EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN/EP 80-150
13 August 1980

STUDY OF TRANSVERSE MOMENTUM, SCALING, AND A-DEPENDENCE FOR DIMUON PRODUCTION BY π^- AT 150 TO 280 GeV/c.

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ABSTRACT

We have performed a high statistics analysis of muon pair production. Our sample of events of mass between 4.1 - 8.5 GeV/c^2 consists of 2.2×10^4 events at 150 GeV/c, 5×10^3 events at 200 GeV/c and 5×10^3 events at 280 GeV/c. Part of our 150 GeV/c data (1.3×10^4 events) were taken with an improved forward acceptance.

We present results on scaling, p_T distribution and an analysis of our hydrogen data.

INTERNATIONAL CONFERENCE ON HIGH ENERGY PHYSICS
University of Wisconsin, Madison, U.S.A. 17 July - 23 July 1980

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In the present paper we present results obtained from analysis of massive dimuons produced by π^- at 150, 200 and 280 GeV/c on a platinum target and by π^- at 150 GeV/c on a hydrogen target. The data were collected by the CERN-NA3 experiment between September 1978 and December 1979. The experimental apparatus has been described in previous papers[1,2]. It consists of a multiwire proportional chamber magnet spectrometer and a trigger system based on the p_T selection of one or both muons. We recall here that the incident beam is absorbed in a 1.5 m iron-uranium dump mounted at the entrance of the wide acceptance spectrometer magnet. Two targets (6 cm platinum and 30 cm hydrogen) are mounted on the beam line in front of the beam dump at positions chosen to allow clean separation of events produced on each of the targets and on the absorber. The high statistics of the event sample (see Table 1) and the large acceptance of the apparatus (see fig.1) allow a detailed study of the following features :
a) Test of scaling; b) Study of dimuon production on free protons;
c) Transverse momentum distribution

Further results from the same data on the production of J/ψ's, on the extraction of meson and nucleon structure functions as well as the determination of the absolute cross section are presented at this conference in separate papers[3].

1. SCALING

The scaling property predicted by the basic Drell-Yan model : $M^3 d\sigma/dM = f(M/\sqrt{s})$ has been verified by our 200 and 280 GeV/c π^- data[4], selected in the mass range $M_{\mu\mu} > 4.1$ GeV/c^2 and without any x_F cut, and further confirmed by the results of Barate et al.[5] using a π^- beam at 150 and 175 GeV/c. Only the CIP 225 GeV/c π^- data[6] seems to deviate from scaling when compared to the above results, but this discrepancy is probably due to a non-linear A dependence used in the computation of $d\sigma/dM$ by the CIP group.

In the present paper we present the data coming from our more refined analysis at 200 and 280 GeV/c together with the new high statistics data at 150 GeV/c. All data are selected in the range $M_{\mu\mu} > 4.1$ GeV/c^2 and $x_F \geqslant 0$. The results are shown in fig.2. The scaling behaviour of $M^3 d\sigma/dM$ as a function of τ is well verified within the experimental accuracy estimated to be ±15%. Scaling violation observed in deep inelastic scattering[7] and predicted by QCD first order leading log calculations is of the order of few percent, too small an effect to be observed by our present data. The same conclusions were reached by the CFS collaboration for their high statistics proton data[8].

2. PRODUCTION OF DIMUONS ON HYDROGEN

Our new high statistics data on dimuon produced on hydrogen by 150 GeV/c π^- allow the test of two important physics points : A) Measurement of the absolute Drell-Yan cross section on free proton and check of the corresponding value of the K factor (K = $(d\sigma/dM)exp/(d\sigma/dM)D.Y.$ model). B) Test of possible nuclear effects in dimuon production. This is obtained by direct comparison of dimuon events produced simultaneously by the same beam traversing two successive targets (one platinum and one hydrogen). Such a test is almost free of absolute normalization errors.

A) A direct measurement of the K factor on hydrogen has been performed at 200 GeV/c π^- using 138 events in the mass range $M_{\mu\mu} > 4.1$ GeV/c^2 and yielded the value : K = 2.4 ± 0.4[1], for masses between 4.1 and 8.5 GeV/c^2.

Our present 541 events are produced by 150 GeV/c π^- on the same target and using the same apparatus as for the 200 GeV/c experiment with improved acceptance in the forward direction. This provides an independent and more stringent test on the K factor, statistical accuracy being improved and the mass range extending further, up to the T mass. The result is shown in fig.3 where the experimental cross section $d\sigma/dM$ is plotted as a function of $M_{\mu\mu}$ and is compared to the model predictions thus determining a value of K = 2.4 ± 0.4.

B) The question of possible nuclear effects in dimuon production was raised by the results of Anderson et al.[6] indicating an A-dependent behaviour of the cross section which could be parametrized as A^α with $\alpha = 1.12 \pm 0.05$ for 225 GeV/c pions. As stated above,we have collected simultaneously data on platinum and hydrogen targets, and we are able to compare the corresponding rates which are independent of the absolute normalisation. Using our 150 GeV/c data (541 events on hydrogen, 22290 on platinum in the mass interval 4.1 - 8.5 GeV/c^2), we can analyse the ratio of events per nucleon in the framework of the Drell-Yan model. If we neglect the meson sea contribution, we can write :

$$\frac{d\sigma}{dx_1 dx_2} = K \cdot \frac{\sigma_0}{x_1^2 x_2^2} \frac{1}{9} \left[4\bar{u}^{\pi}(x_1)\, u^T(x_2) + d^{\pi}(x_1)\, \bar{d}^T(x_2)\right]$$

where :

$\sigma_0 = \frac{4\pi\alpha^2}{3s}$, $d^{\pi} = \bar{u}^{\pi}$, and $u^T(\bar{d}^T)$ are the up (anti down) quark structure function in the target.

Comparing hydrogen and platinum data, we take into account the different quark content of the target :

H_2 : $u^T = u^P + s^P$, $\bar{d}^T = s^P$;

Platinum : $u^T = 0.4u^P + 0.6d^P + s^P$, $\bar{d}^T = s^P$;

where u^P, d^P and s^P are the valence and sea structure functions of the proton. The ratio of the x_2 distribution can be expressed as :

$$\frac{\left.\frac{d\sigma}{dx_2}\right|_{H_2}}{\left.\frac{d\sigma}{dx_2}\right|_{Pt}} \simeq \frac{K_{H_2}}{K_{Pt}} \times \frac{4u^P(x_2) + 5s^P(x_2)}{1.6u^P(x_2) + 2.4d^P(x_2) + 5s^P(x_2)}$$

The data are shown in fig.4, and we note an increase of $(d\sigma/dx_2)_{H_2}/(d\sigma/dx_2)_{Pt}$ as function of x_2, with a mean value of about 1.4. This behaviour agrees with the prediction of the Drell-Yan model (solid curve in fig.4), using the CDHS structure function for the proton[7]. Note that we are also sensitive to the difference in shape between u and d, as can be seen in fig.4. Our data favour a parametrization of the nucleon structure function of the form $d(x) \propto u(x)(1-x)$ rather than $u(x) = 2d(x)$, although the latter cannot be completely excluded. The ratio between data and the model prediction is 1.03 ± 0.09. This can be expressed as $K_{H_2}/K_{Pt} = 1.03 \pm 0.09$ using linear A dependance (predicted by the Drell-Yan model) or, using an A dependance parametrization A^{α} and the assumption that $K_{H_2} = K_{Pt}$, as $\alpha = 0.994 \pm 0.015$. Note that the quoted error includes systematic errors estimated to be 5%.

3. TRANSVERSE MOMENTUM DISTRIBUTIONS

Our experiment is particularly well suited for studies of transverse momentum, since the acceptance of the apparatus varies very smoothly with p_T between 0 and 6 GeV/c (see fig.1). The high-p_T events may be due to QCD first order corrections to the Drell-Yan model(9) induced by quark-antiquark annihilation into a photon-gluon pair or by the Compton scattering of quark and gluons. The data are corrected for acceptance in bins of rapidity Y, mass M and transverse momentum p_T of the muon pair. The only assumption was an angular distribution equal to $1 + \cos^2\theta$ in the Gottfried-Jackson frame*). We do not see any significant dependence of the p_T distribution with Y, so the data presented here are integrated over the rapidity interval of our apparatus ($-0.6<Y<1.2$).

Fig.5 shows the p_T distribution of the 150 GeV/c data, for different mass bins. As the data do not exhibit any strong dependence in shape with respect to the mass, we can integrate between 4.1 and 8.5 GeV/c^2 excluding the resonance region. Fig.6 gives comparison of these distribution obtained for our three beam energies. In fig.7 and 8 are plotted the moments $\langle p_T \rangle$ and $\langle p_T^2 \rangle$ as a function of the dimensionless variable τ. We observed an increase of these quantities with $\sqrt{s}$ and a flat or slowly rising dependence with τ. On simple dimensional arguments, QCD predicts a linear s dependence.

$$\langle p_T^2 \rangle = \langle k_T^2 \rangle + \alpha_s \cdot S \cdot F(\tau, y)$$

where k_T is the intrinsic transverse momentum of the partons.
We find for $\sqrt{\tau} = 0.275$:

$$\langle p_T^2 \rangle = (0.74 \pm 0.10)(\mathrm{GeV/c})^2 + (0.0029 \pm 0.0003)s$$

and

$$\langle p_T \rangle = (0.49 \pm 0.08)(\mathrm{GeV/c}) + (0.034 \pm 0.004)\sqrt{s}$$

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*) The exchange of the Gottfried-Jackson frame with the Collins-Soper frame induces an increase of 2% for the $\langle p_T \rangle$ and $\langle p_T^2 \rangle$ moments.

4 . CONCLUSIONS

The dimuons produced in the continuum region at masses above 4.1 GeV/c^2 by 150, 200 and 280 GeV/c pions on a platinum target in the same apparatus show a scaling behaviour . This property is in agreement with the basic Drell-Yan model and with proton beam experiments (8) .

The K factor (K = σ exp/σ D.Y. model) measured on hydrogen target is found equal to 2.4 ± 0.4 . When comparing to the platinum data we observe that the ratio of nucleon structure functions reproduces the different quark compositions of the targets . The ratio K_{H_2}/K_{Pt} is equal to 1.03 ± 0.09, assuming a linear A dependance . If we take $K_{H_2} = K_{Pt}$, we find α =0.994 ±0.015 .

The transverse momentum distributions show a very weak dependance with the mass, and a regular increase with the center of mass energy . Using our three energies, we find a parametrization for the transverse momentum squared, at $\sqrt{\tau} = 0.275$:

$$\langle P_T^2 \rangle = 0.74\ (\mathrm{GeV/c})^2 + 0.0029\ S$$

REFERENCES

(1) J. Badier et al., Phys. Lett., 86B (1979) 98 .

(2) J. Badier et al., A large acceptance spectrometer to study high mass muon pairs ; CERN-EP Preprint 80/36 (1980) ; submitted to Nuclear Instruments and Methods .

(3) J. Badier et al., Determination of the π and K meson structure functions from massive dimuons produced at 150 and 200 GeV/c ; Paper submitted to the International Conference on High Energy Physics 1980, University of Wisconsin, Madison, U.S.A.

J. Badier et al., Experimental determination of the antiproton structure function by the Drell-Yan mechanism ; Paper submitted to the International Conference on High Energy Physics 1980, University of Wisconsin, Madison, U.S.A.

J. Badier et al., High statistics study of J/ψ production and Υ production by $\pi^{\pm}$ and $p^{\pm}$ in the momentum range 150 to 280 GeV/c. CERN/EP 80-149 ; Paper submitted to the International Conference on High Energy Physics 1980, University of Wisconsin, Madison, U.S.A.

(4) J. Badier et al., Muon pair production at masses above 4 GeV (Drell-Yan continuum) by $\pi^{\pm}$, $K^{\pm}$, $\bar{p}$ and p of 200 GeV/c and $\pi^{-}$of 280 GeV/c on platinum and hydrogen targets . CERN/EP Preprint 79-68, Paper submitted to the International Conference on High Energy Physics, Geneva 1979 .

(5) R. Barate et al., Phys. Rev. Lett.

(6) K.J. Anderson et al., Phys. Rev. Lett., 42 (1979) 944 .

G.E. Hogan et al., Phys. Rev. Lett., 42 (1979) 948 .

(7) J.G.H. de Groot et al., Phys. Lett., 82B (1978) 948 .

(8) A.S. Ito et al., Fermilab-pub-80/19-EXP 7180.288, submitted to Phys. Rev. D .

(9) G. Altarelli, G. Parisi and R. Petronzio, Phys. Lett., 76 (1978) 351 and Phys. Lett., 76B (1978) 356 .

K. Kajantie and R. Raitio, Nucl. Phys., B139 (1978) 72 .

F. Halzen and D.M. Scott, Phys. Rev. Lett., 40 (1978) 1117 and Phys. Rev., 18D (1978) 3378 .

TABLE I

Data (Sept. 78 - Dec. 79)

		Pt TARGET J/ψ	Pt TARGET M > 4.1	H_2 TARGET J/ψ	H_2 TARGET M > 4.1
$-$ 280 GeV/c	π^-	130 000	4 700		
$-$ 200 GeV/c	π^-	145 000	4 970	3 000	138
	K^-	2 800	90	56	
	$\bar{P}$	1 000	32	17	
+ 200 GeV/c	π^+	108 000	1 750	2 200	40
	K^+	16 000	170	340	
	P	101 000	1 070	2 200	
$-$ 150 GeV/c	π^-	703 000	21 600	18 800	541
	K^-	24 000	688	550	
	$\bar{P}$	9 000	275	250	

FIGURE CAPTIONS

Fig. 1 Acceptance of the apparatus, as function of $X = 2\,p_L^*/\sqrt{s}$, of the transverse momentum p_T and of the dimuon mass M .

Fig. 2 Plot of $M^3 d\sigma/dM$, as a function of $\sqrt{\tau} = M/\sqrt{s}$ for π^- at 280, 200 and 150 GeV/c . Points in the upsilon region are not plotted .

Fig. 3 Plot of $d\sigma/dM$ on hydrogen target at 150 GeV/c (541 events) .

Fig. 4 Ratio of the $d\sigma/dx_2$ distributions, per nucleon, on hydrogen and platinum targets, function of x_2 .

Fig. 5 Differential cross section $1/p_T \cdot d\sigma/p_T$ of 150 GeV/c pions for different mass bins .

Fig. 6 Comparison of $1/p_T\, d\sigma/dp_T$ for different energies, and mass between 4.1 and 8.5 GeV/c^2 .

Fig. 7 Average value $\langle p_T \rangle$, function of $\sqrt{\tau}$, for 280, 200 and 150 GeV/c pions .

Fig. 8 Average value $\langle p_T^2 \rangle$, function of $\sqrt{\tau}$ for all energies .

Fig. 9 Variation of $\langle p_T^2 \rangle$ with s, for $\sqrt{\tau} = .275$. The straigh line is a linear fit from our three points .

ACCEPTANCE

IN X, P_T, $M_{\mu\mu}$ at 200 GeV/c

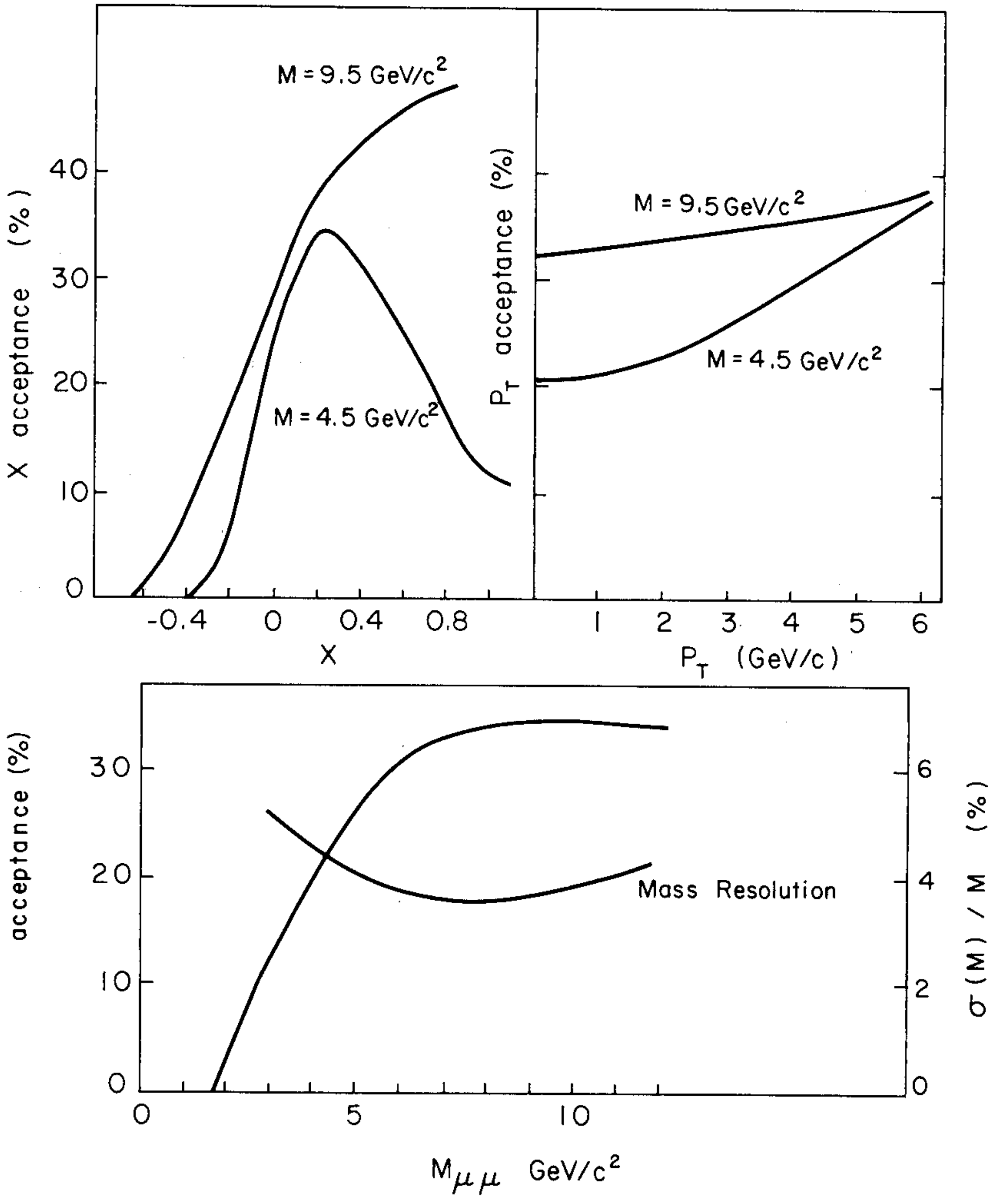
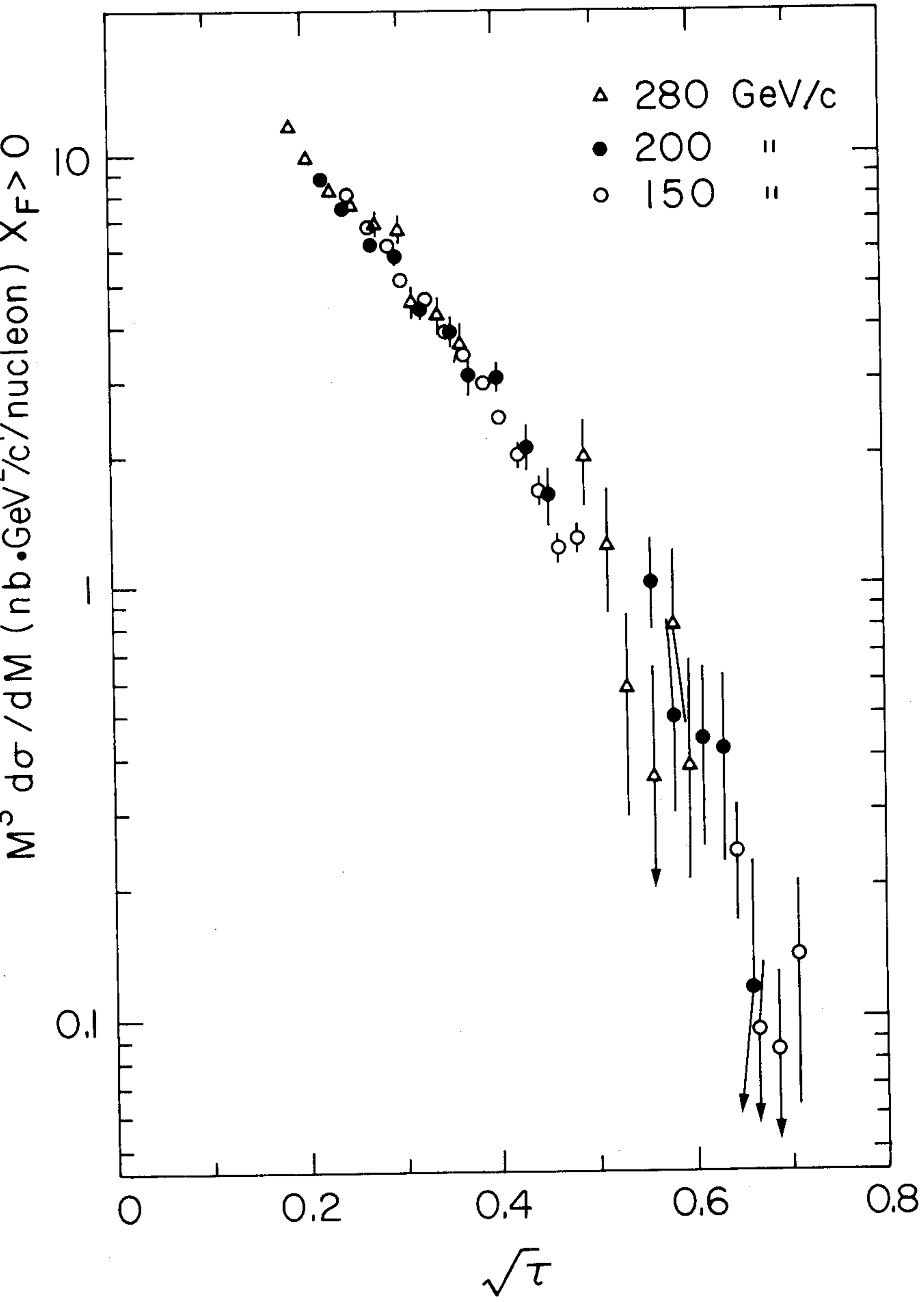
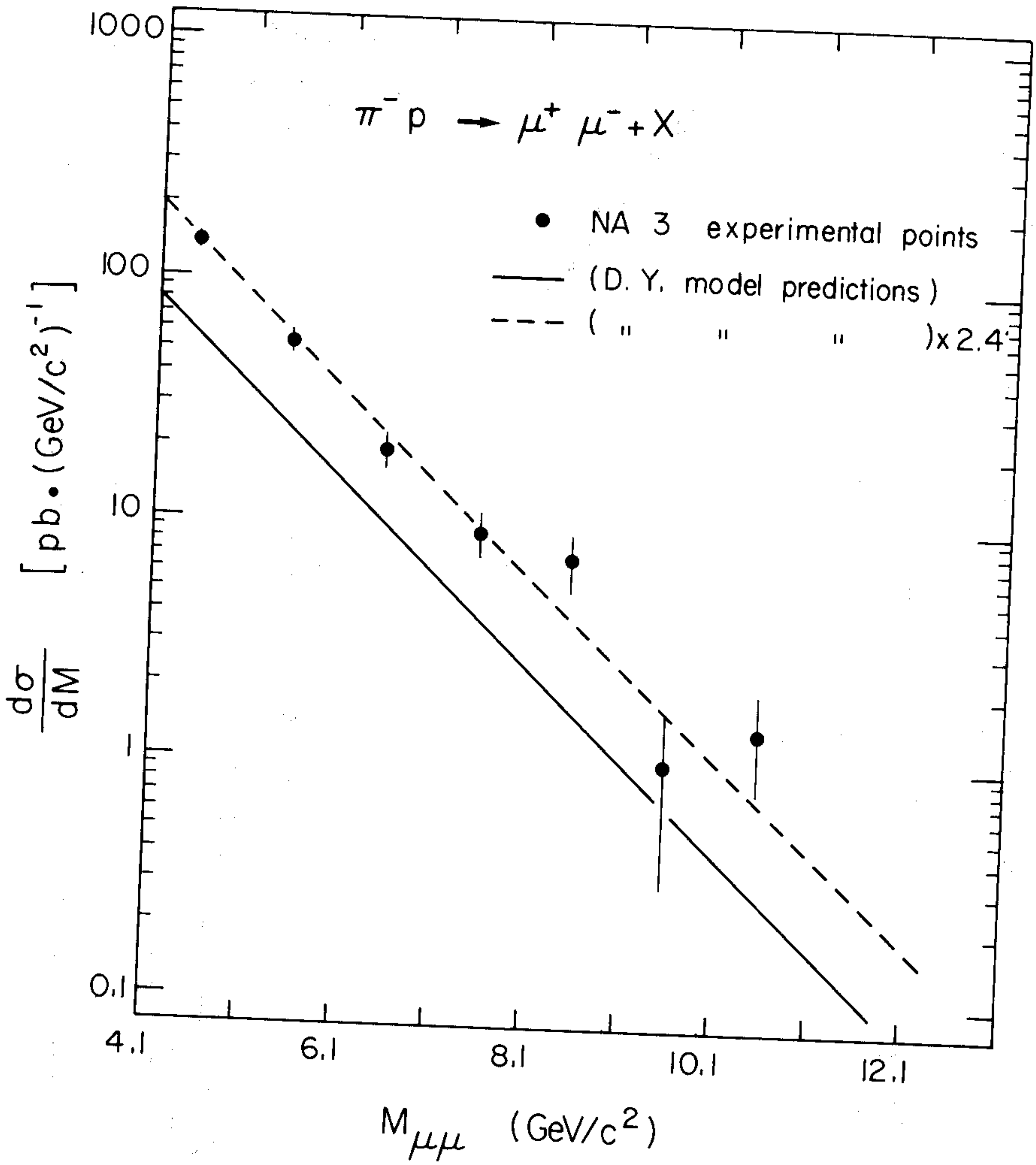


FIG. 1



△ 280 GeV/c
● 200 "
○ 150 "
M³ dσ/dM (nb•GeV²/c⁴/nucleon) X_F > 0
10
1
0.1
0
0.2
0.4
0.6
0.8
√τ

Fig. 2



1000
100
10
1
0,1
4,1
6,1
8,1
10,1
12,1
$\pi^- p \rightarrow \mu^+ \mu^- + X$
NA 3 experimental points
(D. Y. model predictions)
(" " ")x 2.4
$\frac{d\sigma}{dM}$ [pb • (GeV/c^2)$^{-1}$]
$M_{\mu\mu}$ (GeV/c^2)

Fig. 3

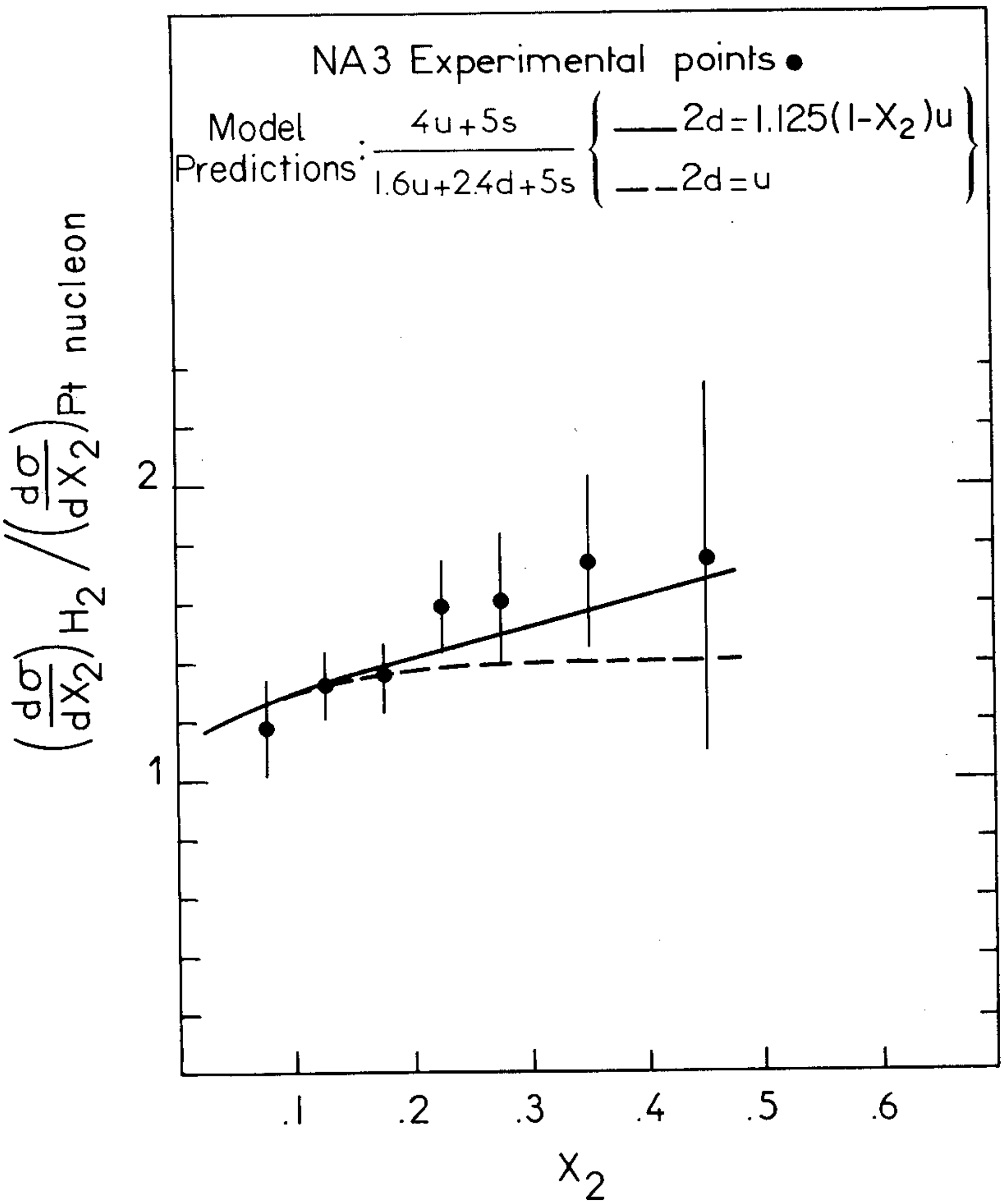
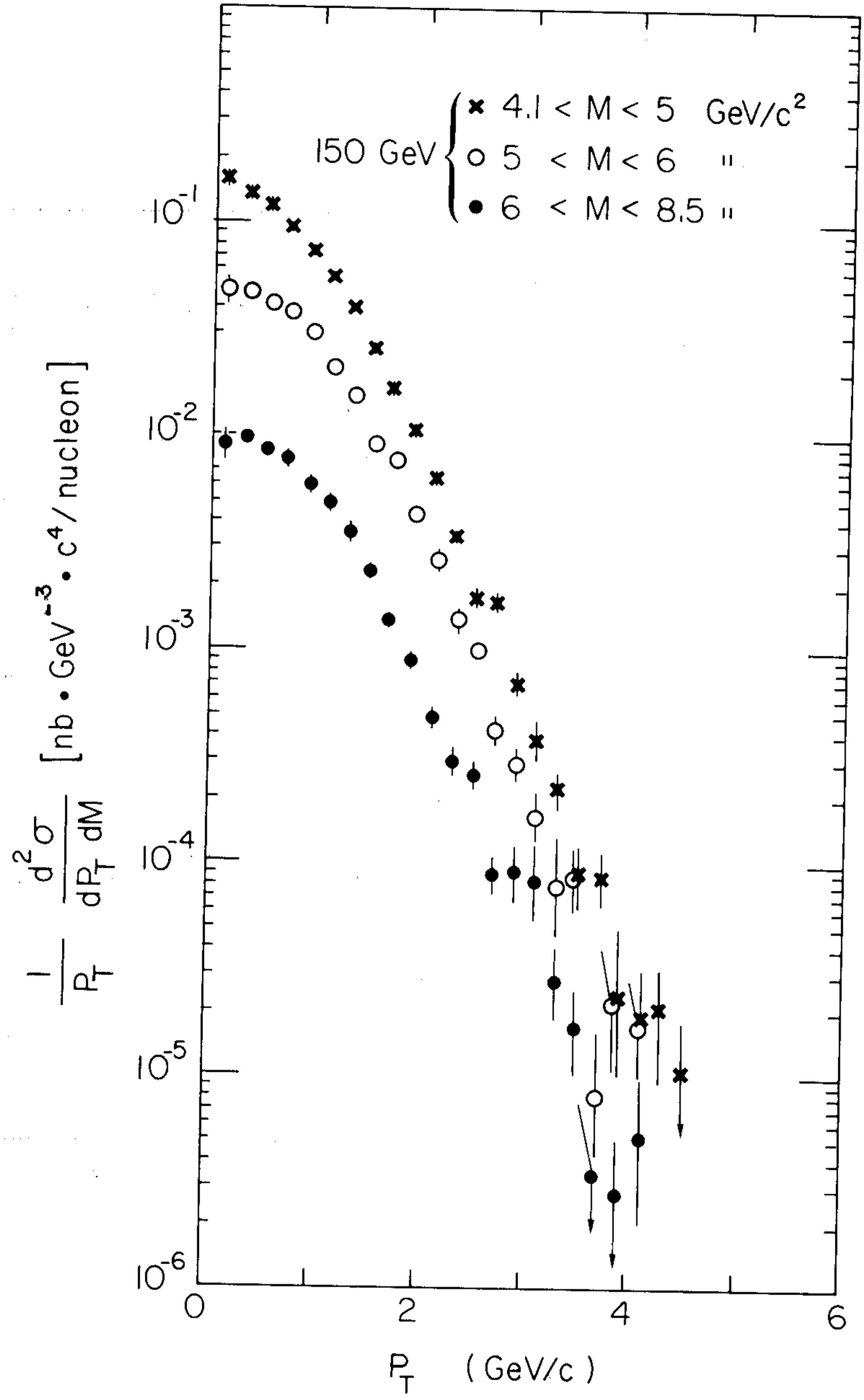

NA3 Experimental points •
Model Predictions : $\frac{4u+5s}{1.6u+2.4d+5s}$ { —— 2d = 1.125(1-X$_2$)u ; – – 2d = u }
$\left(\frac{d\sigma}{dX_2}\right)_{H_2} \Big/ \left(\frac{d\sigma}{dX_2}\right)_{Pt\ nucleon}$
2
1
.1
.2
.3
.4
.5
.6
X_2

Fig. 4



150 GeV
4.1 < M < 5 GeV/c²
5 < M < 6 "
6 < M < 8.5 "
10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶
0
2
4
6
P_T (GeV/c)
1/P_T d²σ/dP_T dM [nb • GeV⁻³ • c⁴/nucleon]

Fig. 5

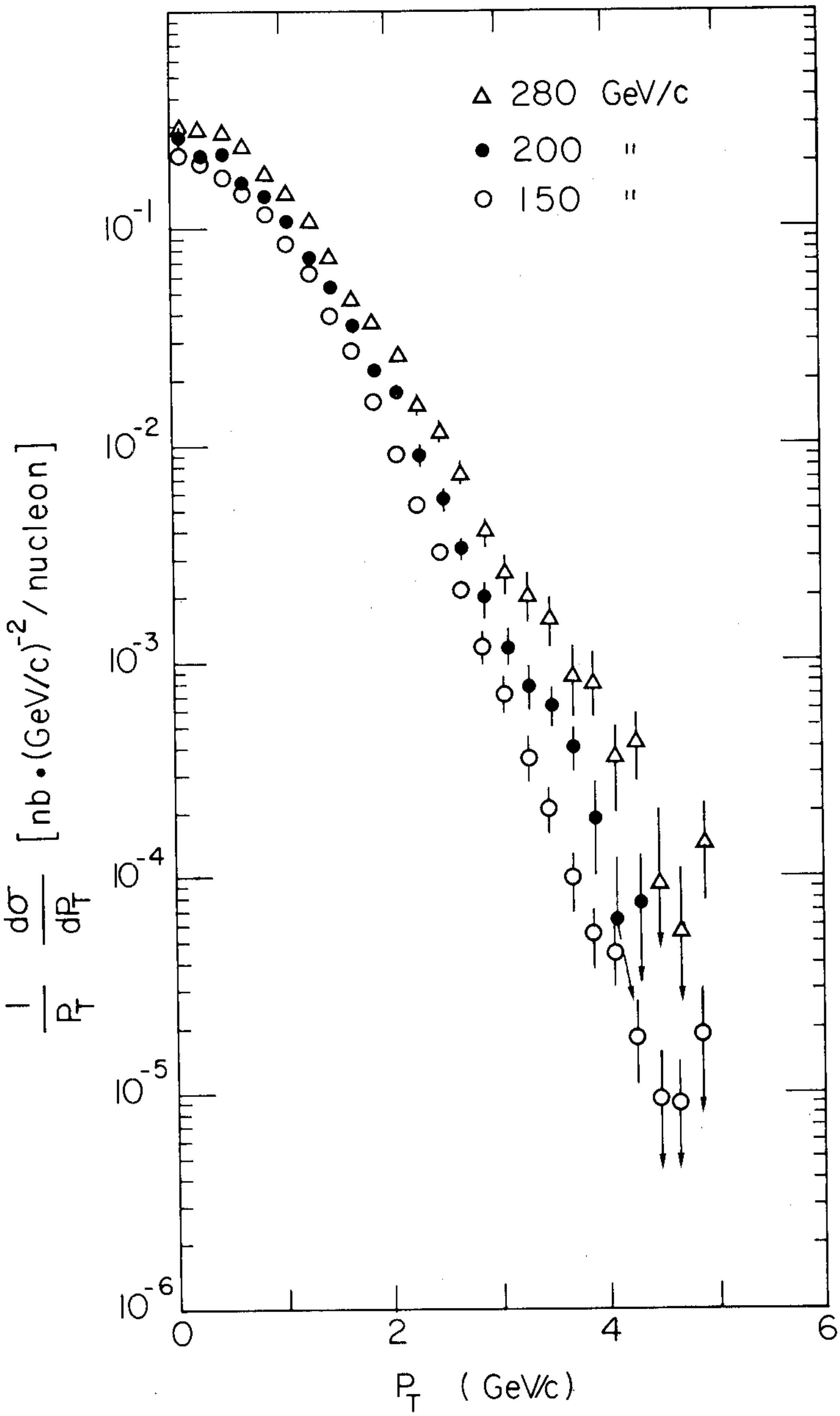

280 GeV/c
200 "
150 "
$\frac{1}{P_T}\frac{d\sigma}{dP_T}$ [nb • (GeV/c)$^{-2}$ / nucleon]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
0
2
4
6
P_T (GeV/c)

Fig. 6

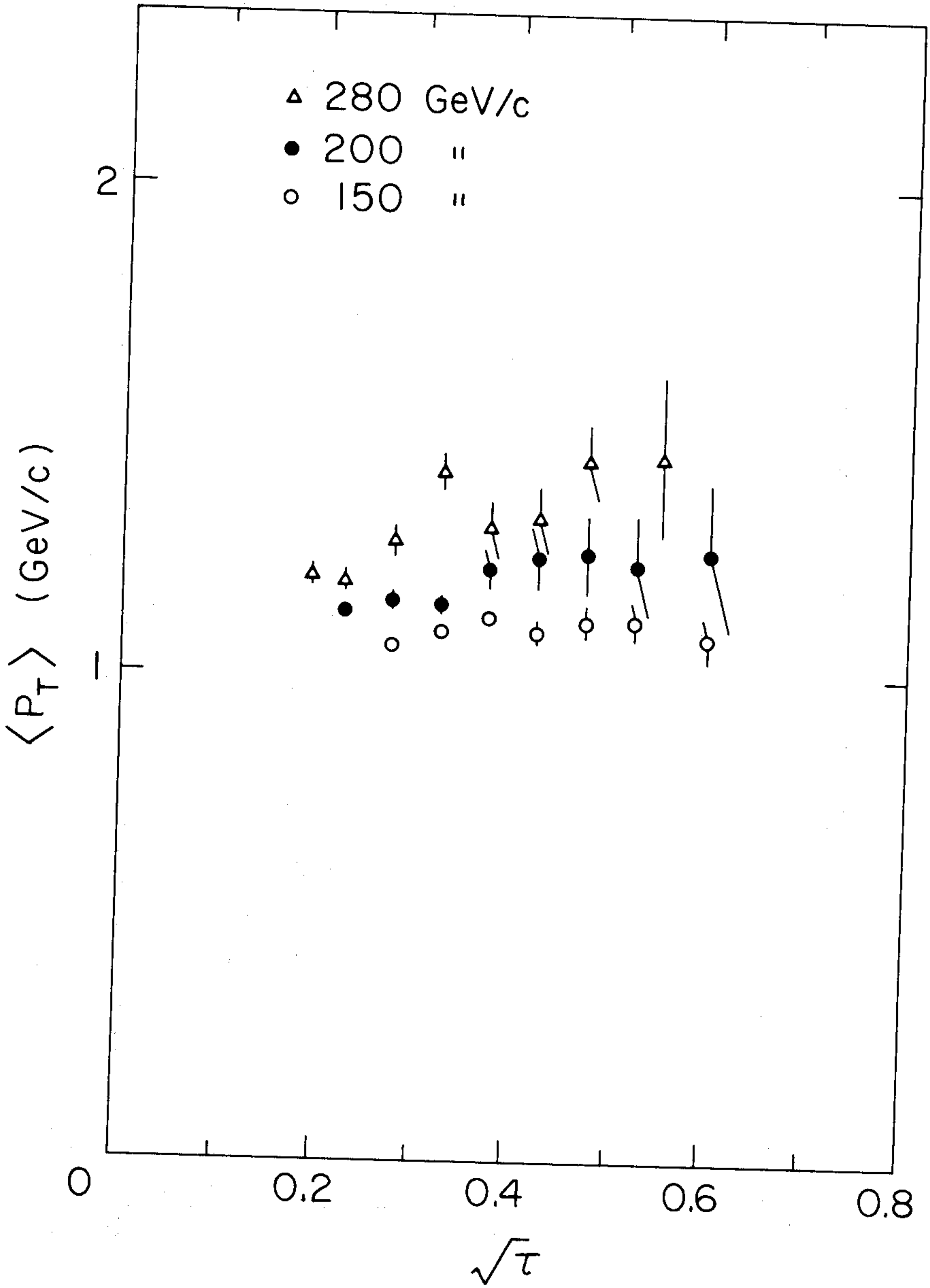
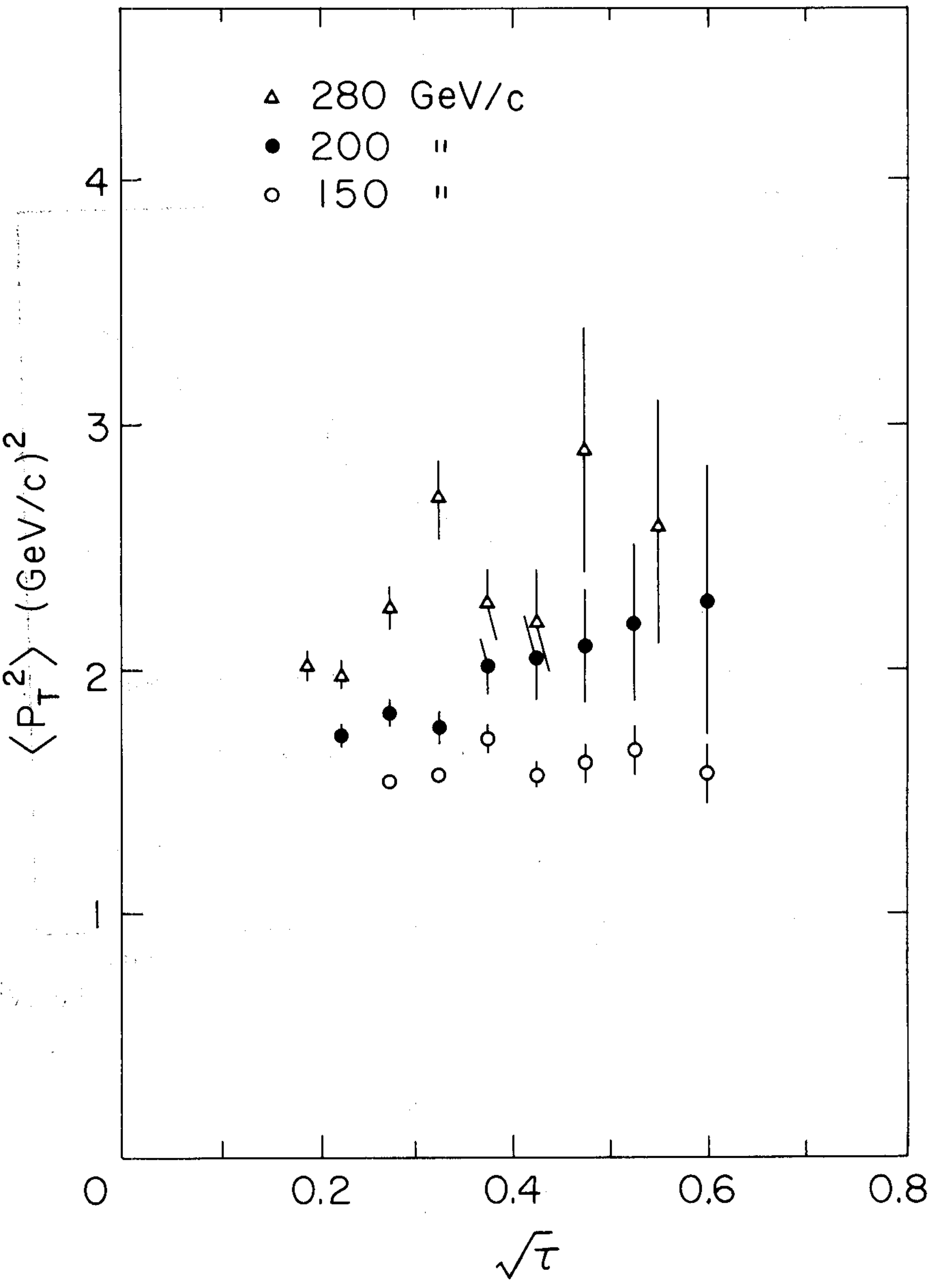
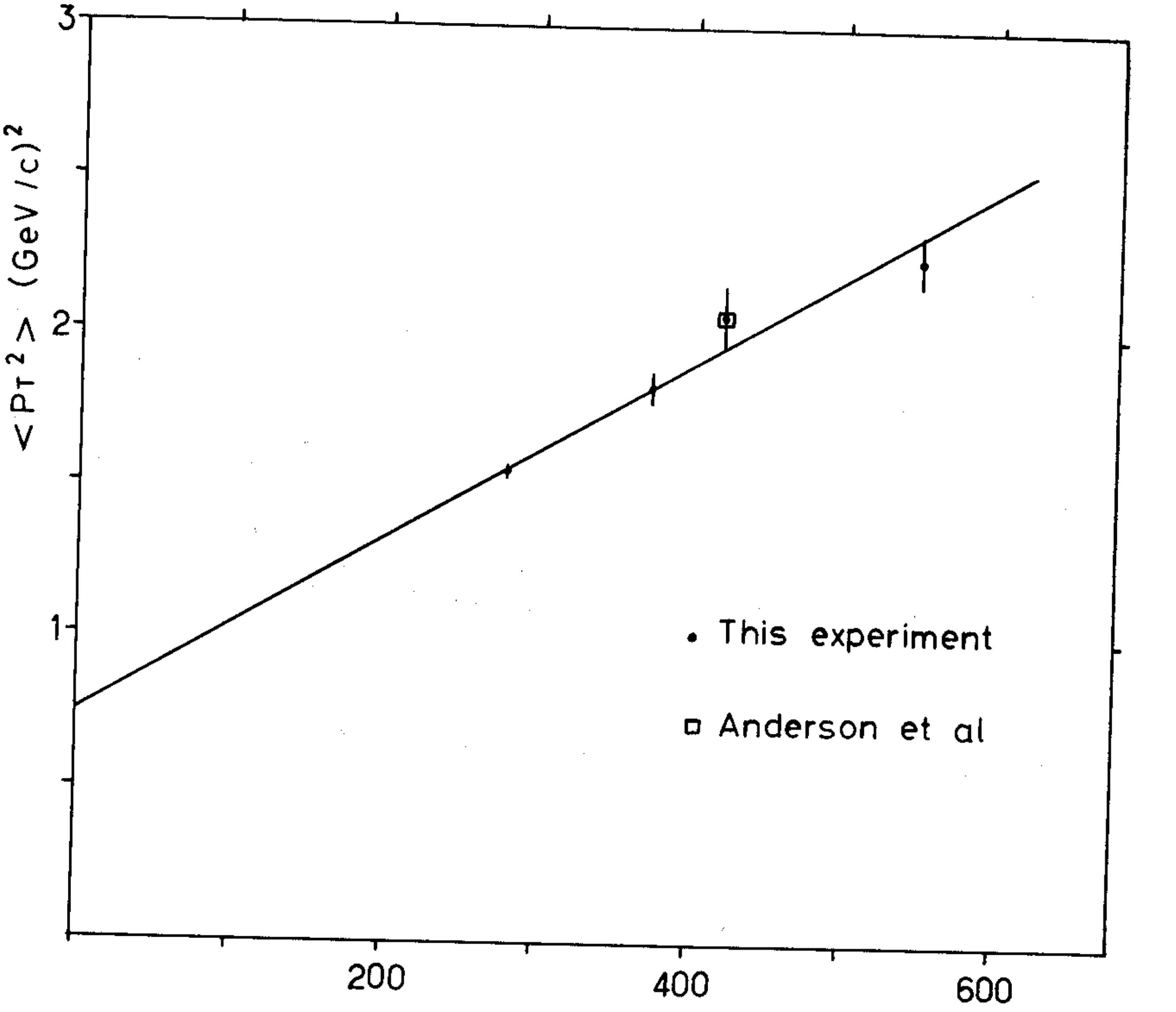


Fig. 7



280 GeV/c
200 "
150 "
$\langle P_T^2 \rangle$ (GeV/c)^2
4
3
2
1
0
0.2
0.4
0.6
0.8
$\sqrt{\tau}$

Fig. 8



3
2
1
$<P_T^2>$ (GeV/c)^2
200
400
600
S (GeV^2)
• This experiment
□ Anderson et al

Figure 9