Fermi National Accelerator Laboratory

FERMILAB-Pub-76/23-EXP
7100.288

(Submitted to Phys. Rev. Lett.)

PRODUCTION OF ψ (3100) IN p-Be COLLISIONS AT 400 GeV

H. D. Snyder, D. C. Hom, L. M. Lederman,
H. P. Paar, J. M. Weiss, and J. K. Yoh
Columbia University, New York, New York 10027

and

J. A. Appel, B. C. Brown, C. N. Brown,
W. R. Innes, and T. Yamanouchi
Fermi National Accelerator Laboratory, Batavia, Illinois 60510

and

D. M. Kaplan
State University of New York at Stony Brook,
Stony Brook, L. I., New York 11794

February 1976

Operated by Universities Research Association Inc. under contract with the Energy Research and Development Administration

PRODUCTION OF ψ(3100) in p-Be COLLISIONS AT 400 GeV*

H. D. Snyder, D. C. Hom, L. M. Lederman, H. P. Paar,
J. M. Weiss, J. K. Yoh
Columbia University, New York, New York 10027

and

J. A. Appel, B. C. Brown, C. N. Brown,
W. R. Innes, T. Yamanouchi
Fermi National Accelerator Laboratory, Batavia, Illinois 60510

and

D. M. Kaplan
State University of New York at Stony Brook,
Stony Brook, L.I., New York 11794*

ABSTRACT

We report preliminary results on the production of electron-positron pairs in the mass range 2.5 to 4 GeV in 400 GeV p-Be interactions. Production cross-sections of the ψ(3100) near x = 0 as a function of p_t, x and the decay angle are presented and implications of this new data for single direct leptons are discussed. A 90% confidence level upper limit on $\sigma B(\psi(3700))/\sigma B(\psi(3100))$ of .02 is measured.

*Work supported by the National Science Foundation.

We have reported the observation of high mass ($\geq$ 4 GeV) e^+e^- pairs produced in 400 GeV proton-beryllium collisions.[1] In the same experiment we have observed a strong J/ψ(3100) signal. In this letter we present the details of J/ψ production cross-sections as a function of p_T, x and the decay angle.

The two-arm magnetic spectrometer used to make these measurements is described in detail in Ref. 1. The techniques described in Refs. 1 and 2 of comparing the energy deposited in a lead-glass array with the measured momentum and the use of the longitudinal shower development in the lead-glass array permit rejection against hadrons of 4×10^{-4} per arm while retaining an efficiency for electrons of .80 ± .08.

The observed mass spectrum dσ/dm for electron-positron pairs is presented in Fig. 1. Outside the ψ peak the data is consistent with accidental background. To obtain cross-sections we assumed that the production at all masses is similar to that observed here for the ψ(3100) and specified below in Eq. 3. Cross-sections reported here have been corrected for trigger and reconstruction efficiencies which lead to a combined efficiency before electron cuts of .8 ± .1 for electron pair events. Corrections have also been made for electron cut inefficiency, target absorption of the proton beam, and for events lost due to bremsstrahlung of the electrons (estimated to be .075 ± .025 of the events at 3 GeV).

The ψ(3100) resonance is observed with a width of 40 MeV (rms) which is in good agreement with the calculated resolution of the apparatus. We measure a mass value of 3.096 ± .030 GeV. The cross sections for ψ production times its branching ratio to e^+e^- are shown in Figures 2a and b plotted versus $x = p_{\parallel}^{cm}/p_{max}$ and p_t. No dip or significant variation in the invariant cross-section is observed in our narrow range of x-acceptance near x = 0. The average invariant cross-section on beryllium for x near 0 is found to be well described by a quadratic exponential in p_t:

$$E \frac{d^3\sigma}{dp^3} \cdot B = (1.7 \pm .4) \times 10^{-32}\ e^{-ap_t^2}\ cm^2/GeV^2/\text{Be Nucleus} \qquad (1)$$

with $a = 1.1 \pm .35\ GeV^{-2}$,

where B is the branching ratio of ψ(3100) to e^+e^- and the p_t range measured is $0 < p_t < 2.0$ GeV. An equally valid description of our data is given by:

$$E \frac{d^3\sigma}{dp^3} \cdot B = (2.5 \pm .6) \times 10^{-32} e^{-bp_t}\ cm^2/GeV^2/\text{Be Nucleus} \qquad (2)$$

with $b = 1.6 \pm .35\ GeV^{-1}$.

The errors on the cross-sections presented here are dominated by the systematic uncertainty in the absolute normalization. The decay angle distribution in the ψ rest system (helicity frame) is shown in Fig. 2c to favor $1 + \cos^2\theta^*$ (confidence level .20).[3] The approximately 5% of background[1] under the ψ has not been subtracted in Fig. 2, but this does not significantly change any of these distributions.

The differential cross sections are measured to be:

$$\left(\frac{d\sigma}{dx}\right)_{x=0} \cdot B = (2.6 \pm .7) \times 10^{-31}\ \text{cm}^2/\text{Be Nucleus} \quad -.06 \leq x \leq .08$$

$$\left(\frac{d\sigma}{dy}\right)_{y=0} \cdot B = (6.4 \pm 1.6) \times 10^{-32}\ \text{cm}^2/\text{Be Nucleus} \quad -.28 \leq Y \leq .32$$

where y is the center of mass rapidity. To obtain the total cross section, a distribution in x away from the x = 0 region must be assumed. Using

$$E\,\frac{d^3\sigma}{dp^3} \propto (1 - |x|)^{4.3} \cdot e^{-1.6p_t} \qquad -1 \leq x \leq 1 \tag{3}$$

which characterizes data from this and other experiments at high x[4,5] we obtain a total cross section times branching ratio on beryllium of

$$\sigma \cdot B = (1.00 \pm .25) \times 10^{-31}\ \text{cm}^2/\text{Be Nucleus}$$

Assuming a linear A-dependence, the total cross section per nucleon is

$$\sigma \cdot B = (1.1 \pm .3) \times 10^{-32}\ \text{cm}^2/\text{nucleon}.$$

No evidence is seen for production of the $\psi(3700)$. Taking 5 events as the 90% confidence level leads to the upper limit

$$\frac{\sigma \cdot B\ (\psi(3700))}{\sigma \cdot B\ (\psi(3100))} < .02.$$

Table I shows a comparison of the results of this experiment with other measurements of $\psi(3100)$ production in hadron collisions.[5] Although some additional assumptions, indicated in the table, are necessary to compare these experiments, the agreement seems to be quite good with experiments with $\sqrt{s} > 20$ GeV. Below that value, a substantial s-dependence is apparent: there is a factor of 10 between Fermilab and Serpukhov energies and a factor of 100 between Fermilab and BNL energies.

Finally, we calculate the yield of single direct leptons resulting from the $\psi(3100)$ production cross-section measured here. Figure 3 shows a comparison of this yield, using Eq. (1), with the dashed curve representing $\frac{\pi^+ + \pi^-}{2} \times 10^{-4}$ which is consistent with the direct lepton yield measured previously by this and other groups.[2,7] We conclude that for single lepton p_t between 1.6 GeV and 2.3 GeV, a substantial fraction, if not all, of the single lepton cross-section comes from the $\psi(3100)$. However, the drop in e/π below 1.5 GeV which results from this source is not observed.[8] Above 2.3 GeV, the contribution depends on an extrapolation of the measured ψ yield. The quadratic form (Eq. 1) suggests that even at higher p_t, the $\psi(3100)$ makes a major contribution, and the linear form (Eq. 2) gives more direct leptons at high p_t than are observed.[9]

We gratefully acknowledge the support of the Fermi National Accelerator Laboratory, especially of the Proton Laboratory and of the staffs of our respective home institutions, especially

Messrs. P.-A. Bury, K. Gray, P. Lucey, F. H. Pearsall, B. Tews, and S. J. Upton. We especially acknowledge the crucial contributions of W. Sippach and H. Cunitz of the Nevis Electronics Group. We also appreciate the assistance of Dr. J. R. Sauer in the early stages of the experiment and Prof. H. Jöstlein for help in data taking.

REFERENCES

[1]D. C. Hom, et al., to be published in Phys. Rev. Lett.

[2]J. A. Appel, et al., Phys. Rev. Lett. 33, 722 (1974).

[3]An isotropic distribution with confidence level .05 cannot be ruled out and would lead to an increase of 20% for all cross sections reported here.

[4]An x-distribution given by $E\, d^3\sigma/dp^3 \propto e^{-6|x|} e^{-1.6p_t}$ for $|x| > .3$ and flat in x for $|x| < .3$ also seems to describe the data in Ref. 5. Assuming such a distribution would decrease the total cross sections quoted here by 20%. The differential cross sections, however, are not significantly affected.

[5]J. J. Aubert, et al., Phys. Rev. Lett. 33, 1404 (1974).
B. Knapp, et al., Phys. Rev. Lett. 34, 1044 (1975).
Y. M. Antipov, et al., IHEP 75-125, Serpukhov (1975).
F. W. Büsser, et al., Physics Letters 56B, 482 (1975).
K. J. Anderson, et al., submitted to Phys. Rev. Lett. (1975).
G. J. Blanar, et al., Phys. Rev. Lett. 35, 346 (1975).

[6]J. W. Cronin, et al., Phys. Rev. D11, 3105 (1975).

[7]J. P. Boymond, et al., Phys. Rev. Lett. 33, 112 (1974).
F. W. Büsser, et al., Phys. Lett. 53B, 212 (1974).
V. V. Abramov, et al., Proc. VIIth Inter. Conf. on High Energy Physics, London (1974).
D. Bintinger, et al., Phys. Rev. Lett. 35, 72 (1975).

[8]F. W. Büsser, Direct Leptons at the I.S.R. II, Proc. of the International Conf. on Lepton and Photon Interactions, Stanford (1975).

[9]For the ψ to be the dominant source of direct leptons at all s, the s-dependence of ψ production must be similar to that of direct leptons. We note that direct leptons behave (see Ref. 10) with s much as do pions, i.e., $\sim e^{-25\, p_t/\sqrt{s}}$. Our comparison with ψ yield is made near $\sqrt{s} = 27$ GeV. The s-dependence of ψ's is as yet poorly known, but is not inconsistent with the above form.

[10]F. W. Büsser, Direct Leptons at the I.S.R. I, Loc. Cit.

TABLE I

$\psi(3100)$: COMPARISON WITH OTHER EXPERIMENTS

EXPERIMENT	$\sqrt{s}$	CROSS-SECTION		ADDITIONAL ASSUMPTIONS NECESSARY
This Expt. Busser et al.	27.4 mostly 52	$\left.\frac{d\sigma}{dy}\right\|_{y=0} \cdot B$	$7.1 \pm 1.8 \times 10^{-33} cm^2$/Nucleon $7.5 \pm 2.5 \times 10^{-33} cm^2$/Proton	A^1 ------------
This Expt. Knapp et al.	27.4 21.7	$\sigma \cdot B$	$1.1 \pm .3 \times 10^{-32} cm^2$/Nucleon $\sim 1.0 \times 10^{-32} cm^2$/Nucleon	$A^1, (1 - \|x\|)^{4.3}$
This Expt. Anderson et al.	27.4 16.8	$\left.\frac{d\sigma}{dy}\right\|_{y=0} \cdot B$	$6.4 \pm 1.6 \times 10^{-32} cm^2$/Be Nucleus $5.9 \times 10^{-32} cm^e$/Be Nucleus	------------ corrected for $1 + \cos^2\theta^*$ decay distribution
This Expt. Antipov et al.	27.4 12.0	$\sigma \cdot B$	$1.0 \pm .25 \times 10^{-31} cm^2$/Be Nucleus $9.5 \pm 2.5 \times 10^{-33} cm^2$/Be Nucleus	$(1 - \|x\|)^{4.3}$ ------------
This Expt. Aubert et al.	27.4 5.1	$\sigma \cdot B$	$1.1 \times 10^{-32} cm^2$/Nucleon $\sim 10^{-34} cm^2$/Nucleon	$A^1, (1 - \|x\|)^{4.3}$ $e^{-6p_t}, p_{\parallel}$ independent

FIGURE CAPTIONS

Fig. 1: Electron-Positron Mass Spectrum: $d\sigma/dm$ per nucleon versus the effective mass. A linear A-dependence is assumed.

Fig. 2: $\psi(3100)$ Cross-Sections: a) Invariant cross-section versus $x \equiv P_{\parallel}^{cm}/P_{max}^{cm}$ (integrated over p_t^2).

b) Invariant cross-section versus p_t near $x = 0$.

c) Decay angle distribution in the helicity frame of the ψ. (Plotted errors are statistical only).

Fig. 3: Single direct leptons coming from the $\psi(3100)$. The dotted and dot-dashed curves are two possible extrapolations beyond p_t values for which this cross-section is determined in this experiment.

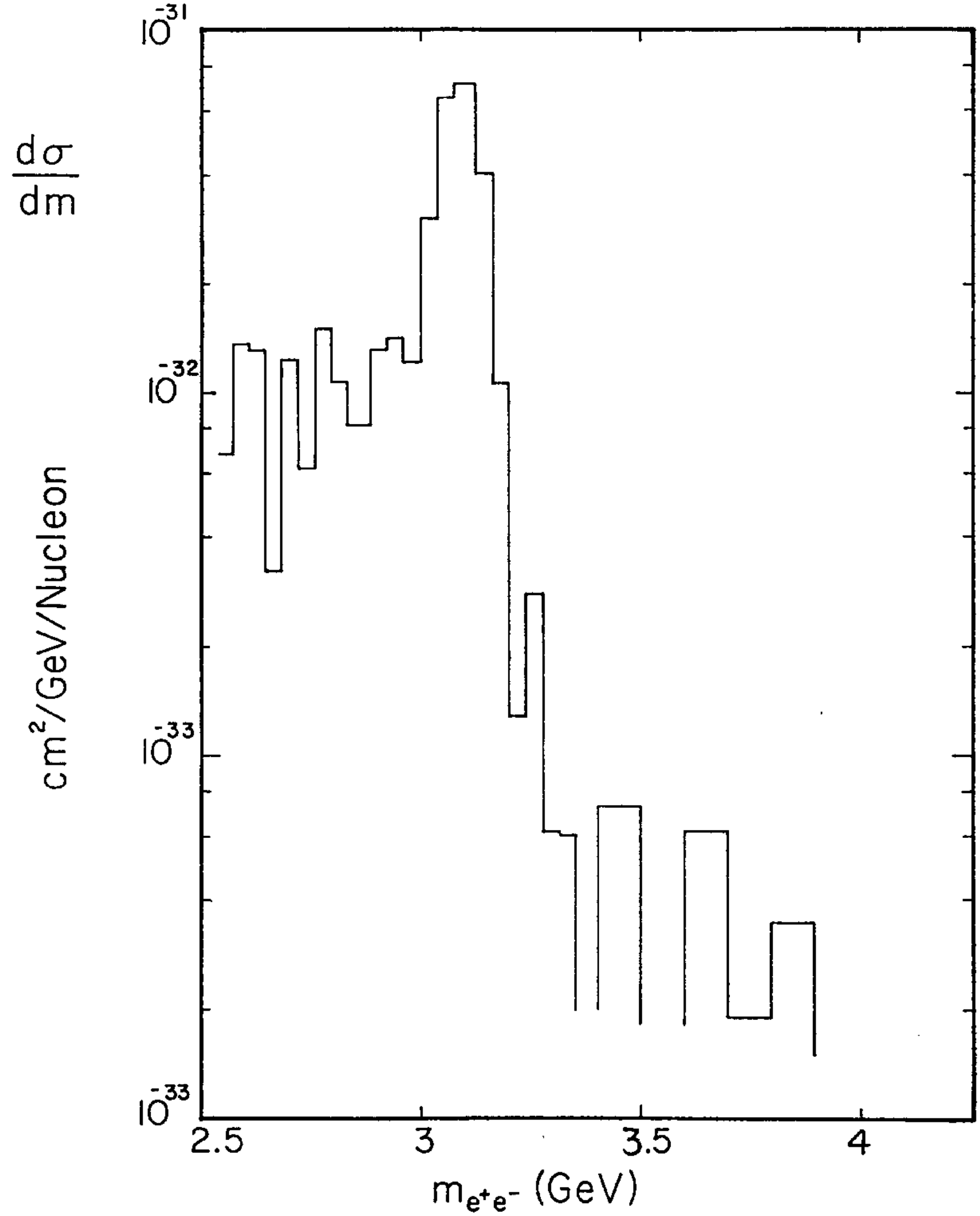
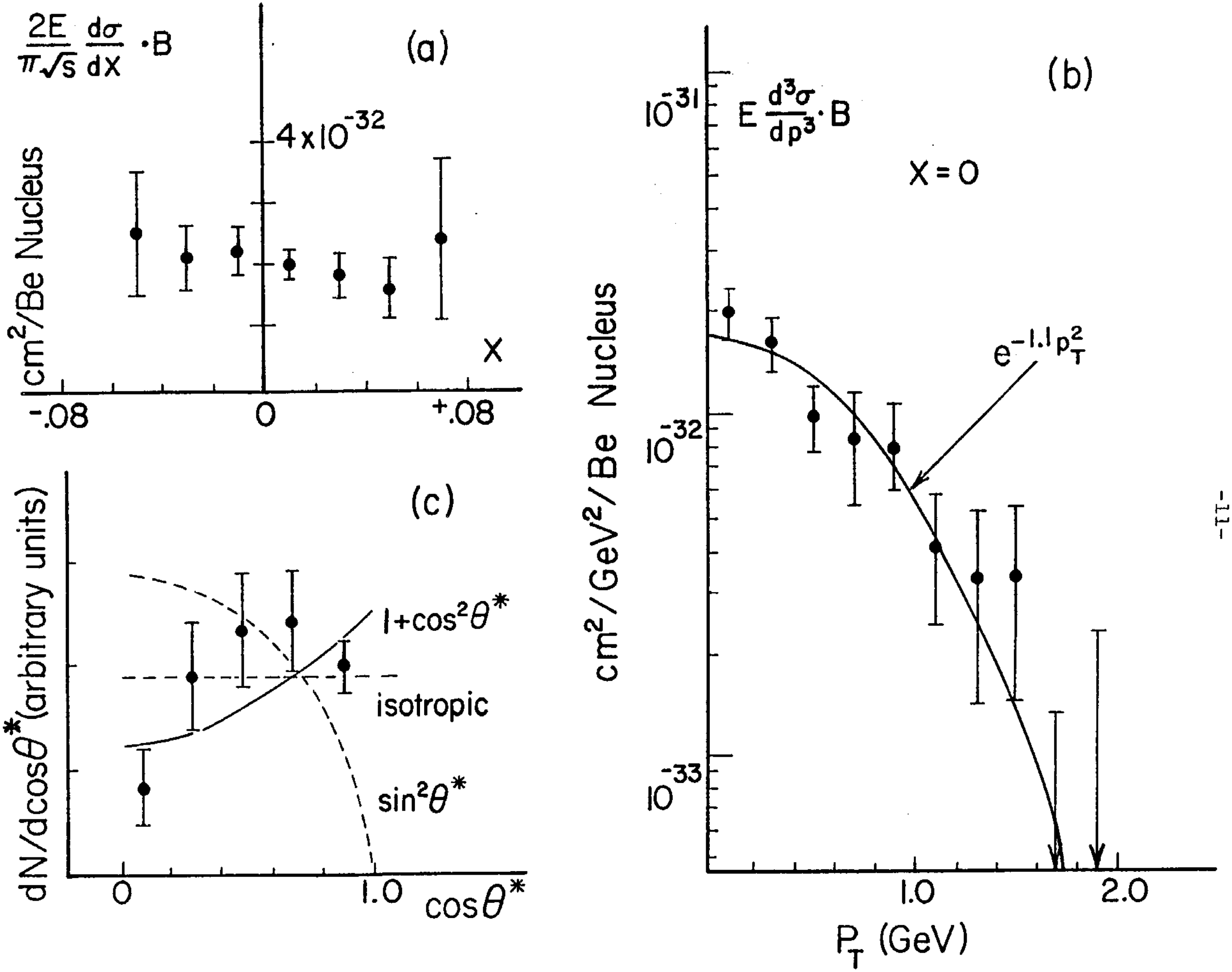
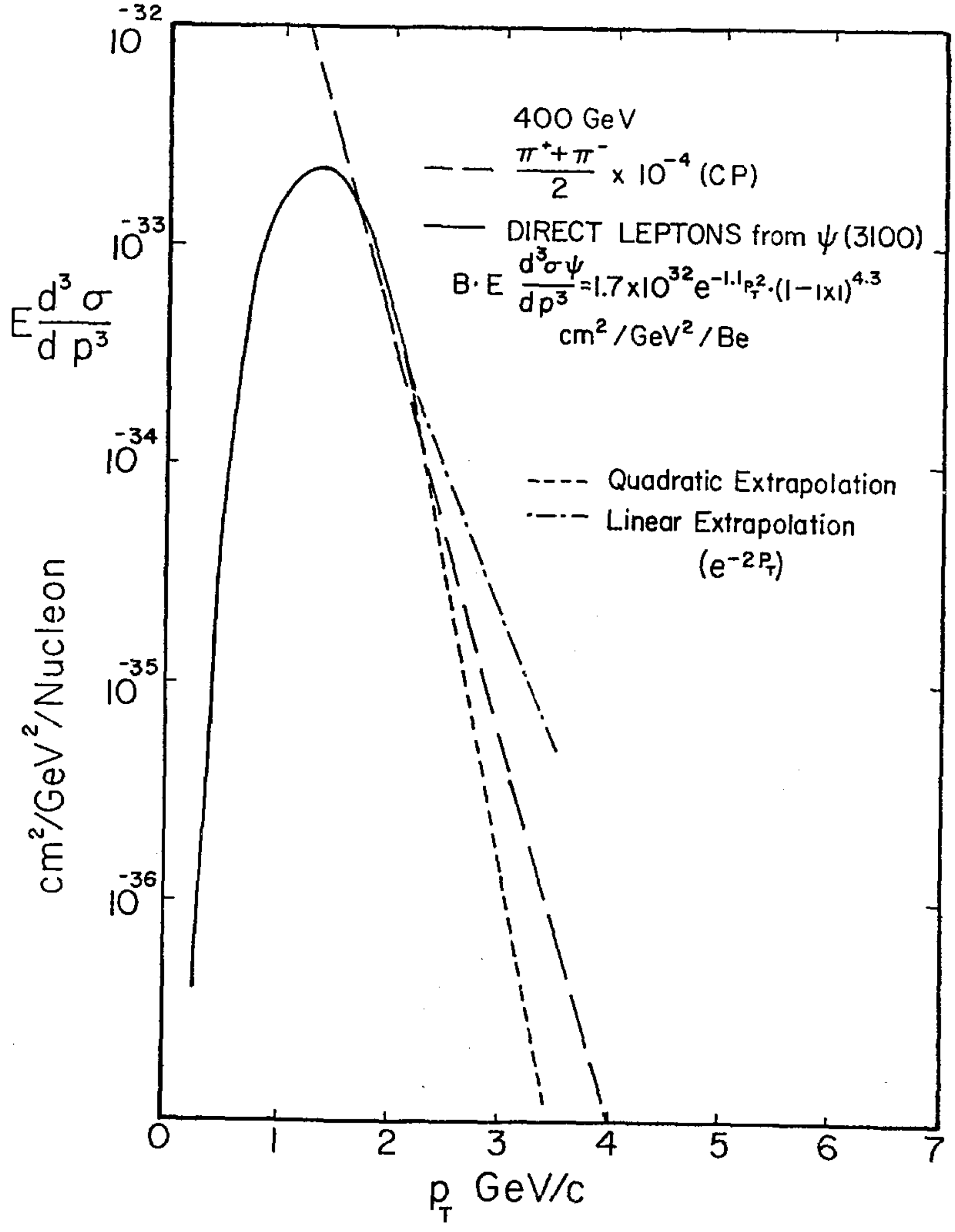


Fig. 1



(a)
$\frac{2E}{\pi\sqrt{s}} \frac{d\sigma}{dX} \cdot B$
cm^2/Be Nucleus
4×10^{-32}
X
-.08
0
+.08
(b)
$E \frac{d^3\sigma}{dp^3} \cdot B$
X = 0
$e^{-1.1 p_T^2}$
cm^2/GeV^2/Be Nucleus
10^{-31}
10^{-32}
10^{-33}
1.0
2.0
P_T (GeV)
(c)
dN/dcosθ^*(arbitrary units)
$1+\cos^2\theta^*$
isotropic
$\sin^2\theta^*$
0
1.0
$\cos\theta^*$

Fig. 2



400 GeV
$\frac{\pi^+ + \pi^-}{2} \times 10^{-4}$ (CP)
DIRECT LEPTONS from ψ(3100)
$B \cdot E \frac{d^3\sigma\psi}{dp^3} = 1.7 \times 10^{32} e^{-1.1 p_T^2} \cdot (1-|x|)^{4.3}$
$cm^2/GeV^2/Be$
Quadratic Extrapolation
Linear Extrapolation
(e^{-2p_T})
$E\frac{d^3\sigma}{dp^3}$
cm^2/GeV^2/Nucleon
10^{-32}
10^{-33}
10^{-34}
10^{-35}
10^{-36}
0
1
2
3
4
5
6
7
p_T GeV/c

Fig. 3