Fermi National Accelerator Laboratory

FERMILAB-Pub-76/32-EXP
7100.288

(Submitted to Phys. Rev. Lett.)

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March 1976

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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 $\psi(3100)$ 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 $\psi'(3700)$ signal is observed at a level corresponding to $\sigma(\psi')/\sigma(\psi) = (10. \pm 3.)\%$.

*Work supported by the National Science Foundation.
†This preprint supercedes FERMILAB-Pub-76/23-EXP.

We have reported the observation of high mass (> 5.5 GeV) e^+e^- pairs produced in 400 GeV proton-beryllium collisons.[1] In the same experiment we have observed a strong $J/\psi(3100)$ signal. This letter presents the details of J/ψ production cross-sections as a function of p_t, x and the decay angle and reports the observation of $\psi'(3700)$.

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 spectra for electron-positron pairs is presented in Fig. 1 for three different settings of the spectrometer. To obtain cross-sections, $d\sigma/dm$, we assumed that the production at all masses is similar to that observed here for the $\psi(3100)$ 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).

Figure 1a shows the data taken with spectrometer settings (600 and 800 amperes) optimized at the m = 3 GeV region. A

strong $\psi(3100)$ signal is seen. The acceptance varies slowly over this mass interval and this data is used to study ψ production. Figures 1b and c show data at 1100 amperes which is optimized for masses above 5 GeV. At 1100A the acceptance is increasing rapidly for masses of 3.1 to 3.7 GeV. However, the integrated sensitivity at the ψ' mass is increased here by an order of magnitude over the data in Fig. 1a. Both sets of data give consistent $\psi(3100)$ cross-sections. A clear $\psi'(3700)$ peak is observed in the raw data in Fig. 1b and persists after correction for the acceptance as shown in Fig. 1c.

The $\psi(3100)$ resonance observed in Fig. 1a has 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 Figs. 2a and b plotted versus $x = p_{||}^{cm}/p_{max}^{cm}$ 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:

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

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

where B is the branching ratio of $\psi(3100)$ 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:

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

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 for the $\psi(3100)$ 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

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

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

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

For the $\psi'(3700)$, the ratio of the differential cross-section times branching ratio at y=0 to that of the $\psi(3100)$ is

$$\left.\frac{d\sigma/dy \cdot B\ (\psi'(3700))}{d\sigma/dy \cdot B\ (\psi(3100))}\right|_{y\,=\,0} = (1.7 \pm 0.5)\%$$

under the assumption of similar dynamics to the ψ. This assumption is consistent with our data near y = 0. The resulting ratio of production cross-sections is $\sigma(\psi'(3700))/\sigma(\psi(3100)) = (10. \pm 3.)\%$.

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 Eqs. (1) and (2) 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.[2,6] We find that for single lepton p_t less than 2.0 GeV, the $\psi(3100)$ contributes less than 30% to the single direct lepton signal, in agreement with earlier results.[7]

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. Drs. M. Tannenbaum, S. Segler, J-M. Gaillard and J. Cronin are acknowledged for pointing out an error in our original calculation of the direct lepton yield from ψ.

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[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 $|x| > .2$ and flat in x for $|x| < .2$ also seems to describe the data in Ref. 5. Assuming such a distribution would increase the total cross-sections quoted here by 60%. The differential cross-sections, however, are not significantly affected.

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TABLE I

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

EXPERIMENT	$\sqrt{s}$	CROSS-SECTION		ADDITIONAL ASSUMPTIONS NECESSARY
This Expt. Büsser 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. Blanar et al.	27.4 21.7 21.2	$\sigma \cdot B$	$(1.1 \pm 0.3) \times 10^{-32}$ cm^2/Nucleon $\sim 1.0 \times 10^{-32}$ cm^2/Nucleon $(1.6 \pm 0.8) \times 10^{-32}$ 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 4.1×10^{-32} cm^2/Be Nucleus	---------- ----------
This Expt. Antipov et al.	27.4 12.0	$\sigma \cdot B$	$(1.0 \pm 0.25) \times 10^{-31}$ 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	$\sigma \cdot B$	1.1×10^{-32} cm^2/Nucleon $\sim 10^{-34}$ cm^2/Nucleon	$A^1, (1 - \|x\|)^{4.3}$ $e^{-6p_t}, p_{\|\|}$ independent

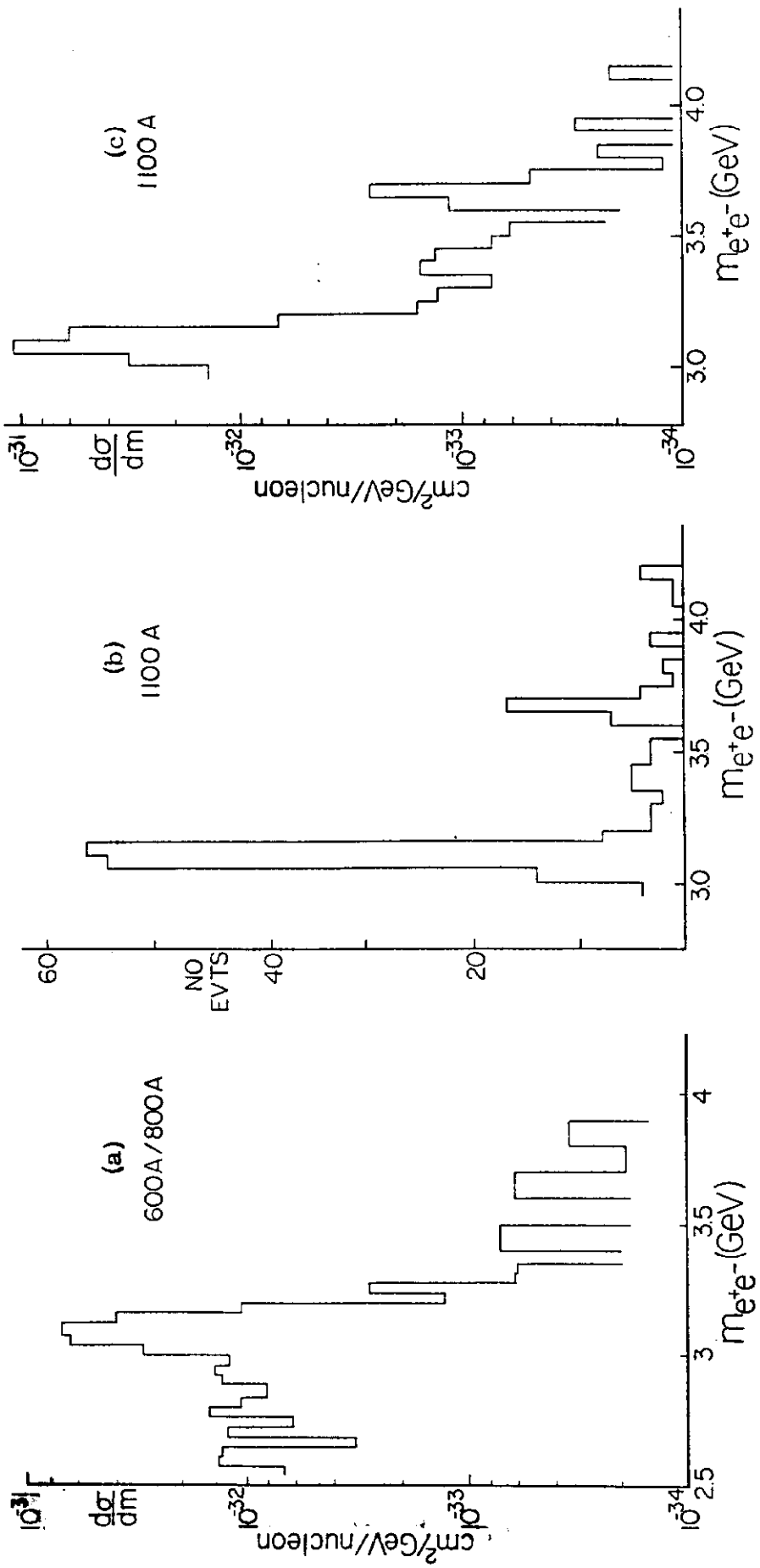

Fig. 1. Electron-Positron Mass Spectra: (a) $d\sigma/dm$ per nucleon versus the effective mass. A linear A-dependence is assumed. (b) Mass spectrum of observed events at 1100A. (c) $d\sigma/dm$ per nucleon for data in (b).

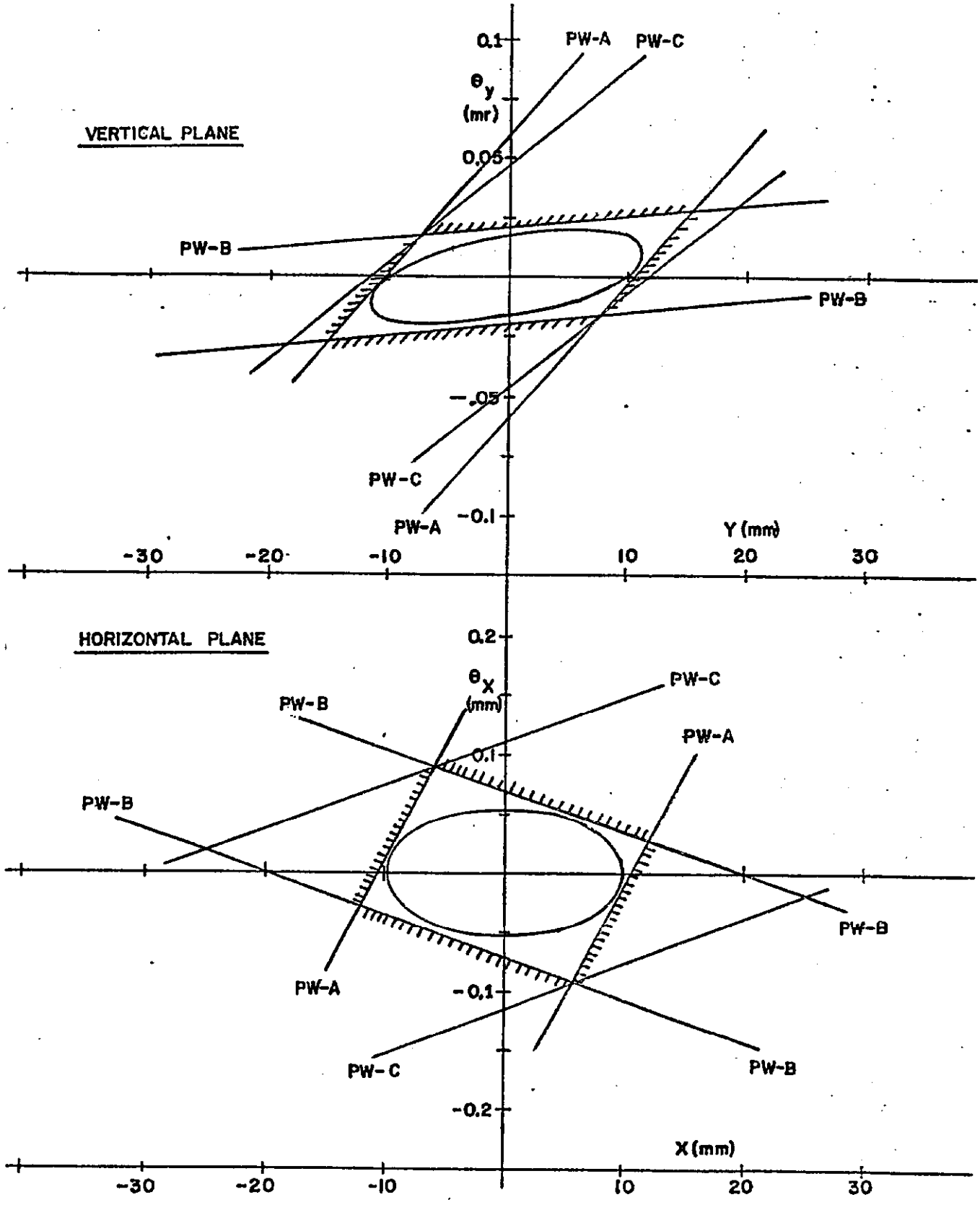

Fig. 2. Phase space masking by collimators and maximum beam ellipses at the entrance to the Proton West pretarget tunnel.

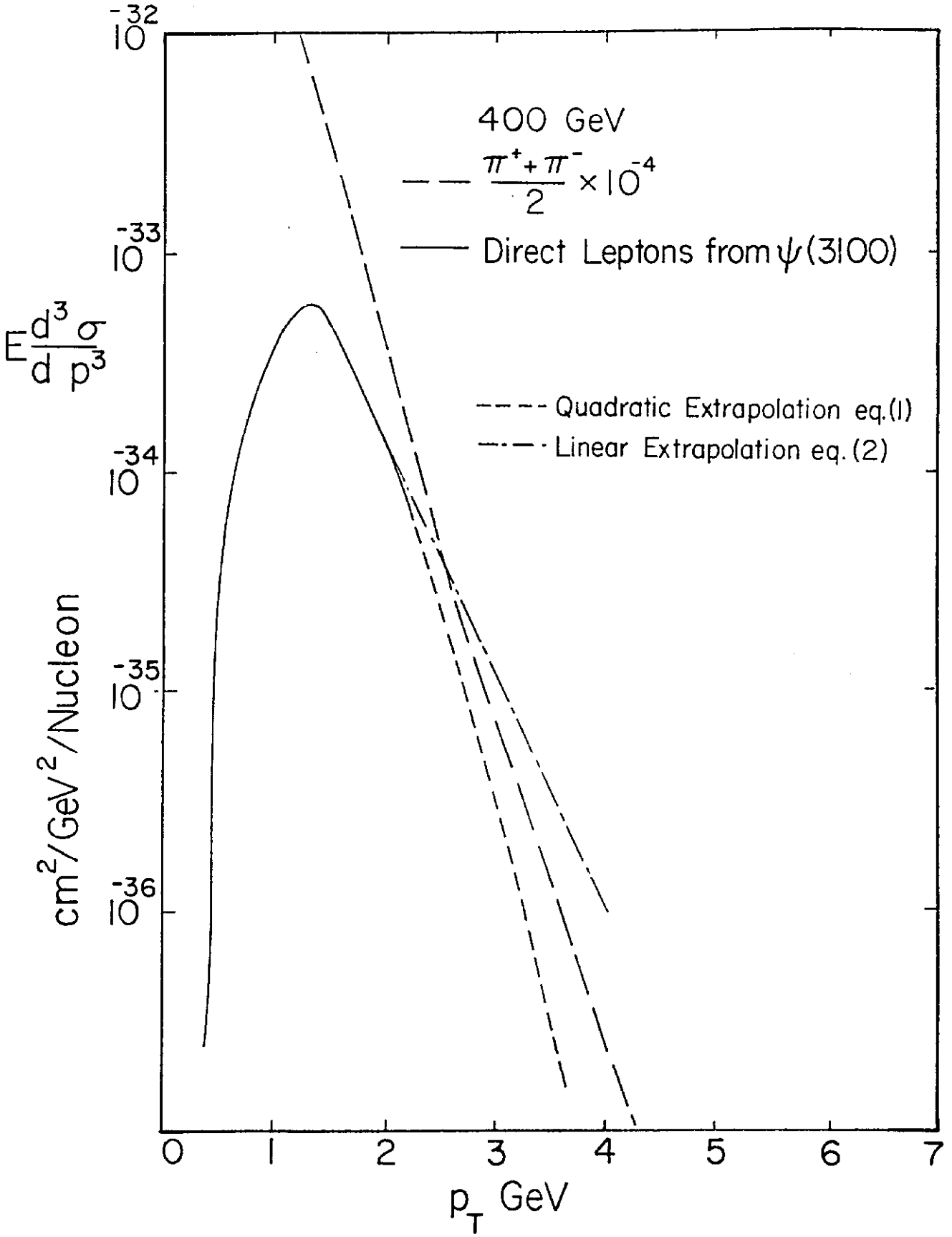

Fig. 3. Cross section for single direct leptons coming from the ψ(3100). The dotted and dot-dashed curves are two possible extrapolations beyond p_t values for which this cross section is determined by this experiment.