Fermi National Accelerator Laboratory

FERMILAB-Pub-76/25-EXP
7500.025

(Submitted to Phys. Rev. Lett.)

MEASUREMENT OF J/ψ (3100) PHOTOPRODUCTION IN DEUTERIUM AT 55 GeV

T. Nash
Fermi National Accelerator Laboratory
Batavia, Illinois 60510 USA

and

A. Belousov and B. Govorkov
Lebedev Physical Institute
Leninsky Prospect 53, Moscow 117 924, USSR

and

D. O. Caldwell, J. P. Cumalat, A. M. Eisner,
R. J. Morrison, F. V. Murphy, and S. J. Yellin
University of California
Santa Barbara, California 93106 USA

and

P. J. Davis, R. M. Egloff, G. Luste, and J. D. Prentice
University of Toronto, Toronto 181
Ontario, Canada

1976

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

Measurement of J/ψ(3100) Photoproduction in Deuterium at a Mean Energy of 55 GeV*

T. Nash
Fermi National Accelerator Laboratory
Batavia, Illinois 60510

A. Belousov and B. Govorkov
Lebedev Physical Institute
Leninsky Prospect 53, Moscow 117 924, USSR

D. O. Caldwell, J. P. Cumalat, A. M. Eisner,
R. J. Morrison, F. V. Murphy,† and S. J. Yellin
University of California, Santa Barbara, California 93106

P. J. Davis, R. M. Egloff, G. Luste, J. D. Prentice
University of Toronto, Toronto 181
Ontario, Canada

Abstract

We report the result of a brief experiment to measure the cross section for photoproduction of J/ψ(3100). At a mean energy of 55 GeV we find this cross section per nucleon to be 37.5 ± 8.2 (statistical) ± 4 (systematic) nb. The result establishes the previously indicated rise in J/ψ photoproduction on protons above 20 GeV and suggests that the rise has occurred by 55 GeV.

The photoproduction cross section of $J/\psi(3100)$ has been measured by several groups[1,2,3] using different nuclei at energies from 11 GeV to over 100 GeV. The lowest energy measurement made near threshold at Cornell and the highest energy measurement made with the Fermilab broad band photon beam used beryllium as a target. Measurements at SLAC well above threshold were made with D_2 and H_2 targets. Despite the difficulty of comparing measurements on different nuclei the results at Fermilab indicated a rise in the cross section per nucleon between SLAC and Fermilab energies.

We report here a first, low statistics, measurement at high energy of the cross section for the production of the $J/\psi(3100)$ on deuterium in the channel $J/\psi \rightarrow e^+e^-$. By a simple procedure we have also determined the single nucleon cross section. This result can be compared directly with the SLAC measurements and establishes a significant rise in the photoproduction cross section of J/ψ between SLAC energies[2] below 20 GeV and the energy range for the data of this experiment (31 - 80 GeV with a mean of 55 GeV). This measurement is based on data taken during a short period of testing of the new Tagged Photon Beam at the Fermi National Accelerator Laboratory. Both the incoming photon and the electron pair energies were measured. The results indicate that the J/ψ were produced elastically or with a very small missing energy.

A beam of 90 ± 2 GeV electrons radiated photons in a $.18X_0$ Cu target. Photon energies between 31 and 80 GeV were tagged (subject to a thick radiator correction to be discussed below) by bending outgoing electrons into a bank of lead glass shower counters. Almost all electrons in the tagging range were detected so that the photon spectrum was essentially that expected from thick target bremsstrahlung. The photon energy resolution was about 2 GeV dominated by the electron beam momentum spread. Veto counters were used to reduce below 2% the probability that a valid tagging signal was not associated with a radiated photon.

The photon beam entered a 1 m long liquid D_2 target followed by a series of nine multiwire proportional chambers and then a stack of 48 totally absorbing SF2 lead glass Cherenkov counters. The three proportional chambers nearest the target had wire spacing of 1 mm and 1.5 mm, while the last six chambers had 2 mm wire spacing. The 6.35 x 6.35 x 58.4 cm lead glass counters 239 cm downstream of the target were arranged in a square array with a central hole of 6.35 cm square. A lead lucite sandwich counter was placed downstream of this central hole to measure the occasional second photon emitted in the Cu radiator and to monitor photons which did not hadronically interact. The trigger required an unvetoed tagging signal with over 65% of the nominal photon energy appearing in the lead glass array. For each trigger, the pulse heights from every shower counter were recorded along with the MWPC information and various latch bits. The shower counters were calibrated in the electron beam and the energy calibrations maintained with a light pulser system.

The main background came from multi-pion events in which at least one photon from each of two π^0's converted to e^+e^- before reaching the MWPC's. This background was strongly suppressed by requiring that good events have at least two MWPC trajectories consistent with a vertex in the D_2 target and that the distribution of pulse heights in the lead glass blocks be consistent with two showers in the stack--each one near the position expected from a track. The analysis used a careful experimental mapping (made with the electron beam) of the pulse height distribution as a function of shower position and direction. Part of the background was rejected because a shower centroid was plainly inconsistent with any measured trajectory. Most of the remaining background was rejected because the energy deposition pattern in a group of neighboring glass blocks was inconsistent with a single shower. The mass distribution of events rejected by the latter cut (Fig. 1a) shows no enhancement at the J/ψ mass, while 25 of the surviving events (Fig. 1b) cluster in a peak between 2.75 and 3.45 GeV. The shaded events in Fig. 1b were clearly inelastic ($\lesssim$ 85% of E_γ in the e^+e^- pair). With these inelastic events removed there remain 24 events in the J/ψ mass region. Based on analysis studies we estimate the residual background to be two events beneath the peak. The mean energy of these events was 55 GeV.

The width of the peak is ± 120 MeV which is the same as that computed by a Monte Carlo program in which the measured lead glass energy resolution was the dominant uncertainty. The same Monte Carlo program was used to calculate the weighted detection acceptance with the following assumptions:

1. The J/ψ decays according to a $1 + \cos^2\theta$ CM distribution, which is consistent with our data and with approximate

s channel helicity conservation.

2. The t dependence is e^{bt}, with b = 1.8 GeV^{-2}. (The results were insensitive to varying b from 1.0 to 4.5 GeV^{-2} and to including a coherent peak.)

These two assumptions lead to a geometrical acceptance vs E_ψ which increases from 0% at 30 GeV to about 50% at $E_\psi \simeq 65$ GeV where the acceptance becomes nearly flat.

3. The J/ψ cross section is constant over the energy range for which there was appreciable acceptance. (This assumption means that the resulting cross section is a weighted average over the accepted energy range.)

4. $E_\psi \simeq E_\gamma$ to sufficient accuracy so that the geometrical acceptance could be evaluated at E_γ. For all but one event (which we exclude from our cross section), $E_\psi \geq .85\ E_\gamma$ empirically. The majority of events had less than 4 GeV missing energy consistent within the resolution with zero.

In carrying out the calculation, the E_γ spectrum we used was determined from the observed spectrum of tagged electrons by correcting for multiple bremsstrahlung in the Cu radiator. An allowance was made for the trigger threshold. Additional corrections were made for beam attenuation in the target and for the MWPC and track reconstruction efficiencies (each about 95%). The resulting cross section for photoproduction on D_2 is 80 ± 17 nb, the error being statistical. We assume here the branching ratio to e^+e^- is[4] .069.

In order to estimate the t dependence of the J/ψ events, we considered the $p_\perp^2 \simeq -t' \equiv -(t-t_{min})$ distribution of the events in the range $2.75 < m_{e^+e^-} < 3.45$ GeV (see Fig. 2). Assuming the incoherent part of the t distribution to be of the form Ae^{bt}, we find $b = 1.8 \pm .4$ GeV^{-2}. We assume equal amplitudes on protons and neutrons and use the known deuterium wave function[5] to calculate the coherent part to be 6%. Neglecting shadowing,[6] we thus determine the J/ψ cross section per nucleon (with less than 15% missing energy) to be

$$37.5 \pm 8.2 \text{ (statistical)} \pm 4 \text{ (systematic) nb}$$

at a mean energy of 55 GeV.

Systematic errors were dominated by uncertainty in the reconstruction efficiency and in the background. This efficiency was studied with a Monte Carlo program and by broadly varying the reconstruction techniques and cuts.

In order to compare this result with other experiments[1,2,3] at different energies and on different nuclei we have listed a selection of measurements in Table I. We have taken the liberty of computing $\sigma(\gamma N \to J/\psi)$ for those experiments that measured $\left.\frac{d\sigma}{dt}\right|_{t'=0}$ and $\frac{d\sigma}{dt}$ for our experiment which measured σ. The arrows indicate the direction in which the calculation is done. This table demonstrates that the cross section for J/ψ photoproduction continues to rise rapidly between 20 GeV and 55 GeV.

We gratefully acknowledge the support of the personnel of the Proton Laboratory of Fermilab as well as the invaluable technical assistance of M. Armstrong, A. Kiang, T. Nunamaker, R. Ploger and D. Simmen. We also thank M. Franklin, J. Liebau,

A. Malensek, M. Obradovich, and J. Pritchett for their help during the running of this experiment. Finally we are thankful to D. Nease for useful discussions regarding Table I.

References

*Work supported in part by the U. S. Energy Research and Development Administration and the National Research Council of Canada.

†Present address: Varian, Palo Alto, California.

[1]B. Gittelman et al., Phys. Rev. Lett. 35, 1616 (1975).

[2]U. Camerini et al., Phys. Rev. Lett 35, 483 (1975).

[3]B. Knapp et al., Phys. Rev. Lett. 34, 1040 (1975); W. Lee in Proceedings, 1975 International Symposium on Lepton and Photon Interactions at High Energies, Stanford, California, p. 213-239.

[4]A. M. Boyarski et al., Phys. Rev. Lett. 34, 1357 (1975).

[5]We used the Hulthèn wave function as given for example by G. F. Chew and H. W. Lewis, Phys. Rev. 84, 779 (1951) and R. Fridman, Fortschritte der Physik 23, 243 (1975).

[6]We expect nuclear shadowing to be small primarily because the Deuterium nuclei have low atomic number and because the J/ψ nuclear cross section, as estimated from VMD, is small (see Ref. 3).

[7]D. L. Nease, Ph.D. Thesis, Cornell Univ., 1976 (unpublished).

[8]L. R. Cormell, Ph.D. Thesis, Univ. of Illinois, 1976 (unpublished).

TABLE I

J/ψ Photoproduction *vs* Energy

Experiment	$\langle E_\psi \rangle$ (GeV)	k_{max} or range (GeV)	A_{tgt}	b (GeV^{-2})	$\frac{d\sigma}{dt}\Big\|_{t=0}$ per nucleon (nb/GeV^2)		σ (nb)
Cornell[1]	11.0	11.8	9	1.25±.2	1.01±0.2	b=1.25 →	0.67± .21
SLAC[2]	13	13.5	2		7.5 ±1.7*		
	19	20	2	2.9 ±.3	19.4 ±1.3*	b=2.9 →	5.2 ± .6
	19	19.5	2		15.5 ±1.4*		
	19	19.5	1		13.9 ±1.4*		
Fermilab (Tagged γ – this experiment)	55	31-80	2	1.8 ±.4	68 ±19	b=1.8 ←	37.5 ±8.2
Fermilab[3] (Broad Band γ)	116	50-210	9	≃2	($\mu^+\mu^-$) 56 ±19[7] (e^+e^-) 59 ±15[8]	b≃2 →	∿28

*Extrapolated to t=0 from data in Ref. 2.

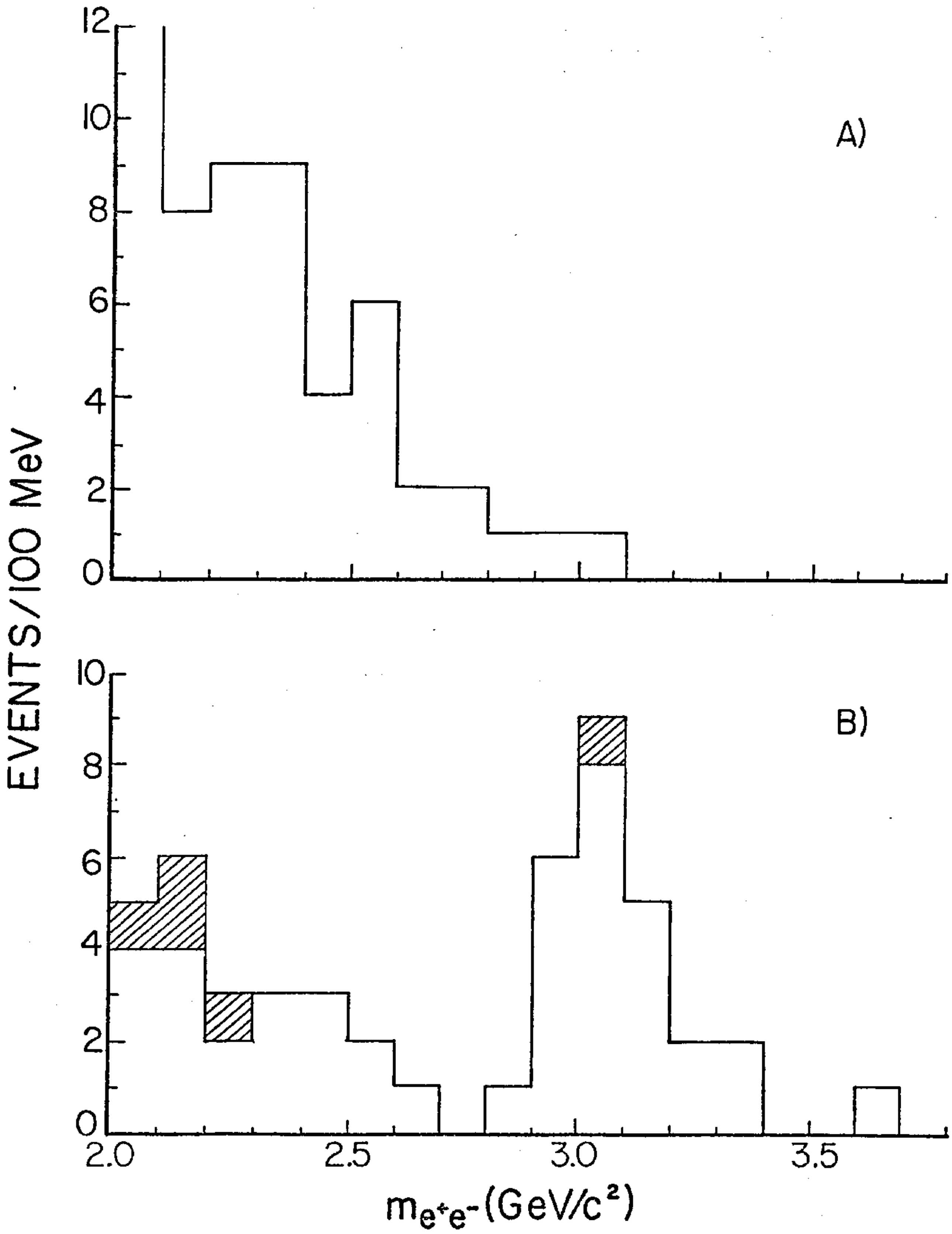

Fig. 1. Mass distribution of (a) background events described in text with lead glass energy patterns inconsistent with two single showers, (b) events surviving all cuts. Shaded events have $E_{e^+e^-} \leq 0.85\ E_\gamma$.

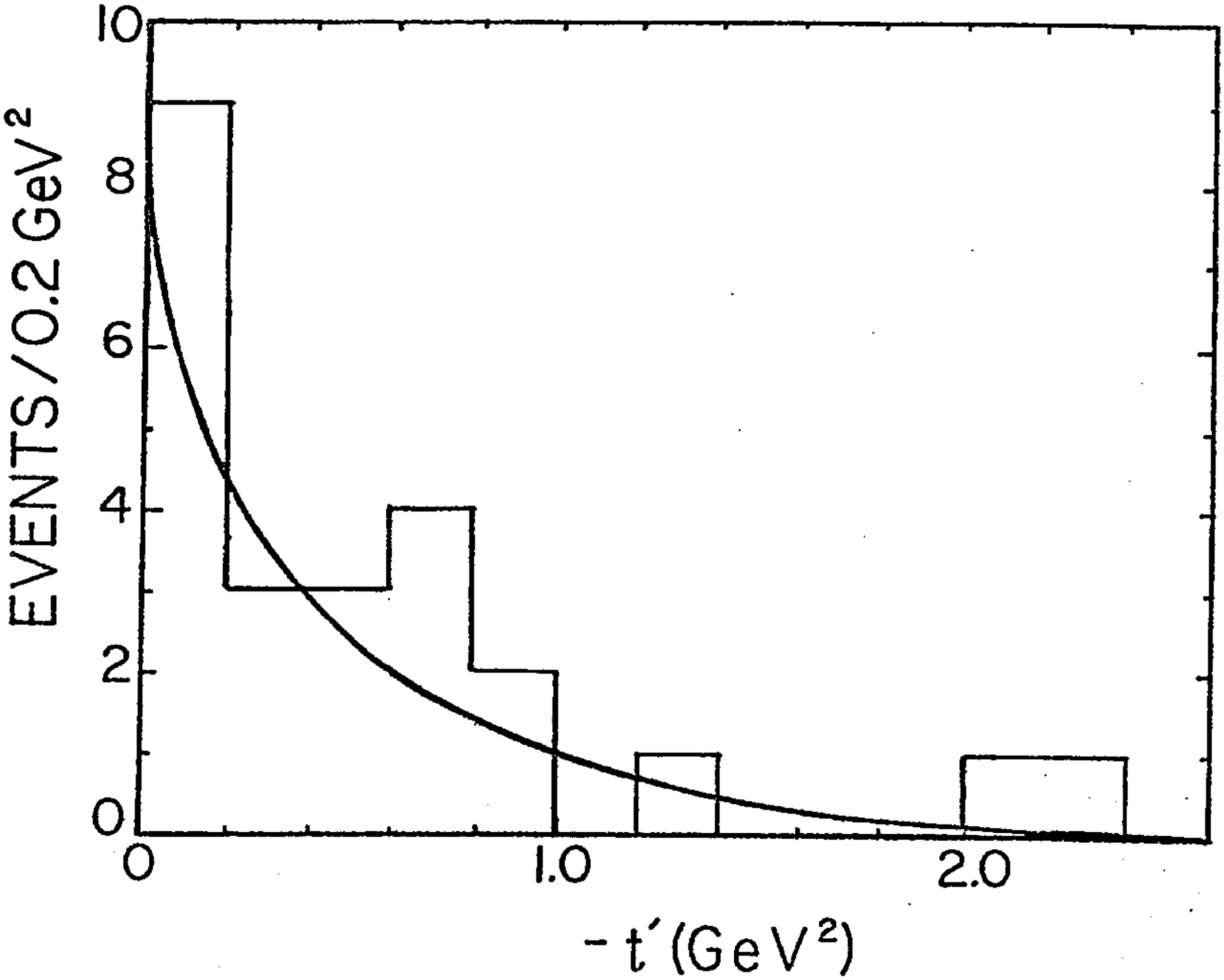

Fig. 2. $P_{\perp}^{2} \approx -t'$ distribution of events with $2.75 < M_{ee} < 3.45$ GeV and $E_{\psi} > 0.85\ E_{\gamma}$. Curve is fit to the form $2A(1+F(t))e^{bt}$; F(t) is the deuteron form factor.