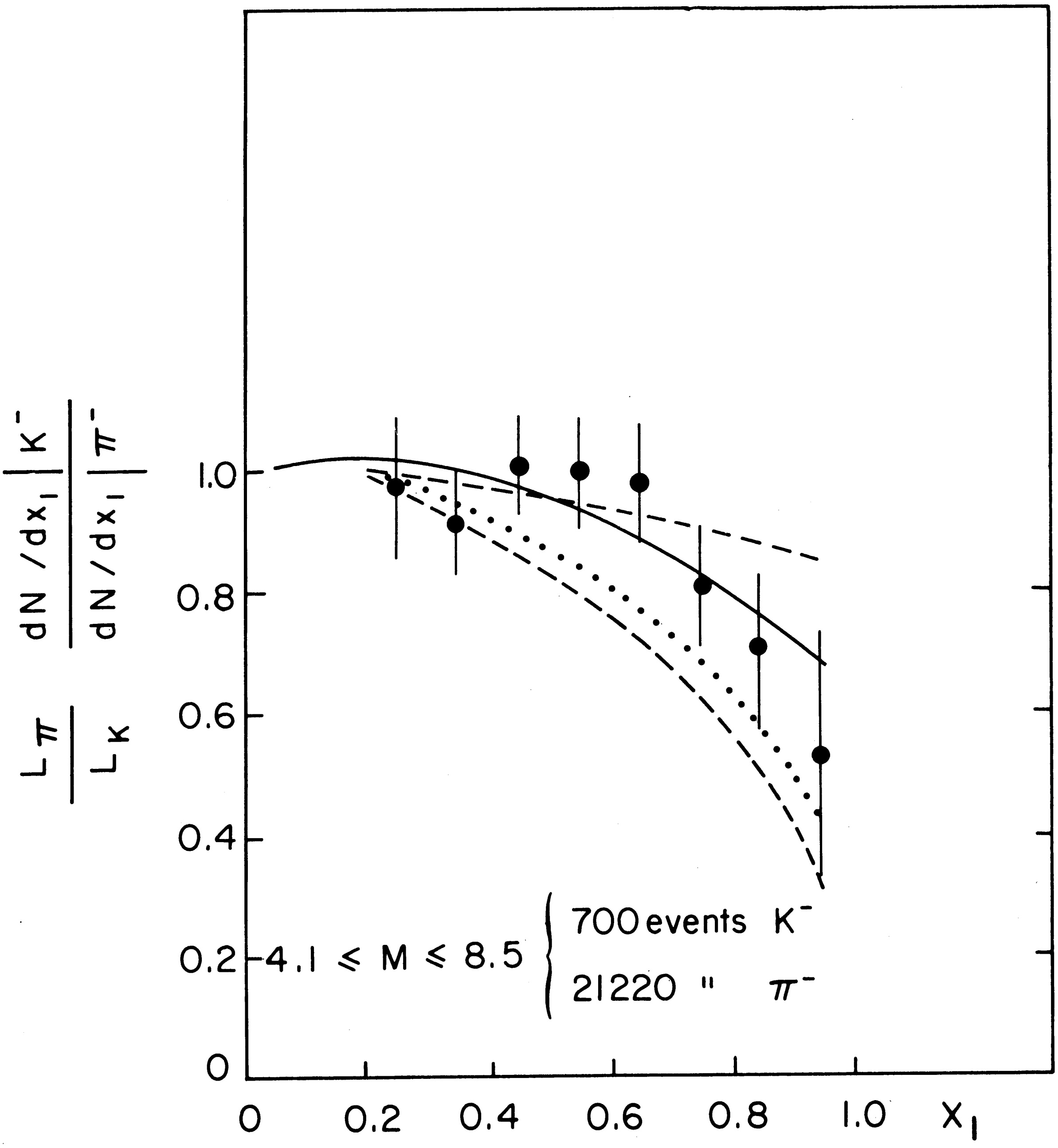


FIG. 2



$\frac{L_\pi}{L_K} \quad \frac{dN/dx_1|_{K^-}}{dN/dx_1|_{\pi^-}}$
1.0
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1.0
X_1
$4.1 \leq M \leq 8.5$
700 events K^-
21220 " π^-

FIG. 3