SLAC-PUB-1988
UCSC #77-064
August 1977
(T/E)

INCLUSIVE PRODUCTION OF ρ^{0} IN INELASTIC MUON-NUCLEON SCATTERING*

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Abstract

We measured the inclusive production of ρ^{0} mesons in virtual photon nucleon collisions. The extracted cross sections are Q^{2} independent and approximately equal to those observed in photoproduction, if one excludes the diffractive (elastic) region where a large decrease is observed. A significant fraction of the inclusive $\pi^{\pm}$ distribution results from the decay of these ρ^{0}'s.

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*Work supported in part by the Energy Research and Development Administration.

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(Sub. to Phys. Rev. Letters)

I. Introduction

The elastic production of vector mesons, predominantly the ρ^0, has given rise in photoproduction to the idea of vector dominance[1]. In this model, the photon is visualized as having a vector meson component which scatters hadronically on the nucleon. As a leading particle due to the incident virtual ρ^0 component, inelastic ρ^0 production might be enhanced in the forward "fragmentation region," mirroring the prominent elastic cross section[2].

The total cross section for the collision of virtual photons of large mass-squared, Q^2, with nucleons contains a substantially smaller fraction of elastically produced vector mesons than that for real photons. If we think of this process in terms of the quark-parton model[3], forward inelastic ρ^0 production can originate from a yet poorly understood quark-dressing mechanism. A measurement of the inclusive ρ^0 distribution may serve to constrain such parton models. It has an advantage over inclusive π production whose fundamental features can be masked by the contribution of pions from heavier mesons which decay. The inclusive ρ^0 cross section may well differ substantially from that seen in photoproduction, since, in the two models mentioned above, these processes look dissimilar.

With these points in mind, we have measured inclusive ρ^0 cross sections in muon-nucleon scattering, where the muon serves as a source of virtual photons of variable mass. We compare our results to those measured in photoproduction[4]. The experiments from which our data are taken are described in detail in Ref. 5. The data sample contains 7,750 events on hydrogen and deuterium targets.

II. Determination of ρ^o Distributions

A. Structure Functions

Inclusive distributions for the production of a given type of hadron are typically displayed in terms of the Feynman scaling variable[6] x_F, defined to be the longitudinal momentum of the hadron divided by its maximum possible value, in the appropriate center-of-mass system. For the ρ^o, we define a structure function:

$$F^{\rho^o}(x_F) = \frac{E^*}{\pi p^*_{max}} \frac{1}{\sigma_{tot}} \frac{d\sigma^{\rho^o}}{dx_F} ,$$

where x_F = fractional ρ^o momentum along the virtual-photon direction; p^*_{max} is calculated for a given $\pi^+\pi^-$ mass by assuming that this mass recoils against a nucleon, and the cross sections are integrated over given bins in W and Q^2 for the virtual-photon nucleon system.

In lepton-induced reactions, a related variable z[3], equal to a hadron's laboratory energy divided by the energy of the incident virtual photon, provides an alternative way to display inclusive distributions. In this variable, we get a distribution often called a structure function:

$$F^{\rho^o}_{\mu N}(z_{\rho^o}) = \frac{z_{\rho^o}}{\sigma_{tot}} \frac{d\sigma^{\rho^o}}{dz_{\rho^o}} .$$

This function particularly emphasizes the fragmentation region of the virtual-photon for a target nucleon of type N (proton or neutron).

B. Extraction of Distributions

To calculate the functions discussed above for given W and Q^2 ranges, we chose bands of x_F or z_{ρ^o} and fitted the di-pion mass distributions to a Breit-Wigner ρ^0 signal, plus a smooth background for all pairs falling into the given band. To extract $F^{\rho^0}(x_F)$ and $F^{\rho^0}_{\mu N}(z_{\rho^0})$ directly, all pairs are weighted by $\frac{E^*}{\pi p^*_{max}}$ or z_{ρ^0}, respectively, before fitting. The calculated distributions are equal within statistics for both our proton and our deuterium experiments; we have therefore summed all of our data to improve the statistical significance of the results. We note that both diffractive and quark fragmentation models predict that yields in the photon-fragmentation region should be nearly equal for proton and neutron targets. Because of a lack of particle identification, all particles other than the trigger muon are assumed to be pions.

In Fig. 1, we show the mass distributions in bands of x_F, for our full data sample ($2.8 \le W \le 4.7$ GeV, $0.3 \le Q^2 \le 4.5$ GeV^2; $\langle W \rangle = 3.5$ GeV, $\langle Q^2 \rangle = 1.0$ GeV^2). We fitted the mass distribution for $500 \le M_{\pi\pi} \le 1100$ MeV by assuming an exponential background shape to which we add a relativistic P-wave Breit-Wigner form[7], without a skewing parameter, centered at $m_{\rho^0} = 770$ MeV, and with a width $\Gamma_{\rho^0} = 150$ MeV. The $\pi\pi$ mass distribution is binned in 20 MeV bins, and a χ^2 value for the fit is calculated by comparing the predicted bin population for the fit to the binned data. Resulting fits are good, yielding typically a χ^2 of 1 per degree of freedom.

To test our procedure, we checked that the distributions do not change by more than the calculated errors if:

(1) Bin edges are moved by half a bin width.

(2) A second-order polynomial instead of an exponential is used to parametrize the background.

(3) Fits for a band covering several bins are compared with the sum of individually extracted ρ^0 signals.

(4) Exponential fits to $\pi^+\pi^+$ and $\pi^-\pi^-$ distributions have good χ^2 values.

III. Results

A. Distributions in x_F and z_{ρ^o}.

Fig. 2a shows the function $F^{\rho^o}(x_F)$ for our full data sample, as well as the analogous distribution in photoproduction. Our data are only shown for $x_F > .1$, where we feel we can reliably extract the ρ^o cross section. For backward ρ^o's, the signal-to-background is small, and nucleon resonances give reflections (for misidentified protons) which distort the ρ^o mass region.

Fig. 2b gives the structure-function in terms of the variable z_{ρ^o}, on a linear scale, for comparison with structure functions[8] from other processes. As expected asymptotically, $F^{\rho^o}_{\mu N}(z_{\rho^o}) \simeq \pi F^{\rho^o}(x_F)$ in the photon-fragmentation region. The dashed curve shown is a prediction of a specfic parton model[9] under the assumption that only non-strange quarks are found in the proton at our values of Q^2 and W. Both the shape and normalization of the prediction are in reasonable agreement with the data. Fig. 2c shows the analogous structure function calculated from our data[10] for negative hadrons, assumed to be pions, and a measurement of the contribution of π^- from ρ^o decay to this distribution.

In Fig. 3, the quantity $F^{\rho^o}(x_F)$ is presented as a function of Q^2, for three x_F bands. Analogous photoproduction data are again shown.

B. Conclusions

The structure functions for the ρ^o shown in Figs. 2 and 3 lead to the following conclusions:

1. For x_F or $z_{\rho^0} > .9$, we see a strong Q^2 change in the distribution. This region is populated almost entirely (>90% for our hydrogen data, where we use a 4-C fit to constrain the $\mu p \rightarrow \mu p \pi^+ \pi^-$ final state explicitly) by the elastic ρ^0 final state, which decreases by almost a factor of three when compared to photoproduction[2].

2. In the inelastic region ($.1 \leq x_F \leq .9$), the inclusive distribution is very flat in x_F. Furthermore, we see almost no Q^2 dependence. Using our 4C fits to the hydrogen data, we find that this region contains essentially no contribution from the elastic ρ^0 final state, and it does not mirror its Q^2 dependence. The photoproduction distribution is, if anything, a little below the high-Q^2 distribution.

3. The ρ^0 contributes a substantial number of π^- to the structure-function for these particles. For $0.8 \leq z_{\pi^-} \leq 1.0$, $70 \pm 15\%$ of the π^- come from ρ^0 (almost all from elastic ρ^0); for $0.2 \leq z_{\pi^-} \leq 0.4$, $24 \pm 5\%$ come from ρ^0 (mostly inelastic ρ^0). Since the structure function for large z for positive hadrons is about twice as large as for negative hadrons[10], a smaller percentage of these come from ρ^0 decay. If other vector and heavier pseudoscalar mesons are as copiously produced as inelastic ρ^0's, they can account for a very substantial number of the detected pions.

4. The ρ^0 contribution is large in magnitude: In terms of the model of Ref. 9, which gives a reasonable prediction of our measured functions, there is as much direct production of ρ^0 as there is of π^0.

Clearly, it would be desirable to have analogous results from e^+e^- annihilation and neutrino scattering to compare with our data: there are parton-model relations between all of these processes.

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Figure Captions

1. Mass distributions for $\pi^+\pi^-$ in bands of the fractional longitudinal momentum, x_F. Each event is weighted by $E^*/\pi p^*_{max}$ so the bin populations do not reflect the true number of events. Curves are the best fits in terms of an exponential background and a Breit-Wigner.

2a. Distribution function $F^{\rho^o}(x_F)$ for virtual-photon nucleon scattering (solid circles) and real-photon proton scattering (open circles).

2b. Structure function $F^{\rho^o}_{\mu N}(z_{\rho^o})$ for full data sample.

2c. Analogous function, $F^{\pi^-}_{\mu N}(z_{\pi^-})$, for all negative hadrons. Also shown is the contribution of ρ^o decay π^-'s to this function.

3. Distribution function $F^{\rho^o}(x_F)$ for incident virtual-photons of various Q^2. Photoproduction values are shown at $Q^2 = 0$.

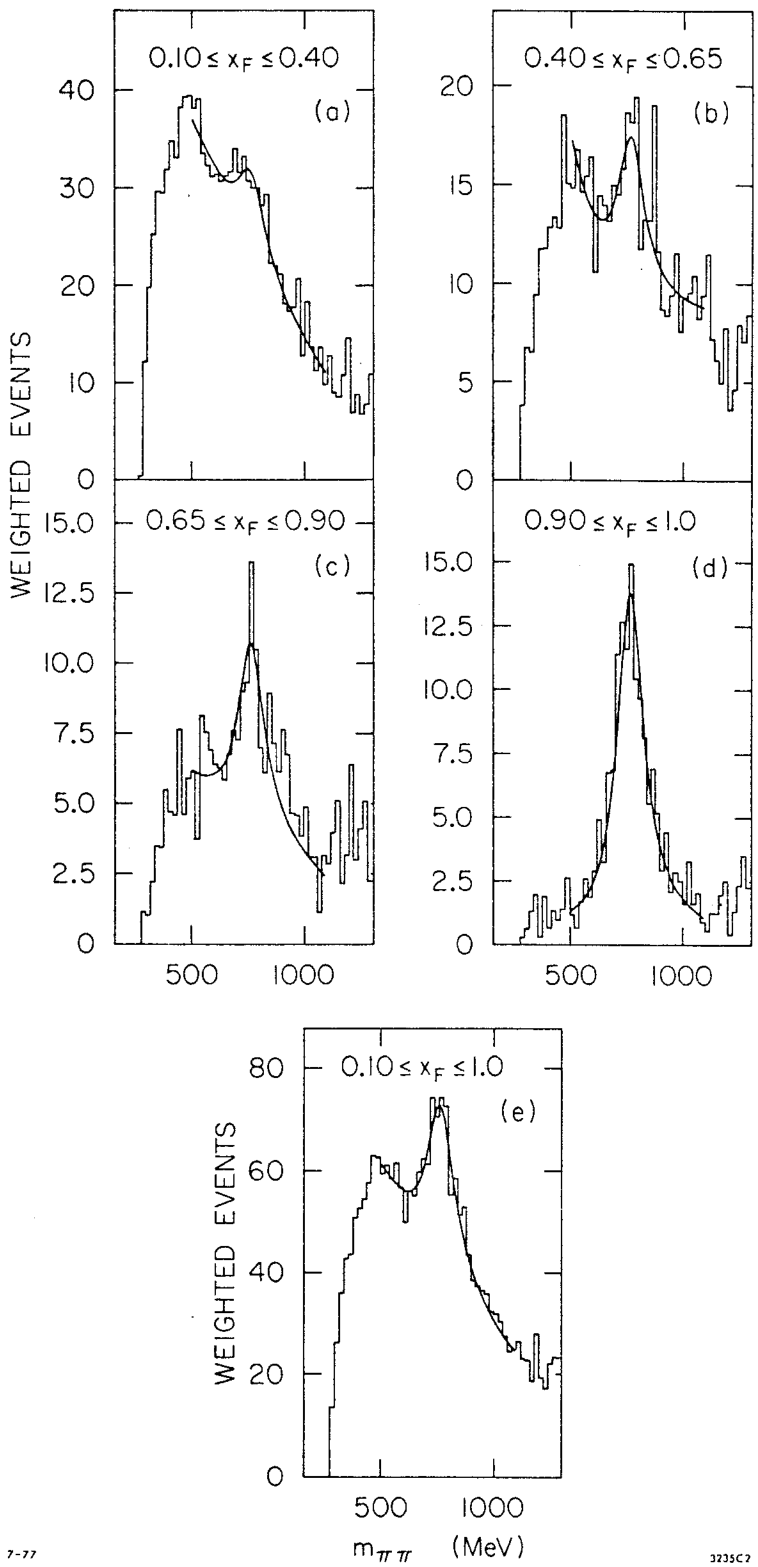
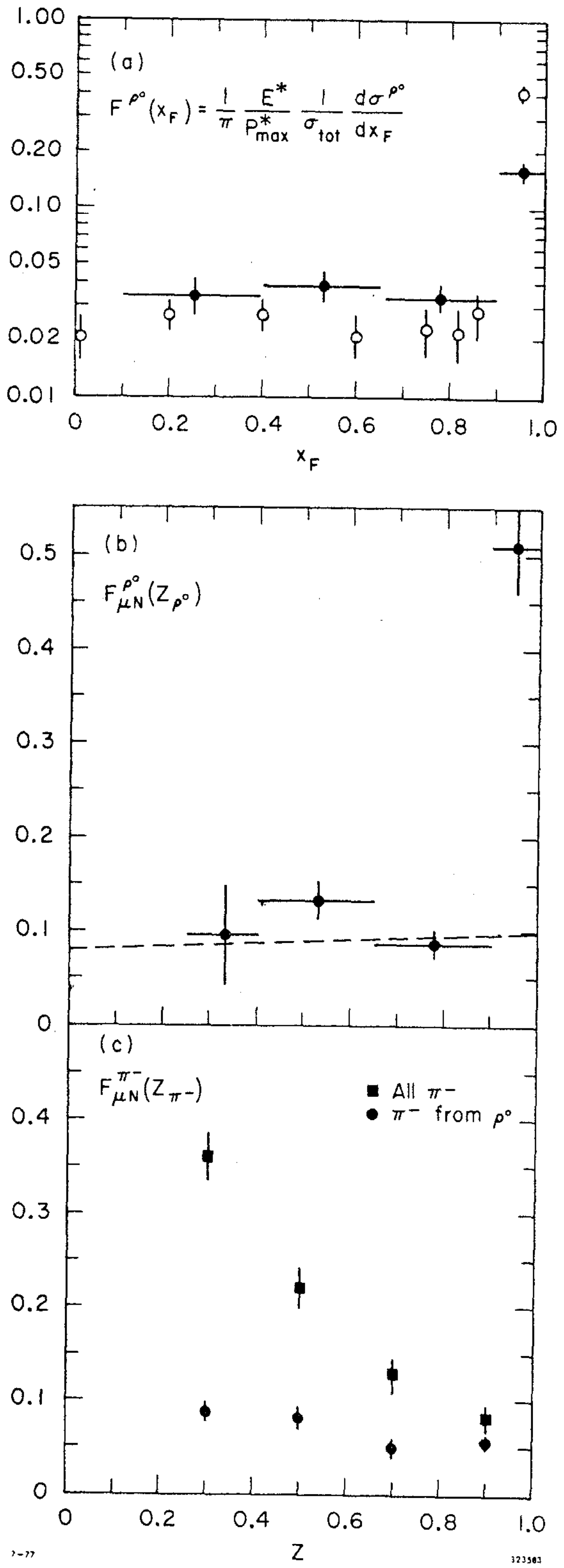

0.10 ≤ x_F ≤ 0.40
(a)
0.40 ≤ x_F ≤ 0.65
(b)
0.65 ≤ x_F ≤ 0.90
(c)
0.90 ≤ x_F ≤ 1.0
(d)
0.10 ≤ x_F ≤ 1.0
(e)
WEIGHTED EVENTS
0
10
20
30
40
5
15
2.5
5.0
7.5
10.0
12.5
15.0
60
80
500
1000
$m_{\pi\pi}$ (MeV)
7-77
3235C2

Fig. 1



(a)
$F^{\rho^\circ}(x_F) = \frac{1}{\pi}\frac{E^*}{P^*_{max}}\frac{1}{\sigma_{tot}}\frac{d\sigma^{\rho^\circ}}{dx_F}$
1.00
0.50
0.20
0.10
0.05
0.02
0.01
0
0.2
0.4
0.6
0.8
1.0
x_F
(b)
$F^{\rho^\circ}_{\mu N}(Z_{\rho^\circ})$
0.5
0.4
0.3
0.2
0.1
0
(c)
$F^{\pi^-}_{\mu N}(Z_{\pi^-})$
All π^-
π^- from ρ°
0.4
0.3
0.2
0.1
0
0
0.2
0.4
0.6
0.8
1.0
Z

Fig. 2

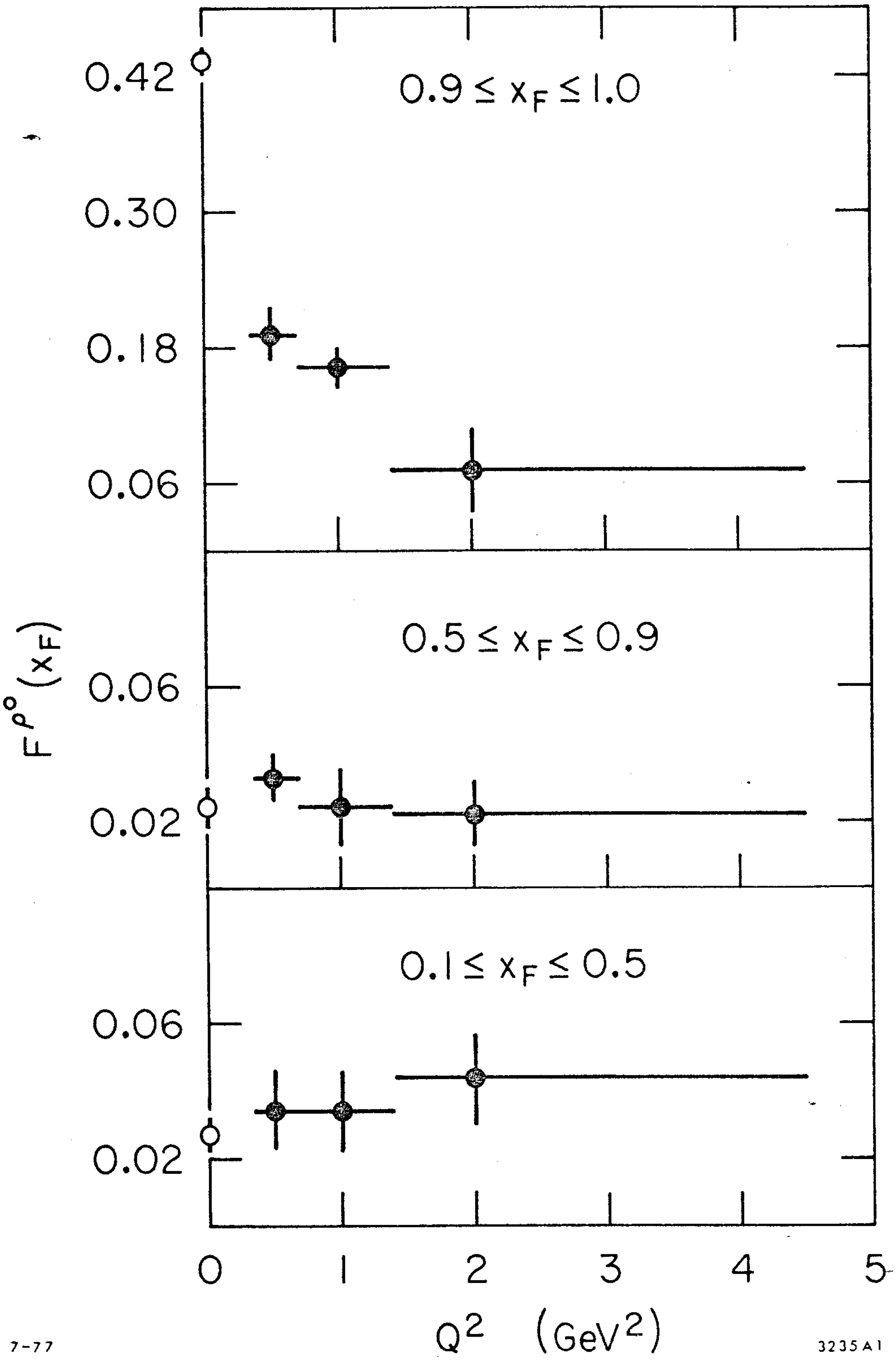

0.42
0.30
0.18
0.06
$0.9 \le x_F \le 1.0$
$0.5 \le x_F \le 0.9$
0.06
0.02
$0.1 \le x_F \le 0.5$
0.06
0.02
$F^{\rho^0}(x_F)$
0
1
2
3
4
5
Q^2 (GeV^2)
7-77
3235A1

Fig. 3