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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.

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ABSTRACT

We have performed in the NA3 experiment a study of high mass dimuon production by an unseparated hadron beam on hydrogen and platinum targets. This experiment collected a large statistics of J/ψ events ($\sim 10^6$ on platinum target and 20,000 on hydrogen) for various beam momenta (150, 200 and 280 GeV/c) and incident particles ($\pi^{\pm}$, $p^{\pm}$). The comparison of the production cross-section for proton and antiproton together with the differential cross-section $d\sigma/dx$ allows us to compare the data with a production mechanism involving quark-antiquark and gluon-gluon interactions. The $\cos\theta^*$ distribution of the same J/ψ data have also been analysed and results will be presented. Finally we have observed Υ production by incident pions of 150 GeV/c.

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INTRODUCTION

New measurements of dimuon production have been obtained in the NA3 experiment at CERN. They provide results on J/ψ and Υ production in hadron-hadron interactions at 150 GeV/c. Statistics on the J/ψ region for hydrogen and platinum targets are given in table 1. The mass spectrum for π^- on hydrogen and platinum targets is shown in fig.1 and fig.2.

This paper is divided into four sections. In section 1 we give the ratio of the J/ψ production by π^+ and π^-, by proton and antiproton, then the A dependence power law, and the total cross sections.

In section 2 we compare the J/ψ differential cross section $d\sigma/dx$ for incident protons and antiprotons with the prediction of a model involving only gluon-gluon and light quark-antiquark fusion.

The angular distribution of dimuons from J/ψ decay for different values of x_1 is studied in section 3. In section 4 we give Υ production by pions.

1. A DEPENDENCE AND J/ψ CROSS SECTION

a) J/ψ production by positive and negative pions

On the mass spectrum, the events called J/ψ are those corresponding to $2.7 < M < 3.5$ GeV from which we have subtracted a continuum background determined by events at higher and lower dimuon masses.

Using our $\pi^\pm$ data on hydrogen and on platinum we can compute :

$$R^+ = \frac{N(\pi^+ H_2 \to J/\psi)}{N(\pi^+ Pt \to J/\psi)} \quad \text{and} \quad R^- = \frac{N(\pi^- H_2 \to J/\psi)}{N(\pi^- Pt \to J/\psi)}$$

which are independant of the incident particle flux calibration, since the two targets are used simultaneously, and $R = R^+/R^-$, which is independent of the acceptance and the number of the nuclei of the target since the apparatus are the same for the two polarities.

Then

$$R = \frac{\sigma(\pi^+ H_2 \to J/\psi)}{\sigma(\pi^+ Pt \to J/\psi)} \Big/ \frac{\sigma(\pi^- H_2 \to J/\psi)}{\sigma(\pi^- Pt \to J/\psi)}$$

Let us call

$$\sigma^+ = \sigma(\pi^+ p \to J/\psi) = \sigma(\pi^- n \to J/\psi)$$

and

$$\sigma^- = \sigma(\pi^- p \to J/\psi) = \sigma(\pi^+ n \to J/\psi)$$

Assuming a power law for the A dependence

$$R = \frac{\sigma^+}{A^\alpha(0.4\sigma^+ + 0.6\sigma^-)} \Big/ \frac{\sigma^-}{A^\alpha(0.4\sigma^- + 0.6\sigma^+)}$$

The A^α cancels and we deduce the ratio σ^+/σ^- directly from the measured values of R. We get :

at 150 GeV/c $\sigma^+/\sigma^- = 0.94 \pm 0.08$

at 200 GeV/c $\sigma^+/\sigma^- = 0.99 \pm 0.06$

where a systematic error of ±0.05 is included.

From these values we deduce

$$R_{Pt} = \frac{\sigma(\pi^+ Pt \to J/\psi)}{\sigma(\pi^- Pt \to J/\psi)} = \frac{(0.4(\sigma^+/\sigma^-) + 0.6)}{(0.4 + 0.6(\sigma^+/\sigma^-))}$$

Then,

at 150 GeV/c $R_{Pt} = 1.01 \pm 0.02$

at 200 GeV/c $R_{Pt} = 1.00 \pm 0.01$

These results allow us to calibrate the π^+/π^- relative luminosity with an accuracy of 2%.

b) A dependence

We use here the π^- data on hydrogen and platinum targets to compute

$$\sigma^- = \sigma(\pi^- p \to J/\psi)$$

and

$$\sigma^-_{Pt} = \sigma(\pi^- Pt \to J/\psi)$$

With the same assumptions as in the paragraph a) we get

$$A^\alpha = \frac{\sigma^-_{Pt}}{(0.4\sigma^- + 0.6\cdot(\sigma^+/\sigma^-)\cdot\sigma^-)}$$

With our values of σ^+/σ^- we find for α the values given in table 2. In this table we have also indicated the results of the other experiments.

The mean value of our measurement is

$$\alpha = 0.94 \pm 0.02$$

c) J/ψ production by protons and antiprotons

The relative luminosity for protons and antiprotons in the positive and negative beam have been determined by threshold and differential (CEDAR) Cerenkov counters, respectively, with an accuracy of 10%. The $p/\bar{p}$ cross section ratios are reported on table 4. The errors are mainly due to the protons and antiprotons identification. The proton to antiproton ratio decreases with energy as it is expected since the light quark fusion mechanism contribution increases when the energy decreases.

d) J/ψ cross section

The J/ψ cross section per platinum nucleus, for $x_F > 0$ is reported on table 3.

Using our A dependence we have plotted on fig.3, on a logarithmic scale, the known values of $M^2\sigma_{tot}$ for $x_F > 0$, as a function of $\sqrt{\tau}$. Note that our point at $\sqrt{\tau} = 0.135$, corresponding to 280 GeV/c comes from our first sample of data and will be improved when we will have analysed all our 280 GeV/c data.

2. dσ/dx DIFFERENTIAL CROSS SECTION

Assuming that the J/ψ is produced only by light quark-antiquark annihilation and gluon-gluon interaction (in fact charmed quark production seems to be negligible [1]) we can write the antiproton over proton differential cross section ratio as

$$R(x) = \frac{(d\sigma/dx)\bar{p}}{(d\sigma/dx)p} = \frac{\sigma_g f_g(x) + \sigma_q f_q^{\bar{p}}(x)}{\sigma_g f_g(x) + \sigma_q f_q^{p}(x)} \qquad (1)$$

where

$$x = 2P_L^*/\sqrt{s}$$

The function $f_g^p = f_g^{\bar{p}} = f_g$ and $f_q^{p,\bar{p}}$, corresponding to the gluon-gluon and quark-antiquark interaction respectively can be calculated using the nucleon structure functions determined by : (a) the CDHS experiment[2], (b) our experiment[12]

The proportion of J/ψ events produced by gluon-gluon interaction can be written as

$$R_g^{p}(x) = 1 - \frac{R(x) - 1}{A(x) - 1} \quad \text{for protons}$$

and

$$R_g^{\bar{p}}(x) = 1 - \frac{A(x)}{A(x) - 1} \cdot \frac{R(x) - 1}{R(x)} \quad \text{for antiprotons}$$

where

$$A(x) = f_q^{\bar{p}}(x)/f_q^{p}(x)$$

which can be calculated using the quark and antiquark structure functions from CDHS experiment[2].

For example, at $x = 0$, using our measured value

$R(0) = 2.0 \pm 0.4$ (systematic error included)

we have computed the proportion of J/ψ events produced by gluon-gluon interaction :

- in proton-proton reaction :

(a) $R_g^{p}(0) = 0.69 \pm 0.15$ (b) $R_g^{p}(0) = 0.67 \pm 0.20$

- in proton-antiproton interaction :

(a) $R_g^{\bar{p}}(0) = 0.35 \pm 0.15$ (b) $R_g^{\bar{p}}(0) = 0.33 \pm 0.18$

Notice that these results are independent of the gluon structure function.

Using these values and the gluon structure function of the nucleon from CDHS, one can compute

(a) $\sigma_q/\sigma_g = 5.5 \pm 2.2$ (b) $\sigma_q/\sigma_g = 5.5 \pm 2.5$

Equation (1) allows to compute $R(x)$ from the value of σ_q/σ_g. Fig. 4 demonstrates that the shape of the computed value $R(x)$ is compatible with the experimental points within the statistical errors.

3. ANGULAR DISTRIBUTION

Using the π^- data we have fitted the J/ψ angular distribution, corrected by acceptance, in the Collins-Soper frame, for different slices in x_F and p_T by the term :

$$\frac{d\sigma}{d(\cos\theta)} = 1 + \lambda\cos^2\theta$$

As an example the acceptance and the angular distribution is given in fig.5 at $0.5 < x_1 < 0.6$, for J/ψ produced by 150 GeV/c pions on platinum.

In fig.6 we show the values of λ vs x_F. From J/ψ events we have subtracted a Drell-Yan type background. This background amounts to about 10% of the J/ψ events. Because of the uncertainty in the background subtraction, we have an additional systematic error of $\Delta\lambda \simeq \pm 0.05$, not indicated in fig.6.

The λ parameter is always close to zero, independent of x_F and p_T. At 200 GeV/c incident pions we found $\langle\lambda\rangle = 0.05 \pm 0.07$ (see ref.3)

This result on λ seems to indicate that, at our energies, the direct J/ψ production by light quark fusion is not dominant,since, in this model λ must be near one. However an isotropic angular distribution is not in contradiction with the J/ψ production by light quark fusion via an intermediate state.

4. UPSILON PRODUCTION

In fig.7 we show the mass spectrum for π^- at 150 GeV, together with the already published mass spectrum at high pion energies[4].
In spite of this relatively low energy, we see an excess of events in the Υ region.

The corresponding cross sections are reported in fig.8 and table 5.

CONCLUSIONS

a) The study of J/ψ (i.e. $2.7 < M < 3.5$ GeV) production by incident $\pi^\pm$ and $p^\pm$ on hydrogen and platinum leads us to the following conclusions :

- The ratio
$$R = \frac{\pi^+ Pt \to \psi}{\pi^- Pt \to \psi}$$
is equal to 1 within less than 2% at 150 and 200 GeV/c.
- Using π^- data on hydrogen and platinum we find an A dependence parameter $\alpha = 0.94 \pm 0.02$
- The ratio of $(\bar{p}N \to \psi)/(pN \to \psi)$ decreases with energy. Assuming that J/ψ is produced via two mechanisms : light quark fusion (σ_q) and gluon-gluon interaction (σ_g) we get, at 150 GeV/c : $\sigma_q/\sigma_g = 5.5 \pm 2.2$
- The angular distribution of J/ψ produced by π^- in the Collins-Soper frame is approximately flat, and it is independent of x_F and p_T. This result can suggest that the fraction of J/ψ production by light quark annihilation occurs mainly via an intermediate state.

b) We have estimated the cross section of Υ production by pions at three energies. This cross section exhibits a strong energy dependence.

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TABLE 1

Statistics of J/ψ events ($x_F > 0$)

Energy GeV/c	Target	π^-	K^-	$\bar{p}$	π^+	K^+	p
150	Pt	605600	19276	6619	7936	409	3642
	H_2	16330	474	194	202	15	118
200	Pt	145000	2800	1000	108000	16000	101000
	H_2	3000	56	17	2200	340	2300

TABLE 2

A dependence power α value for incident pions

References	p_{inc} (GeV/c)	α
Anderson et al (5)	225	0.87 ± 0.05
Antipov et al (7)	43	0.92 ± 0.06
BCP (8)	40	0.97 ± 0.03
this experiment	150	0.935 ± 0.025
this experiment (9)	200	0.95 ± 0.03
this experiment (9)	280	0.935 ± 0.025

TABLE 3

J/ψ cross section per platinum nucleus for π^- (μb/nucleus)

P_{beam}(GeV/c)	150	200	280
$\sqrt{\tau}$	0.179	0.160	0.135
$B\sigma(x_F>0)$	0.77 ± 0.09	0.95 ± 0.12	1.05 ± 0.24

TABLE 4

P_{inc} GeV/c	Target	$\frac{\sigma(\pi^+ \to J/\psi)}{\sigma(\pi^- \to J/\psi)}$	$\frac{\sigma(p \to J/\psi)}{\sigma(\bar{p} \to J/\psi)}$
150	P_T	1.01 ± 0.02	0.50 ± 0.08
	H_2	0.94 ± 0.08	0.51 ± 0.09
200	P_T	1.00 ± 0.01	0.71 ± 0.16
	H_2	0.99 ± 0.06	

J/ψ cross section ratio for $x_F > 0$

TABLE 5

Υ production cross section by pions

Particle	π^-	π^-	π^-	π^+
Energy (GeV/c)	150	200	280	200
Number of Υ events	63 ± 15	55 ± 15	66 ± 20	53 ± 12
$B\sigma(\Upsilon + \Upsilon' + \Upsilon'')$ (pb/nucleon)	0.36 ± 0.15	1.5 ± 0.5	2.4 ± 0.9	1.9 ± 0.6

FIGURE CAPTIONS

Fig. 1 Mass spectrum for π^- on hydrogen at 150 GeV/c.

Fig. 2 Mass spectrum for π^- on platinum at 150 GeV/c.

Fig. 3 $M^2\sigma_{tot}$ for J/ψ production at $x_F > 0$.

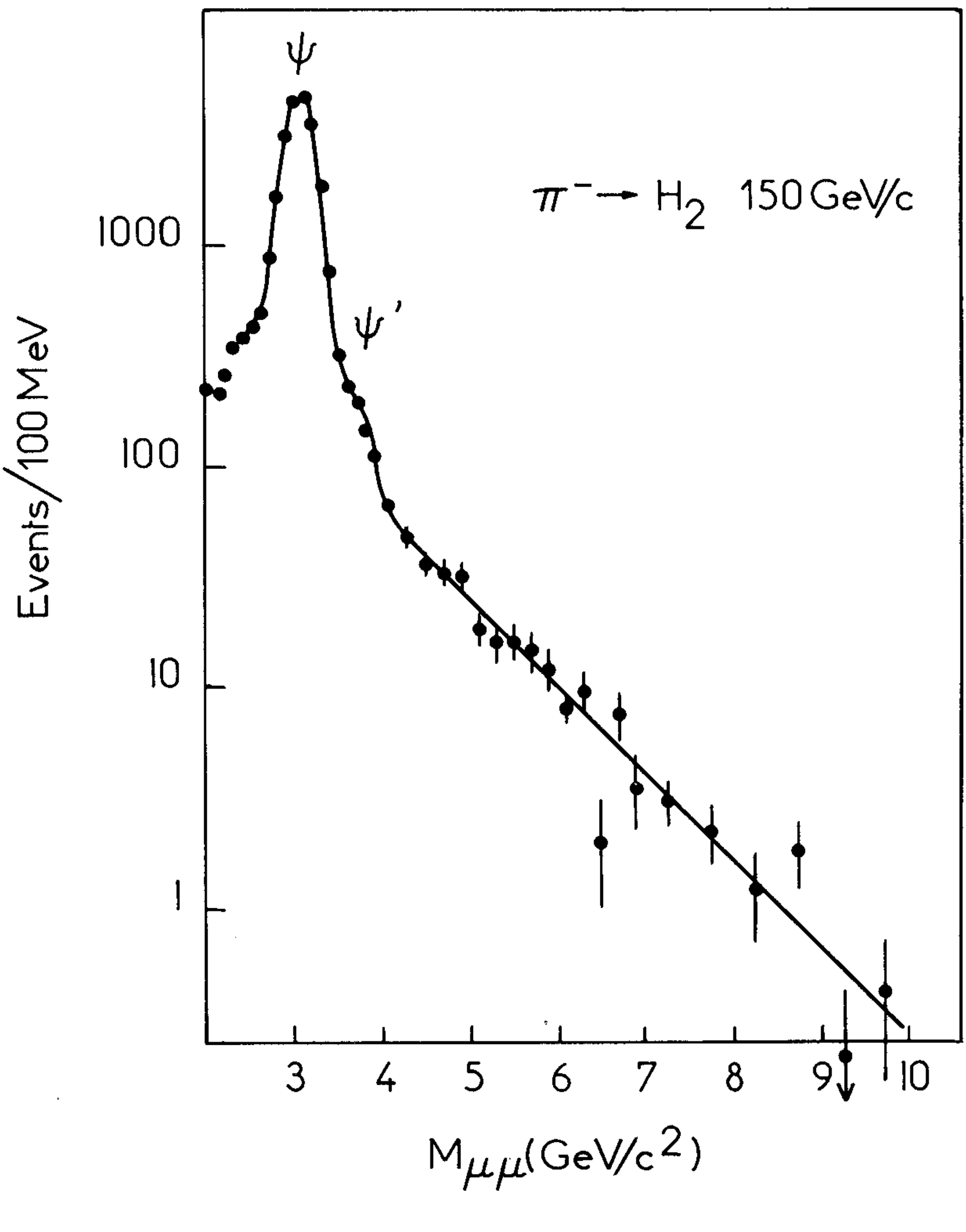
Fig. 4 x distribution of the ratio of J/ψ produced by antiprotons over J/ψ produced by protons. The solid line is the function R(x) calculated with CDHS structure functions.

Fig. 5 Angular distribution of J/ψ production by π^- at 150 GeV/c in the Collins-Soper frame. The solid line is a fit with the form $dN/d\cos\theta_{cs} \propto 1 + \lambda\cos^2\theta_{cs}$ which give $\lambda = 0.07 \pm 0.08$. The dashed curve is the acceptance of the NA3 experiment.

Fig. 6 λ parameter of the J/ψ production angular distribution in the Collins-Soper frame ($d\sigma/d\cos\theta_{cs} \propto 1 + \lambda\cos^2\theta_{cs}$). The indicated errors are those from statistic and acceptance calculation only.

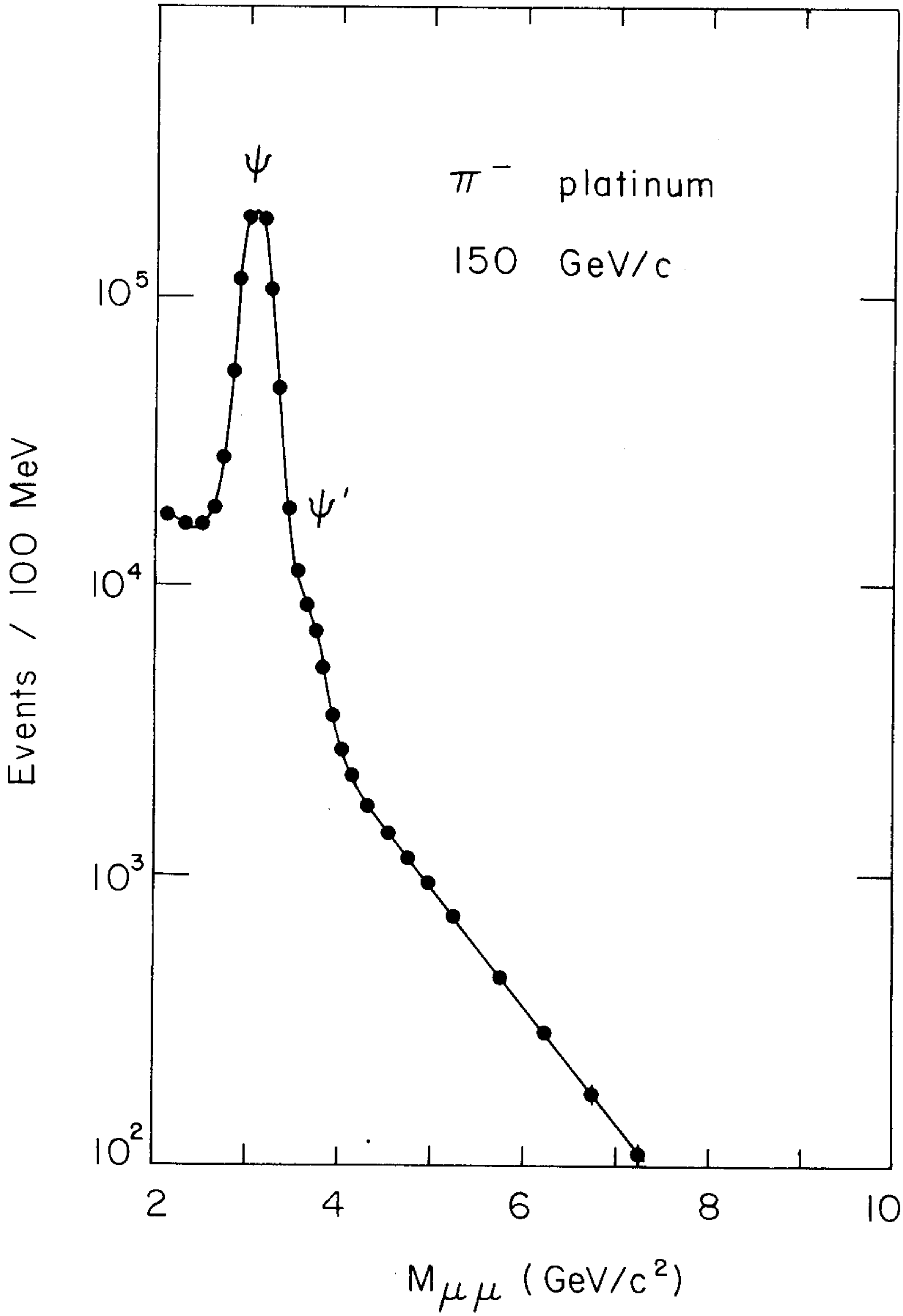
Fig. 7 Mass spectrum for high mass dimuon pairs produced by pions on platinum.

Fig. 8 Cross section of Υ produced by pions.



ψ
ψ'
π⁻ → H2 150 GeV/c
1000
100
10
1
Events/100 MeV
3
4
5
6
7
8
9
10
Mμμ(GeV/c2)

FIG. 1



ψ
ψ'
π⁻ platinum
150 GeV/c
10⁵
10⁴
10³
10²
Events / 100 MeV
2
4
6
8
10
Mμμ (GeV/c²)

FIG. 2

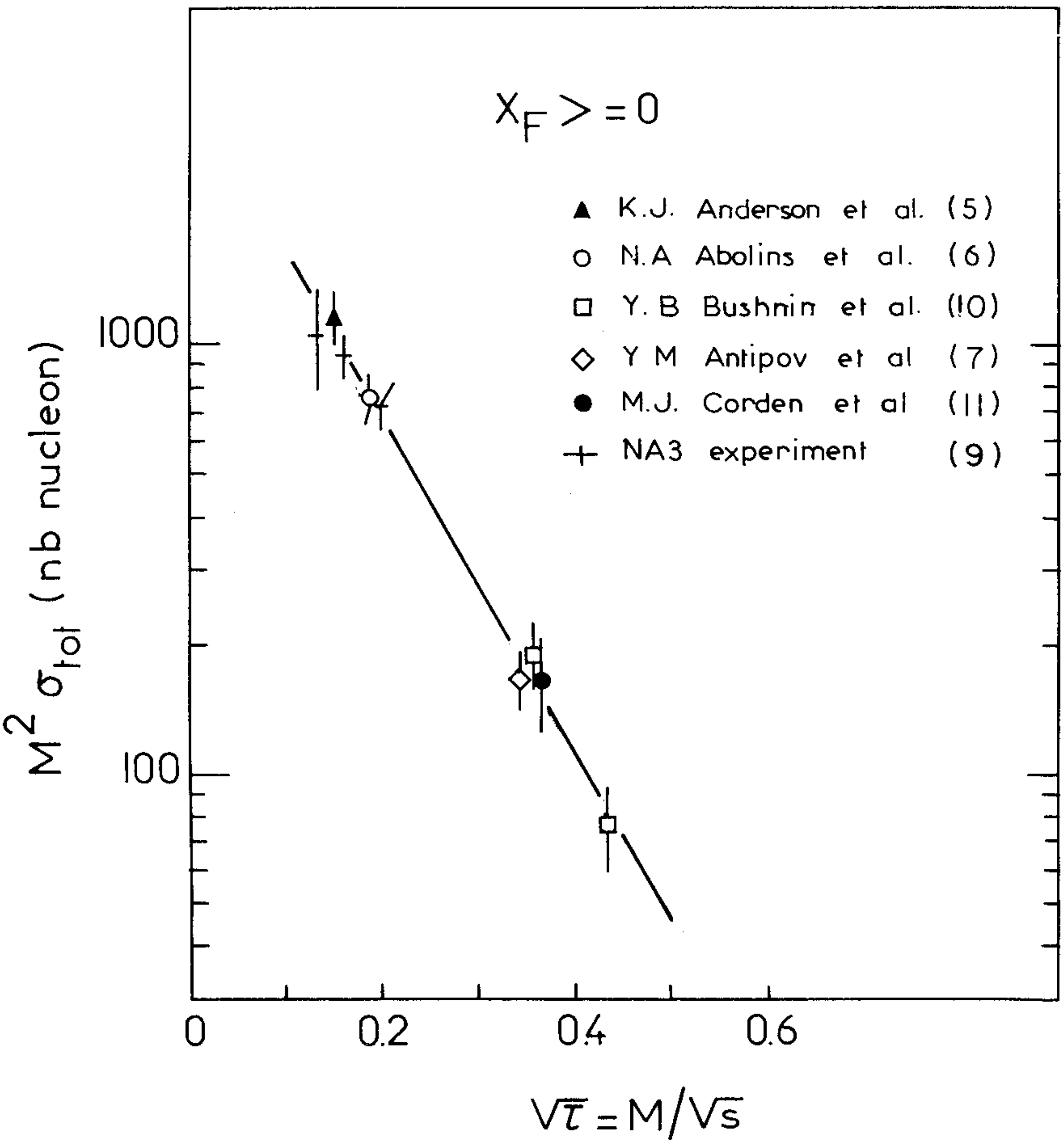

$X_F >= 0$
K.J. Anderson et al. (5)
N.A Abolins et al. (6)
Y. B Bushnin et al. (10)
Y M Antipov et al (7)
M.J. Corden et al (11)
NA3 experiment (9)
1000
100
$M^2 \sigma_{tot}$ (nb nucleon)
0
0.2
0.4
0.6
$\sqrt{\tau} = M/\sqrt{s}$

FIG. 3

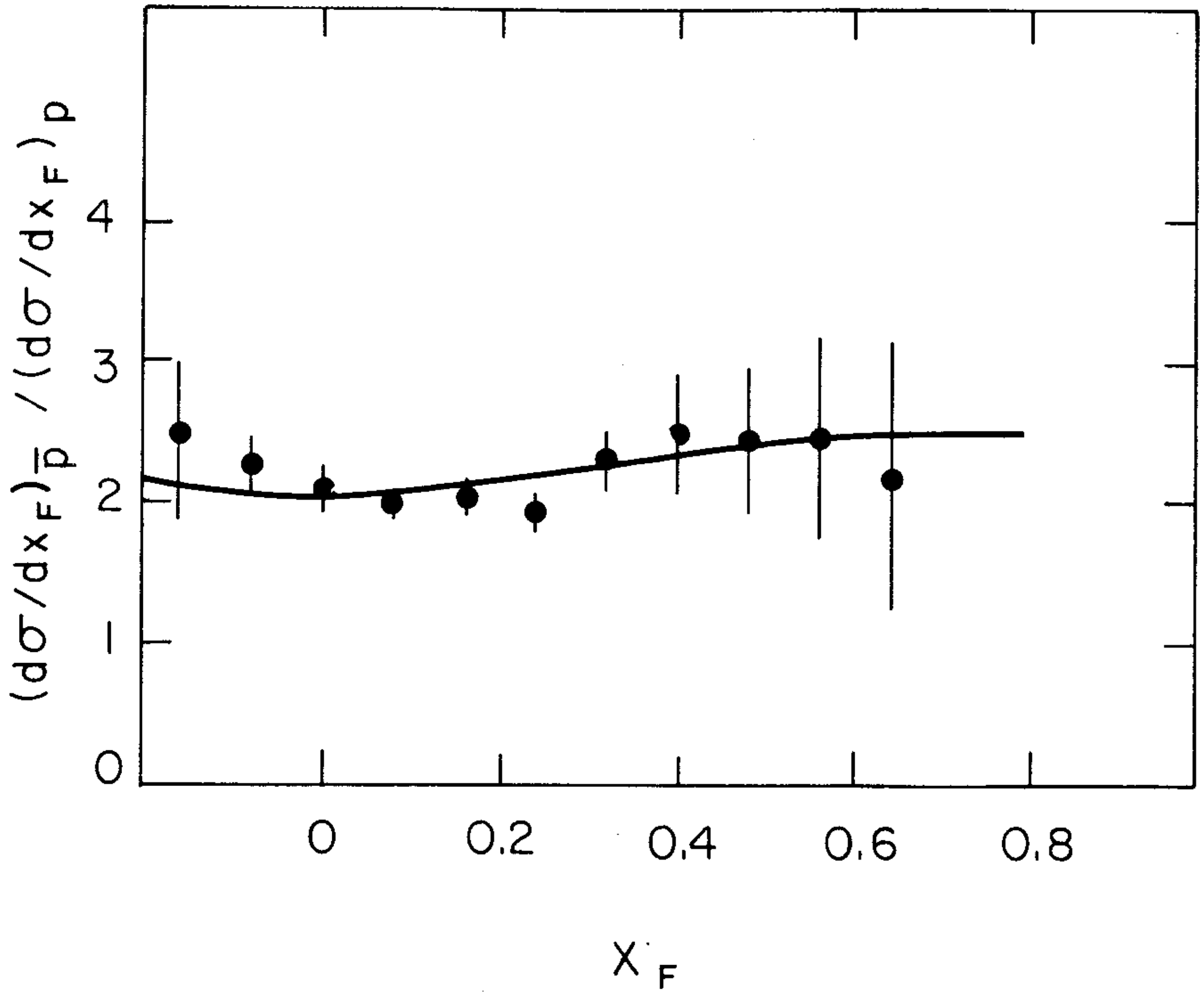
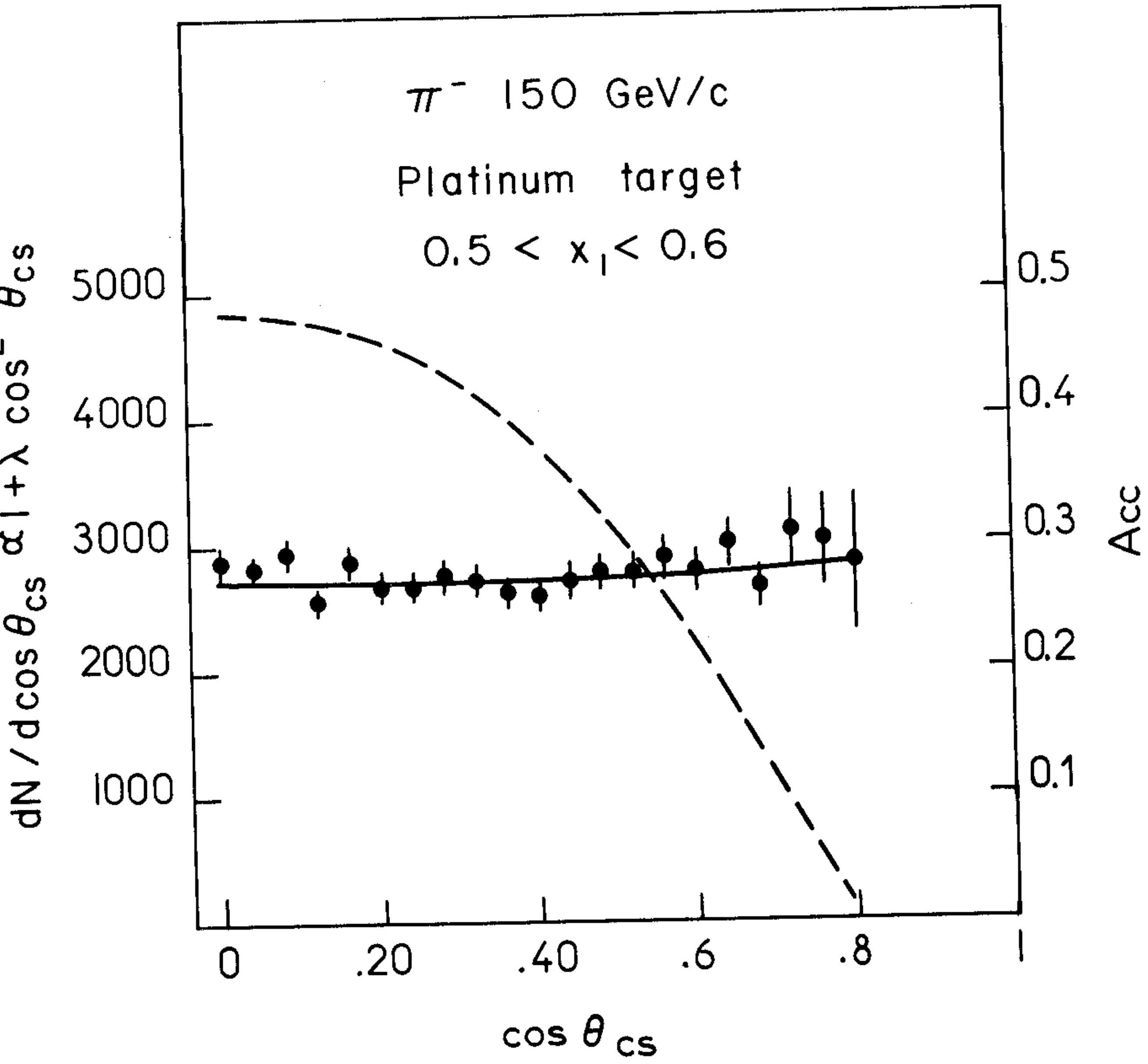
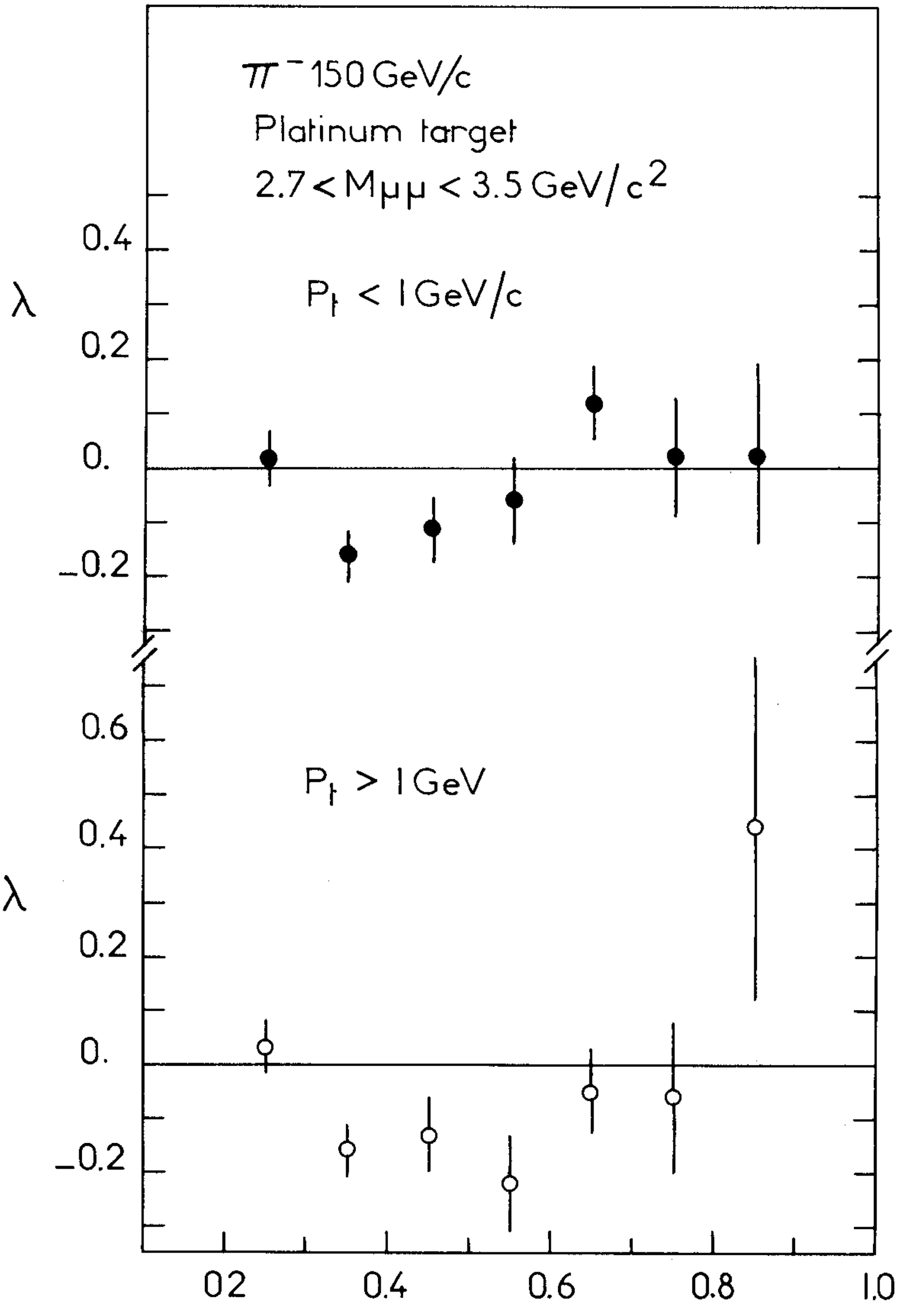


FIG. 4



π^- 150 GeV/c
Platinum target
$0.5 < x_1 < 0.6$
$dN/d\cos\theta_{cs} \propto 1+\lambda\cos^2\theta_{cs}$
5000
4000
3000
2000
1000
0.5
0.4
0.3
0.2
0.1
Acc
0
.20
.40
.6
.8
1
$\cos\theta_{cs}$

FIG. 5



π⁻ 150 GeV/c
Platinum target
2.7 < Mμμ < 3.5 GeV/c²
Pt < 1 GeV/c
Pt > 1 GeV
λ
λ
0.4
0.2
0.
-0.2
0.6
0.4
0.2
0.
-0.2
0.2
0.4
0.6
0.8
1.0
XF

FIG. 6

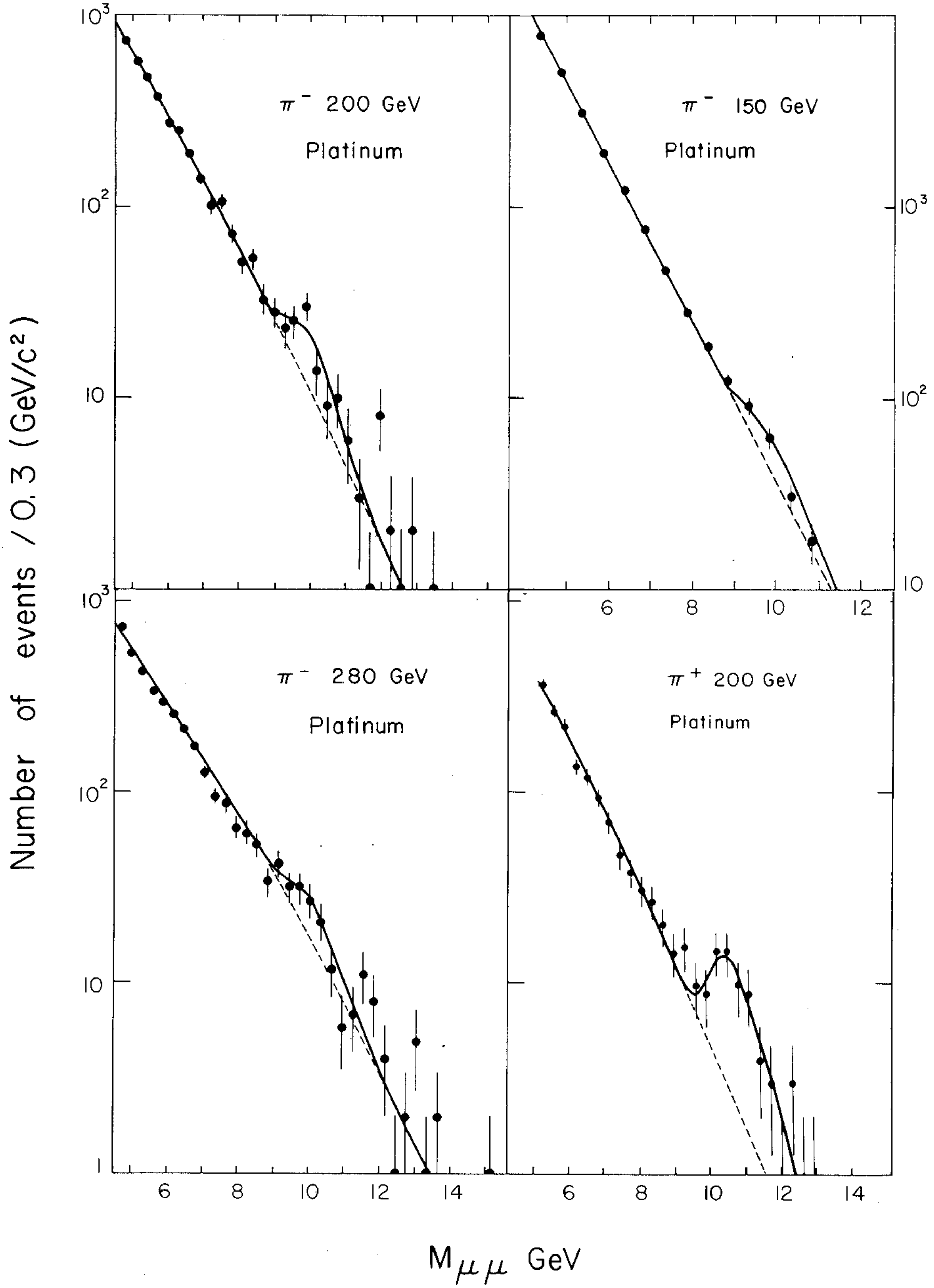

π⁻ 200 GeV
Platinum
π⁻ 150 GeV
Platinum
π⁻ 280 GeV
Platinum
π⁺ 200 GeV
Platinum
Number of events / 0.3 (GeV/c²)
Mμμ GeV

FIG. 7

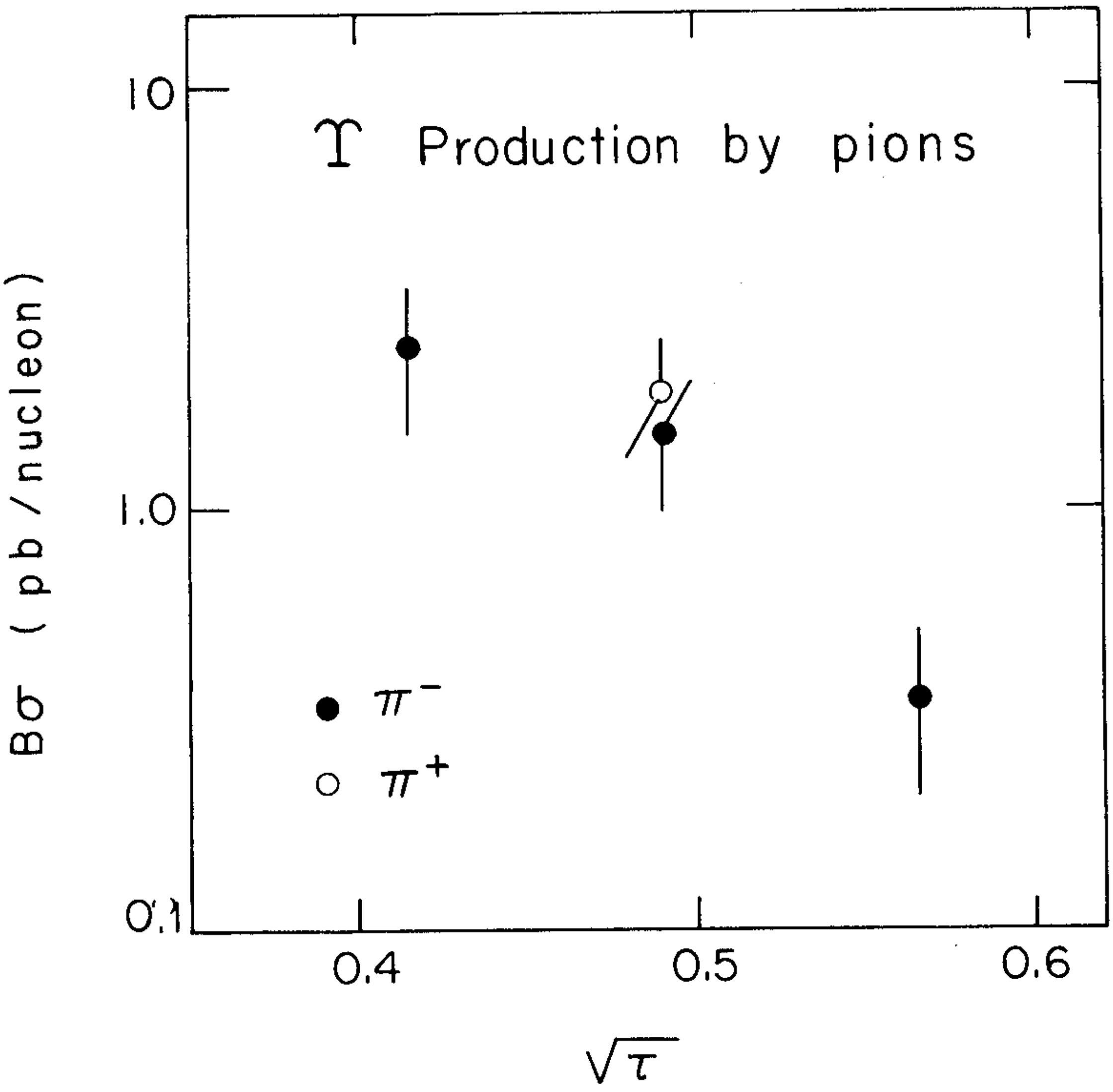


FIG. 8