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EXPERIMENTAL DETERMINATION OF THE ANTIPROTON STRUCTURE FUNCTION BY THE DRELL-YAN MECHANISM.

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ABSTRACT

We present results on the measurement of the shape and absolute normalization of the nucleon structure function by the analysis of massive dimuon events produced by antiprotons and protons at 150 GeV. Agreement is found with the results of the neutrino DIS experiments but for the normalization which comes out to be higher by a factor of 2.3 ± 0.4.

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In a previous paper$^{(1)}$ we have given the results of a series of measurements of the absolute cross section for hadronic production of dimuons

$$h + N \rightarrow \mu^+ + \mu^- + X \qquad (1)$$

using different hadronic beam particles h in the energy range 200-280 GeV and two target elements : platinum and hydrogen. All these measurements have shown that the values of the cross sections consistently exceed the predictions of the simple Drell-Yan model when the nucleon structure function is taken to be identical to the one determined in deep inelastic scattering experiments (DIS)$^{(2)}$. This discrepancy is expressed by the ratio K between the experimental and theoretical cross section; its average experimental value was found to be K = 2.3 ± 0.5, where the error is dominated by systematic effects. As pointed out in ref.(1) the most significant measurement of K can be achieved by using in reaction (1) antiprotons as incident hadrons. In fact, in such a case, the dominant mechanism for producing massive dimuons is the annihilation of a valence anti-quark in the antiproton with a valence quark in a nucleon of the target, thus providing the most direct and simple comparison between the Drell-Yan mechanism and the DIS. Our antiproton data available in the previous analysis consisted of a total of 44 dimuon events with a mass $M_{\mu\mu} \geqslant 4.0$ GeV at a beam energy of 200 GeV, yielding a value of K = 2.4 ± 0.5. We have repeated this measurement with antiprotons of 150 GeV using our spectrometer in essentially the same configuration as for the 200 GeV run with a higher forward acceptance due to the lower beam energy and an improved geometrical configuration of the detector in the forward direction. This measurement provides an independent check on K and at the same time improves on the event statistics.

We have also collected proton data at 150 GeV in order to subtract from the antiproton data the contribution due to the sea quark and the gluons, thus improving the clarity of our analysis.

The antiprotons used in the present experiment represented approximately 1.3% of the total flux of a negative beam derived from the secondary target T4, in the hall EHN1 of the CERN-SPS, operated by the slow extracted proton beam at 400 GeV. The total beam flux at the experiment was 5 x 10^7 particles/burst for an effective spill time of 800 msec on the average. The beam intensity was monitored on-line by two argon ionization chambers at a distance of 10 m in front of the experiment. They had been calibrated at lower intensity ($\sim 10^6$ particle/burst) by counting the beam flux using a scintillation counter hodoscope. The incident antiprotons were identified by a differential Cerenkov counter of the CEDAR type(3,4), placed approximately 60 m upstream of the spectrometer. Because of the high rejection power of the CEDAR counter against π and K particles ($\sim 10^{-4}$), the only π background in the antiproton events is due to random coincidences. For each trigger, the CEDAR time informations were digitized by TDC's, thus providing identification of antiprotons together with a measurement of the accidental coincidence rate. In a 4 nsec time window we accept 95% of the antiproton events and there is a 25% random coincidence which is subtracted in the analysis.

The experimental luminosity is calculated from the calibration of the CEDAR counter at $\sim 10^6$ particle/burst and the measured efficiency variation with beam flux (this variation is less than 10% up to the maximum beam intensity).

Monitoring of the luminosity during data taking was achieved by the measured yield of J/ψ's. The integrated luminosity could then be determined by the measured value of the J/ψ cross section at 150 GeV(5). The overall uncertainty on the antiproton luminosity is estimated to be 15%. The dimuon events were produced in a 6 cm long platinum target placed 40 cm upstream of the 1.5 m iron-uranium hadron absorber at the entrance of the CERN-NA3 spectrometer magnet. The trigger requirements were identical to those of our previous experiment(1,4). In particular, no trigger selection was imposed by the type of incident particle, so that events produced by π^-, K^-, $\bar{p}$ were recorded simultaneously.

In the present paper we present the analysis of 275 dimuons produced by incident antiprotons at 150 GeV. The data sample is obtained by selecting dimuon events with mass larger than 4.1 GeV, after subtraction of the accidental event background. The data sample of dimuons, produced by 150 GeV protons, consists of 35 events obtained for the same mass cut as for the antiproton events and for an integrated luminosity comparable to the antiproton one.

In order to determine the value of K, we first extract from the data the antiproton structure function, following an analysis procedure similar to the one discussed in ref.(1).

From the expression of the Drell-Yan cross section we can deduce the difference :

$$\frac{d^2\sigma}{dx_1dx_2}\Big|_{\bar{p}N} - \frac{d^2\sigma}{dx_1dx_2}\Big|_{pN}$$

between the antiproton and proton differential cross section on the platinum-target nucleon N, (Z/A = 0.4). It contains terms arising from the valence quark-antiquark annihilation only, as all contributions from the sea quark are cancelled in the subtraction, independent of the assumption of their SU_2 symmetry properties :

$$\frac{d^2\sigma}{dx_1dx_2}\Big|_{\bar{p}N} - \frac{d^2\sigma}{dx_1dx_2}\Big|_{pN} = \frac{\sigma_0}{3x_1{}^2x_2{}^2}\,\frac{1}{9}\left(\left[4u(x_1)+d(x_1)\right]\cdot\left[.4u(x_2)+.6d(x_2)\right] + \cdot 2d(x_1)\left[u(x_2)-d(x_2)\right]\right) \qquad (2)$$

where :

$$\sigma_0 = \frac{4\pi\alpha^2}{3s}$$

u(x) and d(x) are the nucleon valence structure functions of the up and down quarks respectively.

It can easily be seen that the term $\cdot 2d(x_1)\left[u(x_2)-d(x_2)\right]$ in expression (2), can be neglected (it contributes less than 2% of the main term) whatever reasonable assumption is made for the up and down valence quark relationship : either the naive model assumption $u(x)=2d(x)$ or the Field-Feymann relation $d(x)=0.56u(x)\cdot(1-x)$. The equation (1) can therefore be written as :

$$\frac{d^2\sigma}{dx_1dx_2}\Big|_{\bar{p}N-pN} = \frac{\sigma_0}{3x_1{}^2x_2{}^2}\,\frac{1}{9}\,f(x_1)g(x_2) \qquad (3)$$

where $f(x_1)=4u(x_1)+d(x_1)$ and $g(x_2)=0.4u(x_2)+0.6d(x_2)$ are the valence structure functions of the antiproton and the target nucleon respectively. Each of the two functions $f(x_1)$ and $g(x_2)$ can be determined in turn from expression (2) after integration over the variable x_2 and x_1 respectively. For $f(x_1)$ we have :

$$f(x_1) = \frac{\frac{1}{L_{\bar{p}}}\int \frac{d^2N}{dx_1dx_2}\Big|_{\bar{p}N} dx_2 - \frac{1}{L_p}\int \frac{d^2N}{dx_1dx_2}\Big|_{pN} dx_2}{\frac{\sigma_0}{3x_1^{\,2}}\int \frac{g(x_2)}{9}\,\frac{A(x_1,\, x_2)}{x_2^{\,2}}\, dx_2} \tag{4}$$

where :

$$\frac{d^2N}{dx_1dx_2} = L\cdot A(x_1,\, x_2)\,\frac{d^2\sigma}{dx_1dx_2}$$

is the measured event distribution in x_1, x_2; L is the integrated luminosity and $A(x_1,\, x_2)$ is the spectrometer acceptance.

In order to evaluate the integral of $g(x_2)$ in expression (3) we use for the quark structure functions a Buras-Gaemers type of parametrization :

$$\begin{aligned} u_p(x) &= A^u_{\alpha\beta}\, x^{\alpha}(1-x)^{\beta}; \quad \int \frac{u_p(x)}{x}\, dx = 2 \\ d_p(x) &= A^d_{\alpha\beta}\, x^{\alpha}(1-x)^{\beta+1}; \quad \int \frac{d_p(x)}{x}\, dx = 1 \end{aligned} \tag{5}$$

we have taken $\alpha = 0.51 \pm 0.02$, $\beta = 2.8 \pm 0.1$ as obtained from the CDHS results at $Q^2 = 20\ \mathrm{GeV}^2$(2).

The two structure functions $f(x_1)$ and $g(x_2)$ thus obtained are shown in fig.1a and b, where the experimental points are compared to the Drell-Yan model predictions based on the CDHS(2) determination of the valence nucleon structure function. We note a very good agreement of the shape of $f(x_1)$ and $g(x_2)$ data points to the model in the intervals : $0.25 \leqslant x_1 \leqslant 1.0$ and $0.15 \leqslant x_2 \leqslant 0.45$. The measured yield requires a normalization factor $K = 2.3 \pm 0.40$, also in good agreement with our previous experimental determination(1). We should also remark that we do not find any evidence in our data of a significant variation of the value of the K factor, as can be seen by comparing to the model predictions : a) the shapes of $f(x_1)$ and $g(x_2)$ (see fig.1) and b) the behaviour of $M^3 \cdot d\sigma/dM$ plotted versus $\sqrt{\tau}$ (see fig.2) for our antiproton data of 150 GeV and our proton data of 200 GeV.

We can now determine the shape of the nucleon valence structure function by fitting our antiproton data after subtraction of the proton data at 150 GeV with a Buras-Gaemers type of parametrization of the valence structure function identical to the one shown in equation (5). We find $\alpha = 0.8 \pm 0.3$, $\beta = 3.3 \pm 0.5$. If we assume $u_p(x) = 2d_p(x)$, we find $\alpha = 0.7 \pm 0.3$, $\beta = 3.3 \pm 0.5$, showing that the determination of the valence structure function from antiproton data is rather insensitive to the assumed parametrization. We can further improve the accuracy of β by fixing $\alpha = 0.51$ in agreement with the results of the CDHS DIS experiment$^{(2)}$; we then find $\beta = 3.0 \pm 0.3$.

Having demonstrated the ability of the Drell-Yan mechanism to reproduce adequately the shape of the valence quark structure function similar to the deep inelastic scattering, we can compare the valence structure function of antiprotons with the overall valence + sea structure function previously obtained by our experiment with 200 GeV/c protons, both being determined using the Drell-Yan mechanism. This is shown in fig.3. As it can be seen the two structure functions superimpose for $x_1 > 0.4$. At lower values of x_1 they separate, clearly showing the sea contribution which is present in the proton data. More specifically we can extract from the 200 GeV proton data the shape of the sea structure function. This can be done by fitting the data with the differential cross section $d^2\sigma/dx_1dx_2$ containing valence-sea as well as sea-sea contributions.

The results of the fit are :

$\beta_s = 8.5 \pm 0.5$

for a SU_2 symmetric parametrization of the sea, $s^u = s^d = 2s^s \sim (1-x)^{\beta s}$;

and $\beta_s = 7.1 \pm 0.5$

for a sea parametrization of the type $s^u = s^d(1-x)^{3.5}$ and $s^s = 1/4(s^u+s^d)$. The values of β_s thus determined agree well with the CFS results$^{(6)}$ obtained with 400 GeV protons.

CONCLUSIONS

The nucleon structure function, as determined by the Drell-Yan mechanism using an antiproton beam exhibits a x-dependence which is in good agreement with the result of deep inelastic scattering experiments. The absolute normalization however requires a scaling factor K = 2.3±0.4, most probably due to QCD first order non leading log corrections(7). This confirms the results of our previous analysis based on proton data at 200 GeV. Finally we can determine the shape of the nucleon overall sea structure function by comparing the antiproton data to our proton data of 200 GeV. Our results agree with the nucleon sea determination by CFS.

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(5) We have performed a measurement of the J/ψ production cross section at 150 GeV by selecting sets of data corresponding to optimal running conditions i.e. small systematic corrections due to accidentals and dead time losses. This gave the following values for the J/ψ cross sections :

$\sigma_{x>o}(\pi^- + \text{platinum nucleus} \rightarrow J/\psi + x) = 770 \pm 90$ nb/nucleus

$\sigma_{x>o}(\bar{p} + \text{platinum nucleus} \rightarrow J/\psi + x) = 670 \pm 90$ nb/nucleus

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FIGURE CAPTIONS

Fig. 1a) Valence structure function $f(x_1)$ of the nucleon as determined by the antiproton data after subtraction of the corresponding proton data at 150 GeV. Data points are compared to the prediction of the Drell-Yan model based on the CDHS determination of the valence nucleon structure function.

b) Same as fig.1a for the structure function $g(x_2)$.

Fig. 2 $M^3 \frac{d\sigma}{dM}\Big|_{x>o}$ versus $\sqrt{\tau} = \frac{M_{\mu\mu}}{\sqrt{s}}$

Data points from antiproton of 150 GeV and protons of 200 GeV are compared to the Drell-Yan model predictions.

Fig. 3 The valence structure function $f(x_1)$ of fig.1a is compared to the overall (valence + sea) nucleon structure function determined by the proton data at 200 GeV. $J(x\ )/I(x\ )$ is defined for our platinum target as$^{(1)}$:

$$\frac{J(x_1)}{I(x_1)} = \frac{\int \frac{(1.6u(x_2) + 2.4d(x_2) + 5S_N)}{x_2{}^2} A(x_1,\ x_2)dx_2}{\int \frac{(2.2u(x_2) + 2.8d(x_2) + 11S_N)}{x_2{}^2} A(x_1,\ x_2)dx_2}$$

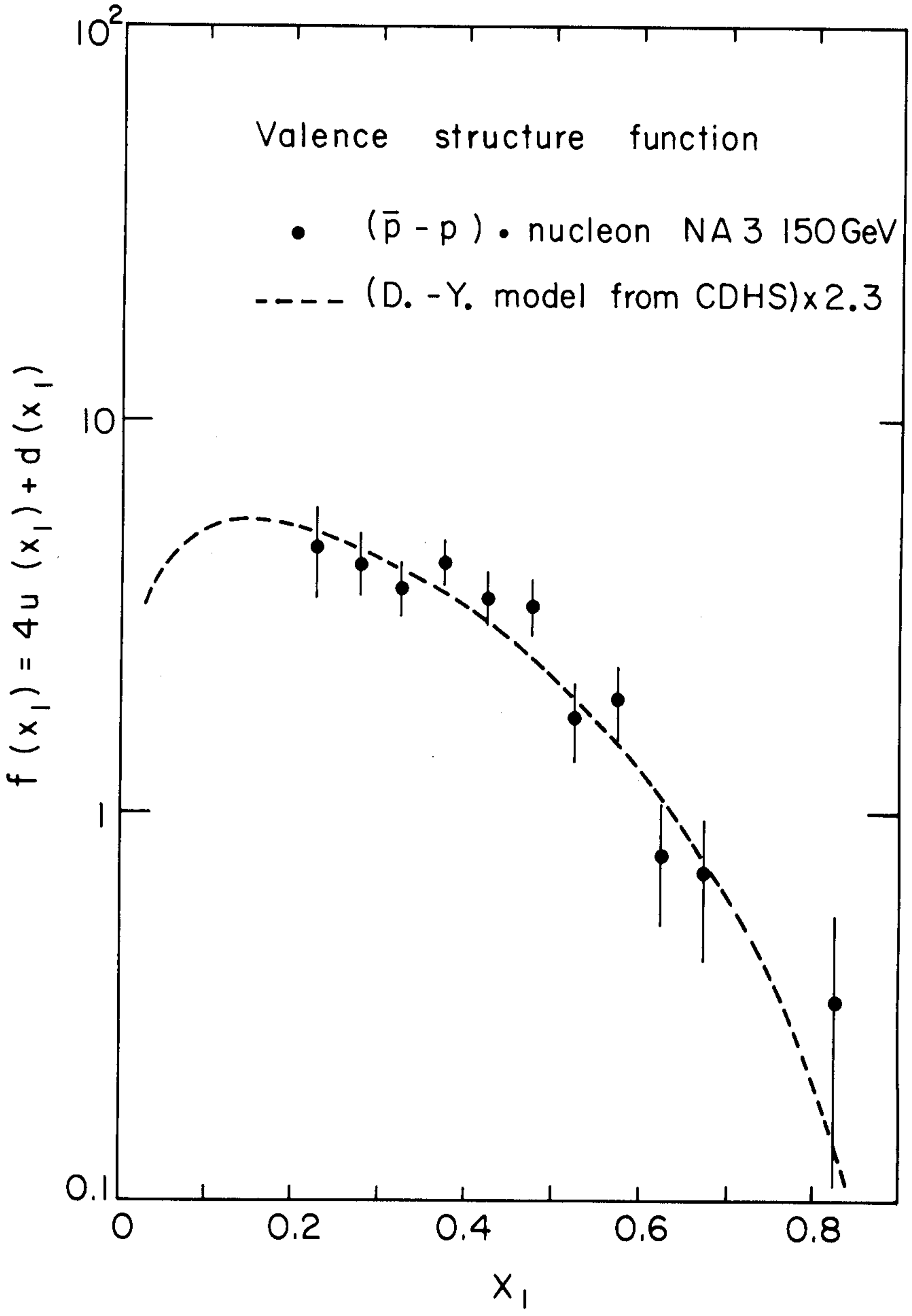

Valence structure function
● (p̄ - p) • nucleon NA 3 150 GeV
---- (D. -Y. model from CDHS) x 2.3
$f(x_1) = 4u(x_1) + d(x_1)$
10^2
10
1
0.1
0
0.2
0.4
0.6
0.8
X_1

Fig.1a

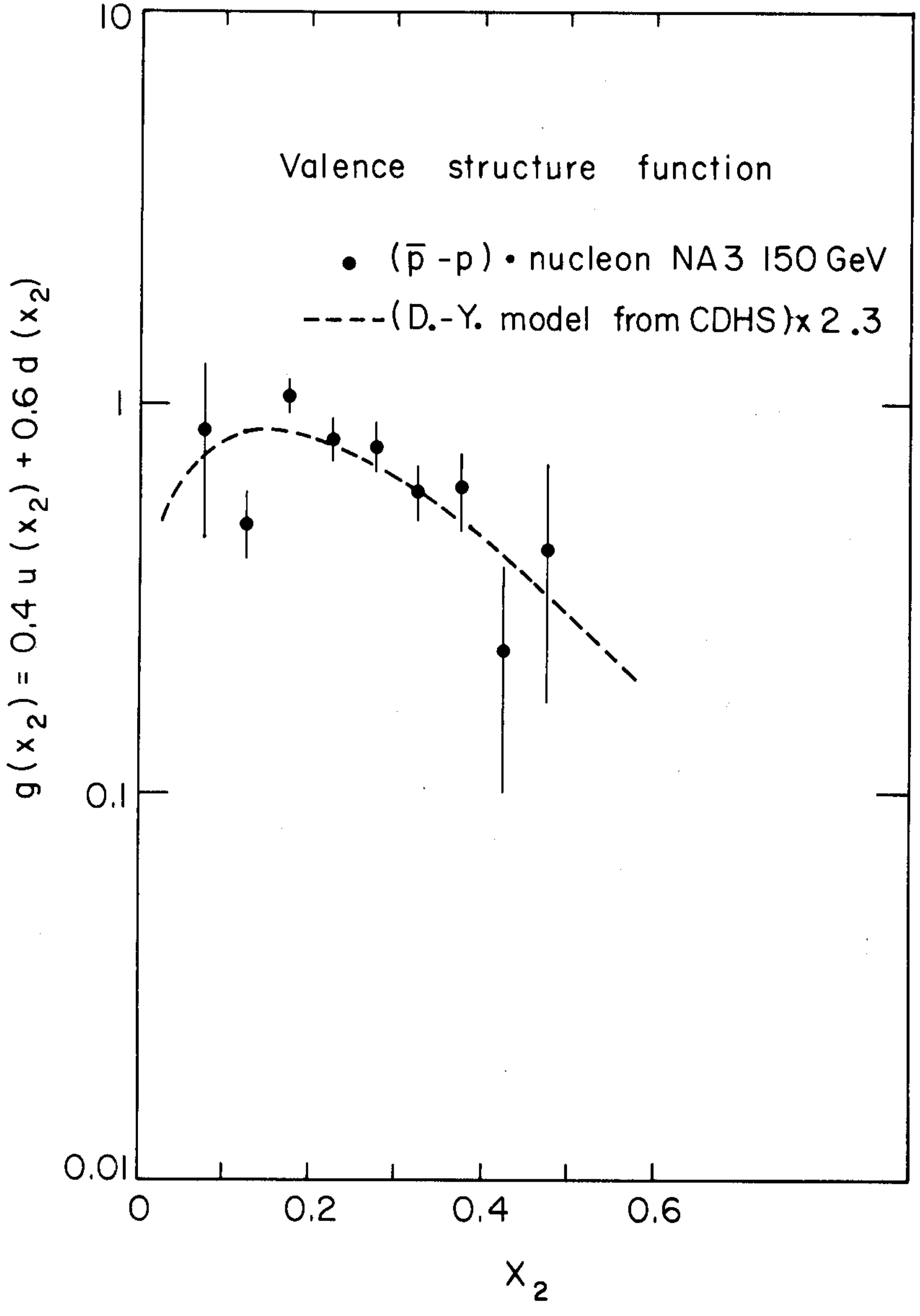
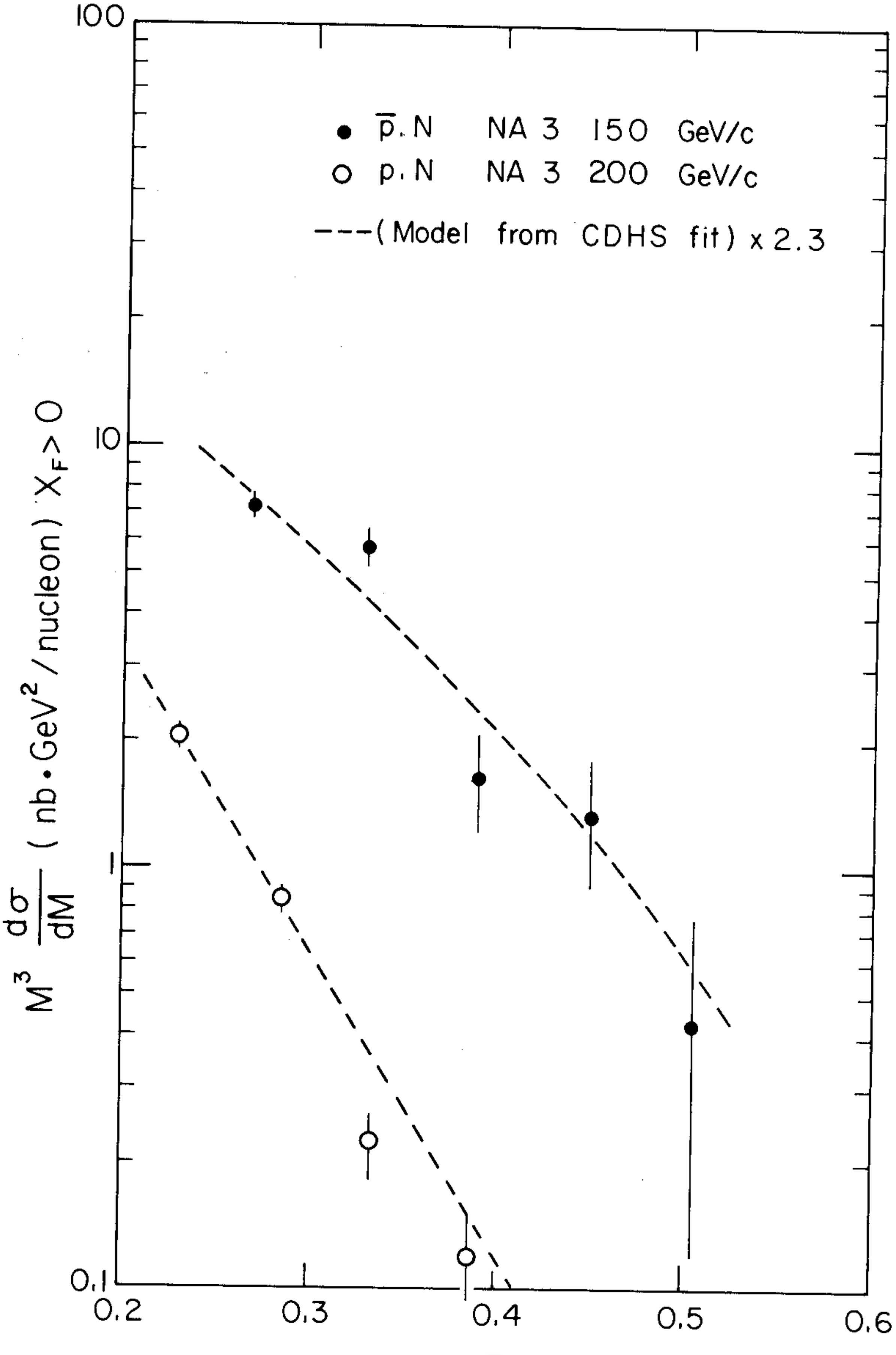

Valence structure function
● ($\bar{p}$ - p) • nucleon NA3 150 GeV
----(D.-Y. model from CDHS) x 2.3
$g(x_2) = 0.4\,u\,(x_2) + 0.6\,d\,(x_2)$
10
1
0.1
0.01
0
0.2
0.4
0.6
X_2

Fig.1b



● p̄.N NA 3 150 GeV/c
○ p.N NA 3 200 GeV/c
---(Model from CDHS fit) x 2.3
100
10
1
0.1
0.2
0.3
0.4
0.5
0.6
$M^3 \frac{d\sigma}{dM}$ (nb • GeV^2 / nucleon) $X_F > 0$
$\sqrt{\tau}$

Fig. 2

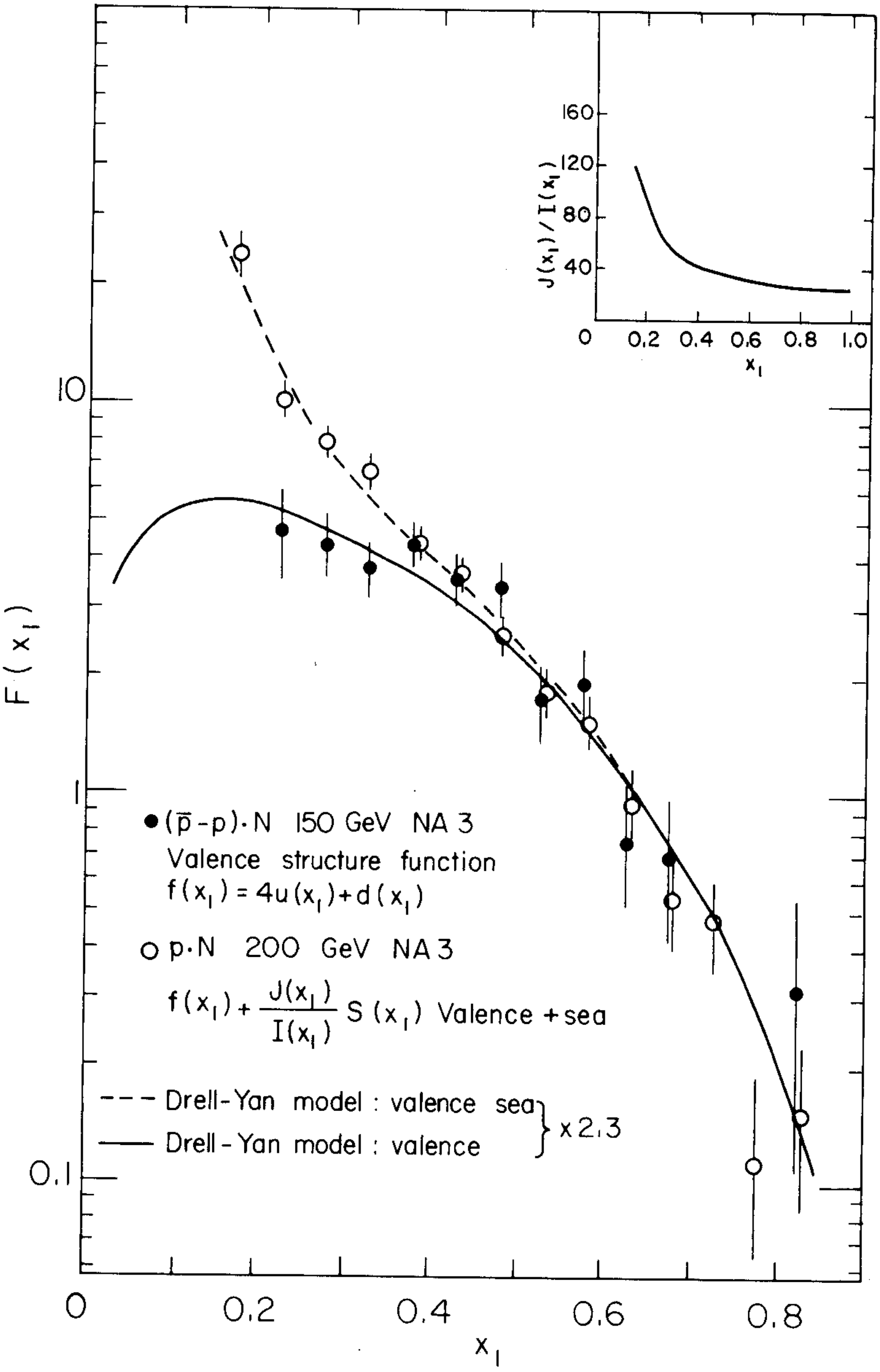

● $(\bar{p}-p)\cdot N$ 150 GeV NA 3
Valence structure function
$f(x_1) = 4u(x_1)+d(x_1)$
○ p·N 200 GeV NA 3
$f(x_1) + \frac{J(x_1)}{I(x_1)} S(x_1)$ Valence + sea
--- Drell-Yan model : valence sea
— Drell-Yan model : valence
x 2.3
F(x₁)
x₁
0.1
1
10
0
0.2
0.4
0.6
0.8
J(x₁)/I(x₁)
40
80
120
160
0
0.2
0.4
0.6
0.8
1.0
x₁

Fig. 3