ρ^0 PRODUCTION IN DEEP INELASTIC μ -p INTERACTIONS

The European Muon Collaboration

CERN¹-DESY(Hamburg)²-Freiburg³-Kiel⁴-Lancaster⁵-LAPP(Annecy)⁶-Liverpool⁷-
Marseille⁸-Oxford⁹-Rutherford¹⁰-Sheffield¹¹-Turin¹² and Wuppertal¹³

J.J. Aubert⁸, G. Bassompierre⁶, K.H. Becks¹³, C. Benchouk⁸, C. Best^{10a)},
E. Böhm⁴, X. de Bouard⁶, F.W. Brasse², C. Broll⁶, S. Brown⁷, J. Carr^{10b)},
R.W. Clifft¹⁰, J.H. Cobb^{5c)}, G. Coignet⁶, F. Combley¹¹, G.R. Court⁷,
G. D'Agostini⁸, W.D. Dau⁴, J.K. Davies^{9d)}, Y. Déclais^{6e)}, U. Dosselli^{1f)},
J. Drees¹³, A. Edwards¹³, M. Edwards¹⁰, J. Favier⁶, M.I. Ferrero^{12g)},
W. Flauger², H. Forsbach¹³, E. Gabathuler¹, R. Gamet⁷, J. Gayler²,
V. Gerhardt^{2h)}, C. Gössling², J. Haas³, K. Hamacher¹³, P. Hayman⁷,
M. Henckes¹³ⁱ⁾, V. Korbel², U. Landgraf³, M. Leenen^{1j)}, M. Maire⁶,
H. Minssieux⁶, W. Mohr³, H.E. Montgomery¹, K. Moser^{3k)}, R.P. Mount^{9l)},
E. Nagy^{6m)}, J. Nassalski², P.R. Norton¹⁰, J. McNicholas⁹ⁿ⁾, A.M. Osborne¹,
P. Payre⁸, C. Peroni¹², H. Pessard⁶, U. Pietrzyk¹³, K. Rith³,
M. Schneegans⁶, A. Schneider¹³, T. Sloan⁵, H.E. Stier³, W. Stockhausen¹³,
J.M. Thénard⁶, J.C. Thompson¹⁰, L. Urban^{6m)}, M. Villers⁹, H. Wahlen¹³,
M. Whalley¹⁰, D. Williams⁷, W.S.C. Williams⁹, J. Williamson^{11p)},
S.J. Wimpenny⁷.

ABSTRACT

Inclusive ρ^0 meson production has been measured in 120 GeV and 280 GeV muon proton interactions. Distributions of z and p_T^2 are presented. Primary ρ^0 production is found to be equal to that of π^0 production within errors.

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- (a) Now at JET, Joint Undertaking, Abingdon, England.
 - (b) Now at Lawrence Berkeley Laboratory, Berkeley, California, USA.
 - (c) Now at University of Oxford, England.
 - (d) Now at Plessey Defence System, Fareham, England.
 - (e) Now at Fac. des Sciences de Luminy, Univ. d'Aix-Marseille II, France.
 - (f) Now at INFN, Sez. Padova, Italy.
 - (g) Now also at Istituto di Fisica, Università di Lecce, Lecce, Italy.
 - (h) Now at Beiersdorf AG, Hamburg, Germany.
 - (i) Now at IBAT, Essen, Germany.
 - (j) Now at Physikalisches Institut der Universität Bonn, Bonn, Germany.
 - (k) Now at BWB Engineering GmbH, Lörrach, Germany.
 - (l) Now at California Institute of Technology, Pasadena, California, U.S.A.
 - (m) Now at Central Research Institute for Physics of the Hungarian Academy of Science, Budapest, Hungary.
 - (n) Now at British TELECOM, Coventry, England.
 - (o) Now at Durham University, Durham, England.
 - (p) Now at RAL, Chilton, Didcot, Oxon, England.

Hadrons observed in the final state of a deep inelastic lepton-nucleon scattering process originate to a large extent from decays of primary produced unstable particles. These decays mask the properties of the primary fragmentation products and so, for a better understanding of the production process, measurements of the primary produced hadrons are important. This letter presents measurements of inclusive ρ^0 production.

The experiment was performed in the CERN muon beam using the EMC forward spectrometer [1]. The event and track selection was similar to that described in Ref. [2]. Cuts were applied to the data, see Table 1, to ensure good acceptance for hadrons and muons and to limit the corrections for secondary interactions and radiative effects.

Table I

E_μ (GeV)	$Q^2_{\min}$ (GeV ²)	$\nu_{\min}$ (GeV)	$p_{\mu'}_{\min}$ (GeV)	$\theta_{\mu'}_{\min}$ (mrad)	W^2 range (GeV ²)	$p_{f\min}$ (GeV)	Target length (m)	No. of events
120	2	20	20	~ 10	20 - 160	2	2	28000
280	3	60	40	~ 8	80 - 420	5	3	41000

The relevant variables are defined by $-Q^2 = q^2 = (p_\mu - p_{\mu'})^2$; $\nu = (P \cdot q)/M$; $W^2 = (P + q)^2$; $z = (P \cdot p_f)/(P \cdot q)$, p_μ , $p_{\mu'}$, being the four momenta of the incoming and outgoing muons, P and M the four momentum and mass of the target proton, and p_f the four momentum of an outgoing hadron. The transverse momentum, p_T , of a hadron is measured with respect to the direction of the virtual photon.

As the ρ^0 distributions of the 120 GeV and 280 GeV data agree, we have combined both data sets. Assigning the pion mass to all hadrons, the resultant uncorrected $h^+ h^-$ spectrum for $z_{\text{pair}} > 0.4$ is shown in fig. 1a. The average experimental mass resolution about the mass of the ρ^0 is 25 MeV as measured with K^0 mesons.

The corrections for hadron acceptance were calculated using a Monte Carlo simulation of the full apparatus including chamber and reconstruction efficiencies and corrections for radiative effects. The model of the Lund group was used to describe the formation of the hadronic final state [3]. The ρ^0 's have been assumed to be unpolarised. Acceptance corrections were then calculated as the ratio of generated and accepted hadron pairs for bins in z_{pair} , $p_{\text{T pair}}^2$, Q^2 and W^2 . In all cases the acceptance is smooth, almost linear as a function of mass, but with a slope which varies as a function of the other variables.

Corrections for reinteractions of pions in the target are more important than for single hadron spectra. A separate Monte Carlo calculation, including full details of the target construction, was used to study this effect. Secondary pions from reinteractions combined with primary pions give a smooth mass spectrum. Therefore, if either of the pions from a ρ^0 interacted, the resultant track combinations do not contribute to the ρ^0 signal. The corrections obtained for the ρ^0 were about 20% with no dependence on kinematic variables. The corrected mass spectrum for the data sample with $z_{\text{pair}} > 0.4$ is displayed in fig. 1b.

The ρ^0 signal was extracted from the corrected mass spectrum by fitting with a p-wave Breit Wigner [4] and a smooth background function. For the ρ^0 mass and width the Particle Data Group values [5] ($m_{\rho^0} = 769$ MeV, $\Gamma_{\rho^0} = 154$ MeV) were used. The form of the background used was [6]

$$B(m) = \alpha (m - 2m_{\pi})^{\beta} e^{-\gamma m}$$

where α , β and γ are treated as free parameters. This particular choice of background was made after inspection of the mass spectra for masses above the ρ^0 , the mass spectra of same sign pairs from the data and from Monte Carlo models with the ρ^0 explicitly excluded. The mass interval for the fit was $0.4 < m < 1.6$ GeV. The adequacy of this description is shown by the comparison in Fig. 1b of the fit to the corrected spectrum. Similar fits were performed in each z and p_{T}^2 bin of the data. The χ^2 per degree of freedom for these fits is in the range $0.7 < \chi^2/\text{NDF} < 1.3$ ($\text{NDF} > 50$), with an average value of 1.0. For the low z bin $0.3 < z_{\text{pair}} < 0.4$ we included in the fit

a small contribution from K^0 decays which could not be excluded by the vertex reconstruction.

The analysis yields $4950 \pm 600 \rho^0$ for $z > 0.3$ and the cuts given in Table 1. The mean values of Q^2 and W^2 for these events are $\langle Q^2 \rangle = 17 \text{ GeV}^2$ and $\langle W^2 \rangle = 190 \text{ GeV}^2$. Fig. 1c shows the ρ^0 signal after background subtraction.

The systematic error of the ρ^0 signal is dominated by uncertainties in the background due to contributions of other vector mesons (especially ω and K^{*0}). This has been studied using the Monte Carlo simulation and leads to a systematic error of 15-20% in the ρ^0 signal extracted by this method. There is an additional error in the lowest z -bin from the uncertainty in the K^0 contribution. Inclusion of errors from other sources, namely reinteractions, muon kinematics, radiative corrections and, most important, reconstruction efficiency, leads to a final systematic error of $^{+30\%}_{-20\%}$ on the ρ^0 yield. The subsequent plots do not include this error in the data points.

In fig. 2 the normalised differential multiplicity is plotted as a function of z . Also shown are measurements from previous experiments with electrons [7], muons [8] and neutrinos [9, 10] at lower energies. Our data and the neutrino measurements agree within the large errors of the latter, but seem to be systematically lower than the charged lepton data. At low z there are measurements from e^+e^- [11], also shown in fig. 2, which agree within errors.

At $z = 1$ we expect a contribution from elastic ρ^0 production, $\mu p \rightarrow \mu p \rho^0$. This contribution is expected to show a strong decrease as a function of Q^2 . Indeed we observe most of the ρ^0 's with $z > 0.95$ coming from events with $Q^2 < 5 \text{ GeV}^2$. For $z < 0.95$ there is neither a Q^2 -dependence ($2 \leq Q^2 \leq 60 \text{ GeV}^2$) nor a W^2 -dependence ($20 \leq W^2 \leq 430 \text{ GeV}^2$) in our normalised distributions. In the following analysis we exclude the data with $z > 0.95$.

In order to compare with pion production we plot in Fig. 3a both the ρ^0 data from Fig. 2 and the π^0 data from this experiment [12]. While the π^0 data behave as $\sim e^{-6.6z}$ the ρ^0 data behave like $\sim e^{-5.2z}$ ($z > 0.3$) and at $z \rightarrow 1$ the two are approximately equal. Since the contributions of primary mesons in the π^0 and ρ^0 spectra are different, a difference in shape is expected.

Plotting the ratio of these two sets of data (Fig. 3b), we obtain as $z \rightarrow 1$ the ratio between primary ρ^0 production and primary π^0 production. Within many fragmentation models this is identified with an important parameter, the ratio α_v/α_p of the production probabilities of vector and pseudoscalar particles. The value we obtain by exponential extrapolation is

$$\frac{\rho^0_{\text{primary}}}{\pi^0_{\text{primary}}} = 0.9 \pm 0.35 \text{ (stat.) } {}^{+0.35}_{-0.3} \text{ (syst.)}$$

where the systematic error contains all errors involved in the extraction of the ρ^0 and π^0 cross-section and in addition the error involved in the small extrapolation to $z = 1$. It should be noted that the error for the extrapolation is small and that there is no dependence on a model for the fragmentation process. The result can be compared with values of $1.38 {}^{+1.62}_{-0.69}$ (stat. + syst.) deduced from ref. [11] and $2 \pm 0.5 \pm 0.3$ from ref. [7]. Our measurement excludes the spin statistics value of 3 for this ratio.

In fig. 4 we plot the p_T^2 distribution of the ρ^0 mesons produced for the range $0.4 < z_{\rho^0} < 0.95$ corresponding to previous measurements. The distribution is well described by

$$\frac{1}{N_{\mu}} \frac{dN}{dp_T^2} \sim e^{-bp_T^2}$$

with $b = 2.5 \pm 0.6$ in the range $0 < p_T^2 < 1 \text{ GeV}^2$. Also plotted in Fig. 4 is the distribution for single charged hadrons [13] in the same W^2 range. The slopes of the distributions agree within errors. The p_T^2 dependence of ρ^0 mesons as observed in an electroproduction experiment [7] at lower energies ($\langle W^2 \rangle \sim 10.9 \text{ GeV}^2$) is similar.

In conclusion, we have measured inelastic ρ^0 production in deep inelastic muon scattering and have presented data as a function of z and p_T^2 . From the ratio with π^0 production measurements at $z = 1$ we have determined the ratio of primary ρ^0 to primary π^0 production to be $0.9 \pm 0.35 \text{ (stat.) } {}^{+0.35}_{-0.3} \text{ (syst.)}$.

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Figure Captions

- Fig. 1 a) Raw data mass spectrum ($z_{\text{pair}} > 0.4$)
 b) Corrected mass spectrum ($z_{\text{pair}} > 0.4$). The full line is the fit to the spectrum, the dashed line the fitted background.
 c) Resultant ρ^0 mass spectrum ($z > 0.4$) after background subtraction. The line is the fitted p-wave Breit Wigner.
- Fig. 2 z-dependence in comparison with results from ep (DECO [7], $\langle W \rangle^2 = 10.9 \text{ GeV}^2$), μN (del Papa et al. [8], $\langle W \rangle^2 = 12.3 \text{ GeV}^2$), νp (ABCMO [9], $\langle W \rangle^2 = 19.4 \text{ GeV}^2$), νp (Derrick et al. [10], $\langle W \rangle^2 = 11.6 \text{ GeV}^2$) and e^+e^- (TASSO [11] $\langle W \rangle^2 = 906 \text{ GeV}^2$).
- Fig. 3 a) Comparison of ρ^0 and π^0 [12] z spectra.
 b) ratio of ρ^0 and π^0 production as a function of z. The line is an exponential fit.
- Fig. 4 p_T^2 dependence of the ρ^0 production ($z > 0.4$) together with a result for charged hadrons [13] and ρ^0 electroproduction data at low energies [7].

Fig. 1

Fig. 2

Fig. 3

Fig. 4