MEASUREMENT OF J/ψ PRODUCTION IN 280 GeV/c μ^+ IRON INTERACTIONS

The European Muon Collaboration

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Abstract

Virtual Photoproduction of J/ψ mesons has been measured for 280 GeV muon iron interactions in an iron/scintillator calorimeter target. The J/ψ 's were identified by their decay into muon pairs. 315 events were observed, about half of which were elastic. The t , Q^2 and ν distributions of these elastic events are presented. The ν dependence is measured between 40 and 180 GeV and compared with lower energy photoproduction results. The Q^2 dependence is compared with the predictions of the Vector Dominance Model.

Geneva - November 1979

Submitted to Physics Letters

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The production of J/ψ particles by muons is of considerable interest in that it provides a test of vector dominance¹⁾ through the Q^2 dependence of the elastic cross-section and also a test of QCD predictions^{2,3)} through the inelastic cross section. Previous measurements have been made in photoproduction⁴⁻⁷⁾, giving a total cross section of about 40 nbarn at an energy of 80 GeV. This experiment determines the Q^2 dependence up to $15 (\text{GeV}/c)^2$ and extends the photon energy up to 180 GeV. Measurements of energy deposited in a calorimeter target were used to separate elastic and inelastic events. In this paper results are presented for elastic production.

The experiment was performed in the CERN SPS muon beam using the EMC forward spectrometer, a full description of which is given elsewhere.⁸⁾ The beam was optimised for μ^+ with a mean momentum of 280 GeV/c and a momentum bite of 8% FWHM. Each beam track was measured with hodoscopes to $\pm 0.4\text{mm}$ in position, $\pm 0.2\text{mrad}$ in angle and $\pm 0.7 \text{ GeV}/c$ in momentum. The incident flux was measured with additional beam hodoscopes and these measurements corrected for dead time effects. For the data reported here the total incident flux was 8×10^{10} muons, at an instantaneous rate of $10^7/\text{second}$.

The target was a Sampling Total Absorption Calorimeter (STAC) consisting of 36 iron/scintillator sandwich elements of total length 3.75m. Events were selected from a total fiducial target length corresponding to a target thickness of $1.5 \text{ kg}/\text{cm}^2$. The interaction vertex was measured to $\pm 45\text{mm}$ in position along the beam direction, and the hadron shower energy with a resolution $\frac{\Delta E}{E} = 0.41 E^{-0.4}$ (E in GeV).

The scattered muons and muons from the decay $J/\psi \rightarrow \mu^+\mu^-$ emerged from the STAC and were measured in the forward spectrometer which consists of a large aperture magnet and drift and proportional chambers. A magnetised iron absorber, followed by more drift chambers further downstream, was used to identify muons. The momentum resolution of the spectrometer was $\frac{\Delta p}{p} = \pm 1\%$ at 100 GeV/c and the angular resolution was dominated by multiple scattering in the target.

The trigger was made using two scintillation hodoscopes downstream of the magnet and three downstream of the absorber, demanding at least two tracks passing through the absorber. Electromagnetic trident production was suppressed by the requirement of a minimum vertical angle of 13mrad

for at least one track. An extensive arrangement of veto counters upstream of the target was used to suppress triggers not caused by beam muon interactions.

High momentum muons at small angles remained completely in the deadened region of the downstream drift chambers. Two small proportional chambers, upstream of the spectrometer, were used to measure the angles of these tracks (assumed to be μ^+) and their momenta calculated using energy balance between the incident beam, the hadronic shower energy measured in the STAC and the measured outgoing tracks. The track finding efficiency was 90% for particles detected in the spectrometer and 65% for the forward going tracks detected in the small proportional chambers.

A total of 9524 $\mu^+\mu^+\mu^-$ events was obtained. The higher momentum positive track was chosen to be the scattered muon. The mass spectrum of the remaining muon pair $\mu_{s1}^+ \mu^-$ (where μ_{s1}^+ is the lower momentum, positive muon) is given in Fig. 1, showing a clear J/ψ signal. A fit has been made to a gaussian plus a smooth background giving a J/ψ mass of $3.08 \pm 0.02 \text{ GeV}/c^2$, a resolution of $\sigma = 0.22 \text{ GeV}/c^2$ in agreement with the calculated resolution, and $304 \pm 22 \text{ } J/\psi$ events above background.

For J/ψ events the selection criterion for the scattered muon was studied using a Monte Carlo simulation of the reaction. The fraction of incorrect assignments was found to be negligible when the energy ν of the virtual photon was less than 150 GeV and about 10% for $150 < \nu < 180 \text{ GeV}$. The data were corrected for this effect.

To select a clean sample of elastic J/ψ virtual photoproduction events the following cuts were made:

- 1) Mass of $\mu_{s1}^+ \mu^-$ between 2.6 and 3.6 GeV/c^2
- 2) Measured energy deposited in the STAC less than 5 GeV (to select elastic events)
- 3) The momenta of each of the three final state muons greater than 10 GeV/c
- 4) The event vertex to be reconstructed in the upstream 3 metres of the STAC (to eliminate backgrounds due to punch-through hadrons).

A sample of 186 events survived these cuts of which 20 were estimated from the fit to be background. A pure background sample, selected from

the dimuon mass range $2.0 < M < 2.6 \text{ GeV}/c^2$, was used to study the dependence on Q^2 , ν and t . This sample showed that the background distributions were similar to those of the events from within the J/ψ mass peak. Thus the correction for the background under the J/ψ peak was made by subtracting the same fraction of events in each bin of Q^2 , ν and t . Further corrections, for the apparatus acceptance, were necessary and these were calculated assuming that the decay angular distribution was proportional to $(1 + \cos^2 \theta)$ ie. neglecting any contribution from scalar photons.

Fig. 2 shows the distribution of the accepted events per unit t interval as a function of $t' = t - t_{\min}$ for all Q^2 and ν . The acceptance does not vary significantly in this variable. Taking A to be the number of nucleons in the nucleus, the following parametrisation has been used to fit the data

$$\left(\frac{d\sigma}{dt}\right)_{\text{Iron}} = \left(\frac{d\sigma}{dt}\right)_{\text{nucleon}}^{t=0} [A^2 e^{-at} + A e^{-bt}]$$

The two terms describe the coherent and incoherent scattering of virtual photons, neglecting shadowing effects. The slope of the observed coherent peak at small t in the data is dominated by the experimental resolution. Thus the value of a used in the fit was taken from a Monte Carlo simulation of coherent J/ψ production generated with a slope parameter of $135 (\text{GeV}/c)^2$ (derived from low energy photoproduction measurements of Ref. 4 on beryllium extrapolating to iron using the nuclear radius measurements of Ref. 9), and detected and smeared by the resolution in the apparatus. The smooth curve in Fig. 2 shows the best fit obtained with the incoherent slope parameter $b = 2.31 \pm 0.30 (\text{GeV}/c)^{-2}$.

Fig. 3 shows the Q^2 dependence for all ν and t (after correction for acceptance). The naive vector dominance model for elastic J/ψ production by transversely polarised photons predicts a Q^2 dependence of the form $(1 + \frac{Q^2}{M_{J/\psi}^2})^{-2}$. A fit of the form $C (1 + \frac{Q^2}{M^2})^{-2}$ with C and M as free parameters is in good agreement with the data giving $M = 2.4 \pm 0.3 \text{ GeV}/c^2$.

The observed Q^2 dependence and fitted t dependence have been used to calculate $\frac{d\sigma}{dt}$ at $Q^2 = 0$ and $t = 0$ for elastic J/ψ photoproduction. Fig. 4(a) shows this plotted as a function of ν and Fig. 4(b) shows the total cross section variation. The decay branching ratio of the J/ψ into muons was taken to be 7% and a further correction ($\sim 15\%$) applied for elastic events which failed the selection criteria due to radiation by bremsstrahlung of energy greater than 5 GeV. The estimated systematic error on the cross section is $\pm 20\%$ and is not shown in the figure. The data are consistent with a constant cross section for elastic J/ψ production of $52 \pm 5 \text{ nb}/(\text{GeV}/c)^2$ per nucleon. They are also compared with photoproduction (Ref. 4-7) and muoproduction data (Ref. 10).

Taking $\left(\frac{d\sigma}{dt}\right)_{t=0}$ from our data and the J/ψ leptonic width and its mass from Ref. 11 one can derive via the optical theorem and the Vector Dominance Model the forward scattering cross section for the J/ψ and its total hadronic cross section, obtaining $\left(\frac{d\sigma}{dt}\right)_{t=0} (J/\psi N \rightarrow J/\psi N) = 82 \pm 20 \text{ } \mu\text{b}/(\text{GeV}/c)^2$ and $\sigma(J/\psi N)_{\text{total}} = 1.26 \pm 0.31 \text{ mb}$. Here we have neglected any real part in the forward scattering amplitude for elastic J/ψ -N scattering.

To summarise, elastic J/ψ production by virtual photons has been observed in 280 GeV muon iron scattering together with a significant fraction of inelastically produced events. The Q^2 dependence of the elastic sample is in qualitative agreement with the expectations of the naive Vector Dominance Model. The elastic differential cross section for J/ψ production on a nucleon extrapolated to $t = 0$ and $Q^2 = 0$, which increases rapidly with energy for low energy photoproduction, has flattened off and is consistent with a constant value of 52 ± 5 (statistical) ± 10 (systematical error) $\text{nb}/(\text{GeV}/c)^2$.

This experiment could only have been performed with the help of the many people who took part in the building and operating of the muon beam and the experimental apparatus, and the handling of the magnetic tapes during the data analysis. We are extremely grateful for their different but essential contributions to the success of this experiment.

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Figure Captions

- Fig. 1 - Mass spectrum of $\mu_{s1}^+ \mu^-$ for all $\mu^+ \mu^+ \mu^-$ events. The μ_{s1}^+ is the μ^+ with the lower momentum.
- Fig. 2 - t' -distribution of elastic J/ψ events. $t' = t - t_{\min}$. The curve is the parametrisation described in the text.
- Fig. 3 - Q^2 -distribution of elastic J/ψ events, normalised to $Q^2 = 0.10$ $(\text{GeV}/c)^2$. The horizontal error bars show the experimental resolution in Q^2 . The curves are best fits for VDM predictions of the form $\text{const} * (1 + \frac{Q^2}{M^2})^{-2}$, where M is the propagator mass and taken to be $1 \text{ GeV}/c^2$ (dotted line) and equal to the J/ψ mass (solid line).
- Fig. 4a - $(d\sigma/dt)_{[t=0, Q^2=0]}$ for $\gamma N \rightarrow J/\psi N$ as a function of the photon energy ν .
- Fig. 4b - The total elastic J/ψ photoproduction cross section on iron as a function of the photon energy ν .

$\mu^+ \mu^-$ Mass (GeV/c^2)

FIG.1

FIG. 2

FIG. 3

FIG. 4