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ψ AND EXCESS LEPTONS IN PHOTOPRODUCTION*

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ABSTRACT

The A-dependence of ψ photoproduction was measured on Beryllium and Tantalum. From this we found $\sigma_{\psi N} = 2.75 \pm 0.90$ mb. A study was made of excess leptons relative to pion production in photoproduction. A μ/π ratio of $1.40 \pm 0.25 \times 10^{-4}$ was found at 20 GeV incident photon energy. The energy dependence of ψ photoproduction was determined and appeared to have a "pseudo-threshold" at 12 GeV.

INTRODUCTION

This is a preliminary report on an experiment run at the SLAC linear accelerator in Fall 1975. The experiment was motivated by the observation[1] that ψ mesons can be detected via their two lepton decay mode by both coincidence detection of the lepton pair and by detecting one lepton in the kinematically enhanced region corresponding to $p_\perp = M_\psi/2$.

We report the following measurements:

a. The energy dependence of the ψ photoproduction cross section. Results from the 1975 SLAC Photon Conference indicated a strong change in cross section in the neighborhood of 12 GeV. However, data below 11.5 GeV came from a Cornell experiment and above 13 GeV from a SLAC experiment.

b. A direct measurement of the ψ-nucleon total cross section made by determining the A-dependence of the diffractive photoproduction cross section on Beryllium and Tantalum. Previous indirect arguments using vector dominance indicated a total cross section of ~ 1 mb.

c. For photoproduction experiments in contradistinction to hadron production the "excess-lepton" signal is dominated by ψ decays at $p_\perp \sim 1.5$ GeV/c. This made it interesting to investigate prompt lepton production in photoproduction to see whether other sources of prompt leptons such as "charm" might also show up more clearly in photon reactions.

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APPARATUS

The experiment was run using the SLAC End Station A Spectrometer Facility with the standard photon and electron beams. The 8 and 20 GeV/c spectrometers were used to detect muons and pions by means of Čerenkov counters and iron range telescopes. Hodoscope or wire chamber information was not needed for these measurements. The layout of the target area is shown in Fig. 1.

A variety of remotely selectable solid targets was available, including Tantalum, Aluminum, 0.5", 2.0" and 4.0" thick Beryllium, and null targets. The targets were enclosed in a narrow helium-filled scattering chamber with thin aluminum windows. The chamber was made long enough to keep the beam entry and exit windows out of the field of view of the spectrometers. The entire target assembly could be remotely moved from side to side in order to reduce the target material traversed by a particle originating along the beam path as it traveled toward one spectrometer or the other. Since the spectrometers were on opposite sides of the beam line, the target position could only be optimized for one spectrometer at a time. Care was taken to ensure that the beam was fully within the target and not spilling over the edge. The target selection and coordinate were recorded by the computer.

A helium-filled duct downstream from the target reduced room background from the beam. Photon beams were stopped by a secondary emission quantameter (SEQ) within a concrete shielding enclosure at the rear of the end station, which measured the total energy in the beam. Electron beams passed through the end station to a remote shielded beam dump, and were measured by the SLAC integrating toroid monitors upstream of the target. One toroid, ahead of the photon beam production target, was also useful for monitoring the photon beams.

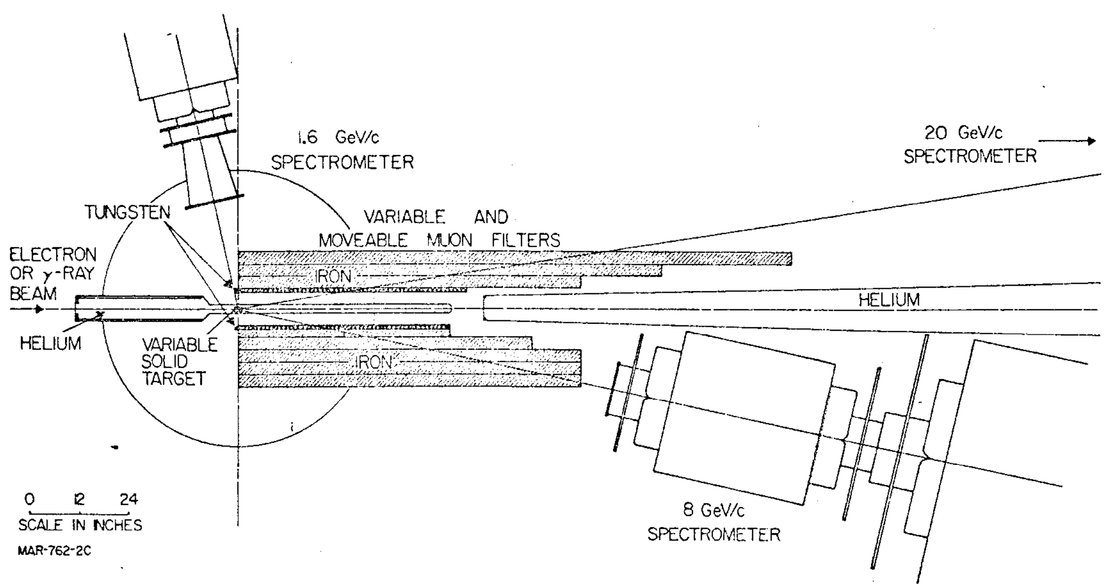


Fig. 1. Plan view of target area for single arm ψ and excess lepton experiment showing details of muon filters.

The 1.6 GeV/c spectrometer was set up to view the target under fixed conditions and provided a stable relative monitor.

Between the target and either spectrometer was a variable thick iron muon filter, which could be adjusted to stop all particles except muons from entering the spectrometers. The filters were suspended from a frame which could rotate about the target center and translate radially from the target center in the horizontal plane. The filters were composed of 3 or 6 separate iron slabs (for the 20 GeV/c or 8 GeV/c spectrometers respectively), which were independently suspended from the frames and remotely retractable in any combination so that they could be completely raised above the flight paths of the relevant particles. The slabs nearest the target were faced with tungsten to increase their stopping power. The number of muons produced as a result of pion decays between the target and the iron could thus be varied by changing the flight path between the target and the filter iron, either by moving the iron sideways or by retracting the front slabs. The effective thickness of the iron between the target and spectrometer could be controlled by varying the number of slabs retracted and by varying the angle of the filters relative to the spectrometer. In one mode of operation, the filters were rotationally locked to the spectrometers so that the relative angle could not change as the spectrometer angle was varied. The slab combinations, positions, and angles were recorded by the computer.

The on-line computer, an SDS9300, recorded on tape the settings and status of the equipment, event-by-event data, scaler readings, and beam monitors. It also provided control of the spectrometers, monitored rates, analyzed samples of the data and created paper and microfilm records of the data. Subsets of the data were transferred to the SLAC computation facility for additional analysis as the experiment progressed.

ENERGY-DEPENDENCE OF THE CROSS SECTION

To measure the production of ψ's, we made sweeps in $p_\perp$ with the 8 GeV spectrometer at 10 GeV, 12 GeV, 14 GeV, and 16 GeV maximum bremsstrahlung energies. The detected momentum at the target was ~5.5 GeV/c for a muon. $p_\perp$ was varied by varying the detection angle. Both the pion and the muon spectra were measured in separate sweeps with and without a hadron filter.

Figure 2 shows the muon yields versus $p_\perp$. The pion spectra were fitted to the form: yield (pions) = $A_\pi \exp(-B_\pi p_\perp)$ (with $B_\pi \sim 6$). The resulting spectrum for muon decay should be of the form:

$$\frac{A_\mu e^{-B_\pi p_\perp}}{B_\pi p_\perp} .$$

The calculated Bethe-Heitler[2] directly produced muons have an almost identical shape. We, therefore, fitted our muon yields to the three parameter form:

$$Y_\mu = \frac{A\ e^{-Bp_\perp}}{Bp_\perp} + C(\psi\text{-shape}) \ .$$

The first term represents muons from pion decay and B. H. production. The values of A and B obtained were close to those that were obtained by calculation from the pion spectrum and B. H. production.

The ψ-shape was obtained from a Monte Carlo calculation. The hard lines in Fig. 2 are computer fits to the yield curves. The dotted lines show the extrapolation of the background terms.

From the values of C obtained, the cross section for ψ's was unfolded. Figure 3 shows the result of $|d\sigma/dt|_{t_{min}}$ evaluated at t_{min}. The major source of error is the value b of the slope parameter to be used for this determination. We used a value of $b = 2\ \mathrm{GeV/c}^{-2}$, which could be in error by a factor 1.5.

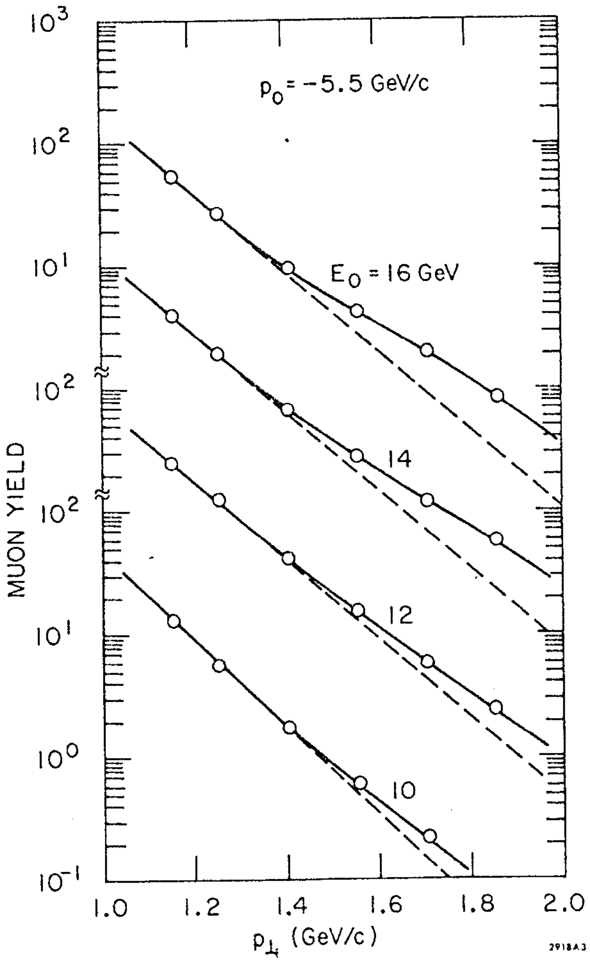


Fig. 2. Muon yields at incident photon energies of 10, 12, 14 and 16 GeV/c for a muon momentum at the target of -5.5 GeV.

We conclude on the basis of Fig. 3 that the new measurements, the Cornell measurements, and our old SLAC measurements are all in reasonable agreement and show a substantial increase at 12 GeV. This is in line with Vector Dominance models that would expect a substantial increase in the ψ-nucleon cross section at the energy for which the charmed D particles can be produced.

ψ-NUCLEON CROSS SECTION VIA A-DEPENDENCE

To measure the ψ-nucleon cross section directly, photoproduction of ψ's was measured from a Beryllium and a Tantalum target, each of 0.3 radiation length thickness. The ψ-nucleon cross section is determined from the measured ratio of the cross sections.

Measurements were made on single muons at a $p_\perp$ of 1.65 GeV/c with the SLAC 20 GeV spectrometer. The primary peak bremsstrahlung energy was 20 GeV and the detected muons had a momentum of -9 GeV/c at the target.

Empty target subtractions even for Tantalum were less than 5%. About 1100 events

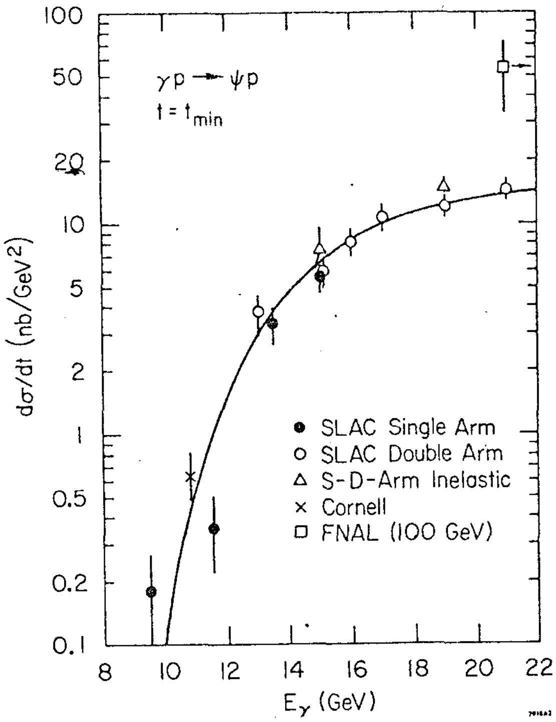


Fig. 3. $d\sigma/dt$ at $t = t_{min}$ for photoproduction. Black circles are this experiment. Note the FNAL point is off to the right on the graph.

were observed from the Tantalum target and about 4000 events from the Beryllium target. To evaluate backgrounds, the pion fluxes were measured from the respective targets and a $p_\perp$ sweep was made for the muon flux to determine the backgrounds from sources other than ψ-decays. Figure 4 shows the detected muons fitted for direct Bethe-Heitler production and ψ-decay. At a $p_\perp$ of 1.65 GeV, 11% arise from pion decay, 20% arise from Bethe-Heitler production, and 69% are from ψ-decay.

The raw measured ratio $|\mu(\mathrm{Be})/\mu(\mathrm{ta})|_{\mathrm{raw}} = 1.19 \pm .04$. The measured ratio of pions from the targets was $1.18 \pm .02$ and hence the ratio for background muons arising from pion decay should also be $1.18 \pm .07$. The calculated ratio for Bethe-Heitler production is $1.03 \pm .02$.

If the raw ratio is corrected for the background, the corrected ratio $|\mu(\mathrm{Be})/\mu(\mathrm{Ta})|_{\psi\text{'s}} = 1.25 \pm .055$. Nuclear physics corrections to the ratio are 6% arising from Pauli suppression, 3% from coherent production and -1% from the Fermi-momentum corrections to cross section for ψ-production. The ratio corrected for nuclear physics is then

$$|\mu\mathrm{Be}/\mu\mathrm{Ta}|_{\psi}^{\mathrm{Corr}} = 1.17 \pm .055 \quad .$$

To determine the ψ-nucleon cross section from this result, we used the standard model with $A_{\mathrm{eff}/A} = 1-\delta/A$

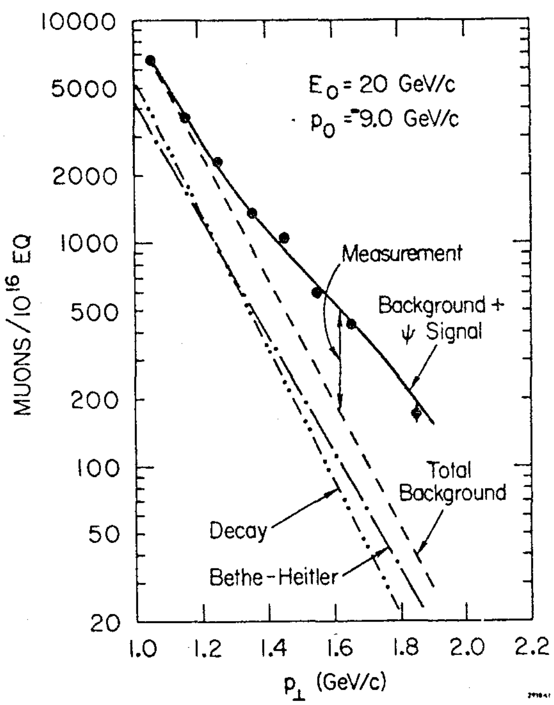


Fig. 4. Muon yield curve obtained with 20 GeV/c spectrometer from a 4-inch Beryllium target used to determine the A-dependence of ψ photoproduction.

$$\frac{\delta}{A} = \frac{9}{16\pi}\left(\frac{\sigma_{\psi N}}{r_o^2}\right)A^{1/3} = 1.33 \cdot 10^{-2}\ \sigma_{\psi N}\ A^{1/3}\ \text{(mb)}$$

yielding

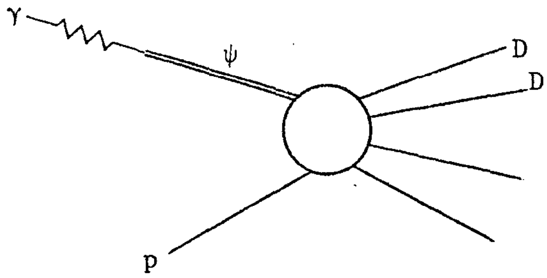
$\sigma_{\psi N} = 2.75 \pm 0.90$ mb
statistical error only.

The estimated systematic error is ~ ± 0.5 mb.

Therefore ψ-nucleon cross section is significantly different from zero mbs. Our result agrees with the value obtained from Vector Dominance arguments using the photoproduction cross section and the value of the photon-ψ coupling obtained from colliding beams.

EXCESS LEPTON PRODUCTION

Sivers, Townsend, and West (S.T.W.) (SLAC PUB-1636) discuss the photoproduction of D's. It is expected that a lower limit for the production of D's is given by the following diagram:



$$\sigma(\gamma p \to D\text{'s} + \ldots) \simeq \alpha\ \frac{4\pi}{f^2_\psi}\ \sigma_{tot}(\psi p)$$

$$\simeq 500 \text{ nanobarns}$$

S.T.W. give $\sigma(\gamma p \to D\text{'s}) \geq 300$ nbarns.

Therefore unlike the case for hadron production there exists a firm estimate of the D's produced via photoproduction. The cross section is comparatively large, being of the order of .4% of the total photoproduction cross section.

We measured "excess" muon production from a Beryllium target to see if we could detect muons produced from non-conventional (new physics) sources. In order to eliminate the muons from pion and kaon decay, measurements were made with the hadron filter at various distances from the target. These displacement curves were extrapolated to zero effective pion decay length to determine the prompt muon flux arising from sources other than decays. To make these extrapolations, we made a Monte Carlo calculation to take into account the multiple scattering effects on the input spectrum and the aperture of the spectrometer. Lateral displacement curves (Fig. 5) were taken at end point energies of 8 GeV, 12 GeV, and 20 GeV and at a $p_\perp$ of 1 GeV^2. The slopes of the lateral displacement curves were used to calibrate the effective aperture of the spectrometer so that prompt

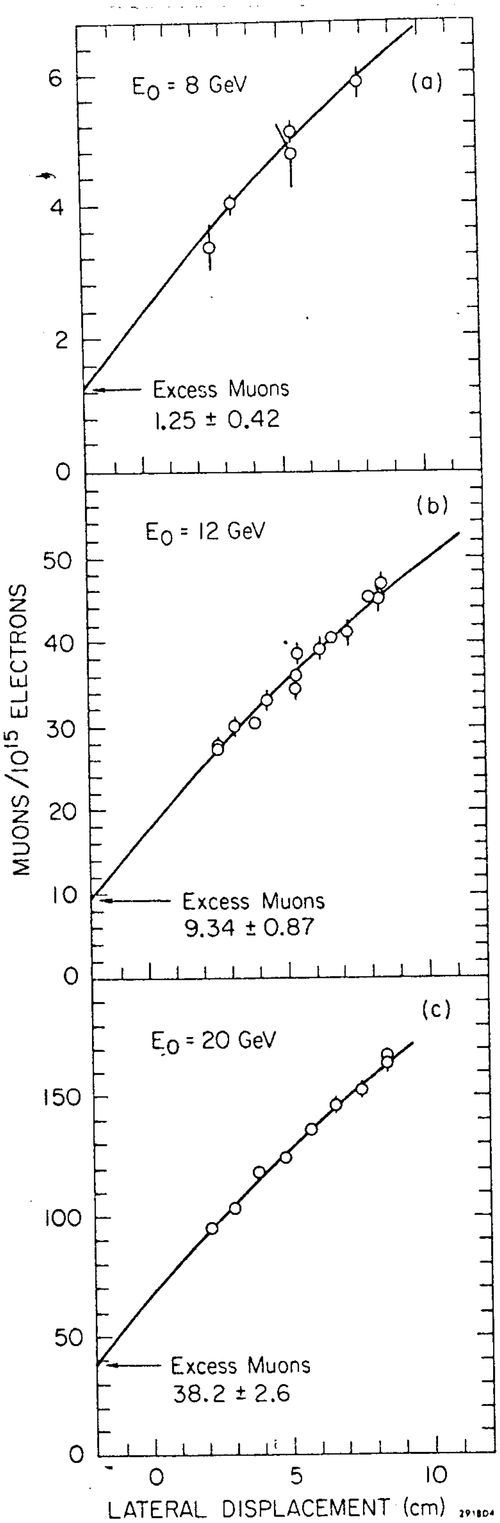


Fig. 5. Excess leptons at 8, 12, and 20 GeV photon energies obtained by displacing muon filters relative to the target.

muons arising from Bethe-Heitler production could be calculated.

Results are given in Table I. The signal at 8 GeV and 12 GeV is accountable from the prompt muons arising from Bethe-Heitler pair production. There appears to be a significant signal at 20 GeV with a μ/π ratio ~ 10^{-4}. This is similar to that observed in hadron experiments. To eliminate systematic effects, the only variable changed was the energy of the primary bremsstrahlung beam. Therefore the secondary momentum of the muons was held constant. A variation of primary energy, therefore, also corresponded to a variation in Feynman x. It is, therefore, possible to attribute the observed variation in the μ/π ratio to either the variation in Feynman x or to the variation with energy.

If all the excess muons at 20 GeV are attributed to charmed D decays, we can compare our result with model estimates. If we assume D's are produced with an integrated cross section proportional to the ψ-cross section, and with a shape

$$\frac{d\sigma}{dp^2\, dx} \propto e^{-5m_\perp}(1-x)^2$$

(of course, other assumptions can be made)

$$m_\perp = \sqrt{m_D^2 + p^2}$$

then our result is $\sigma(\gamma p \to D)$ x(Branching ratio to D's) = 2 10^{-33} cm^2 at a $p_\perp$ of 1 GeV/c and a muon momentum of ~5.5 GeV/c.

Estimating from theory, by combining the S.T.W. cross section with a 5% branching ratio gives $\sigma(\gamma p \to D)$ x BR ≥ 15 10^{-33} cm^2, a factor seven times higher than the observed value. This disagreement is uncomfortable, but it cannot be ruled out that other production

TABLE I. Excess Muons

E (GeV)	Total Excess/10^{15} e's	Calc B.H.	Net Excess (Total+B.H.)	Net Excess In Units Of $\mu/\pi \cdot 10^5$
8	1.25 ± 0.42	1.15 ± 0.25	0.1 ± 0.5	1.4 ± 7.0
12	9.34 ± 0.87	6.90 ± 1.70	2.4 ± 2.0	4.8 ± 4.0
20	38.20 ± 2.60	14.40 ± 3.60	23.8 ± 4.4	14.0 ± 2.5

spectrum assumptions would produce agreement between observation and expectation.

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REFERENCES

1. cf. R. Prepost, Lepton Photon Conference, 241 (1975).
2. Y. Tsai, Rev. Mod. Phys., 46, 815 (1974).