ELECTROPRODUCTION OF $\rho^0$ MESONS

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Abstract

Cross-sections for \( \rho^0 \) electroproduction measured in a streamer chamber experiment are separated into elastic (ep + e\( \rho^0 \)) and inelastic production channels. For the inelastic channel \( \frac{d\sigma}{dz} \) and a density matrix element are shown and compared to quark-parton model predictions. The ratio of \( \rho^0 \) to \( \pi^0 \) production is measured to be 2.0 ± 0.5. For the elastic channel, the total cross-section and \( t \)-dependence are presented.

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An analysis of \( \rho^0 \) production has been carried out using data from an electroproduction experiment performed at the Wilson Synchrotron Laboratory. The apparatus consisted of a streamer chamber with an internal hydrogen target triggered by a scattered electron.\(^1\)

Two different physical mechanisms are thought to contribute to \( \rho^0 \) electroproduction: coherent diffractive production, chiefly elastic (ep + e\( \rho^0 \)), and non-diffractive production described in parton models by the fragmentation of a single struck quark\(^2,3,4\). For the elastic channel we present measurements up to \( Q^2 = 4 \text{ GeV}^2 \) and compare with previous measurements at lower \( Q^2 \)\(^5,6,7\). The inelastic data are compared with quark fragmentation models and with results from muoproduction, \( e^+e^- \) annihilation and antineutrino interactions. A comparison of \( \rho \) production to direct \( \pi \) production is of interest because the \( \rho \) and the \( \pi \) have the same quark content and differ only in quark spin alignment.

We define \( Q^2, \nu, W \) and \( x (=Q^2/2Mv) \) in the usual manner; \( z \) is defined to be \( z \frac{E_h}{\nu} \), where \( E_h \) is the laboratory energy of hadron \( h \).

To investigate the reaction ep + e\( \rho^0 \), those events satisfying the 4-constraint kinematical fit to ep + e\( \pi^+ \pi^- \) were separated from the rest of the data. Using techniques described by P. Joos, et al.\(^5\) this ensemble of events was fit to a mixture of \( \pi^+\pi^-\pi^+\pi^- \), \( \rho^0 \), and phase space contributions.

The resulting virtual photon cross-sections are shown in Fig. 1, and are compared with photoproduction and other leptoproduction experiments. The data are normalized to the total cross-section as measured by S. Stein, et al.\(^8\)

The elastic cross-section, \( \frac{d\sigma}{dt} \), has been determined for \( W > 2.1 \text{ GeV} \) in two intervals of \( Q^2 \). For 4-momentum transfers \( -t' = -(t-t_{\min}) \) less than 0.6 \( \text{ GeV}^2 \), our data show an exponential dependence, \( e^{At'} \). The decrease in \( A \) with increasing

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Q^2 seen by comparison with other work in Fig. 2 can be interpreted as shrinkage of the effective photon-proton interaction radius or could be due to insufficient formation time, which for our data is less than 10 GeV^{-1}.

For the inelastic part of our data, we present results in terms of quantities which are independent of energy in the quark fragmentation model. These results are shown for \( z > 0.4 \), in the kinematic region \( 1 < Q^2 < 6 \text{ GeV}^2 \), \( 2.8 < W < 4.2 \text{ GeV} \), and \( x > 0.1 \), with \( <Q^2> = 2.9 \text{ GeV}^2 \), \( <W> = 3.3 \text{ GeV} \), and \( <x> = 0.2 \). Elastic events were removed from the sample.

To determine the z-dependence of the \( \rho^0 \) cross-section, the invariant mass and z for each oppositely charged hadron pair were calculated, assuming each hadron to be a pion. The invariant mass distribution of pairs with \( z > 0.4 \) is shown in Fig. 3. In each z-bin, the mass distribution was fitted to a five term Laurent series plus a Breit-Wigner function with mass and width 0.773 and 0.150 GeV, respectively. The integral of the Breit-Wigner was assumed to be the number of \( \rho^0 \) mesons.

The average \( x^2 \) for the above fits was 49 for 44 degrees of freedom. The sensitivity of the results to the various assumptions in the analysis procedure was investigated. Other background parametrizations were used, including estimated contributions from \( \Delta^*, \omega, K^* \) and \( n \) production. Other forms of the Breit-Wigner function were tried. None of the above effects changed the results by more than 10%. Corrections for lost tracks (10-15%) and radiative effects (-20%) were applied, both of which exhibited a slight z-dependence.

The quark-parton model relates the distribution of the cross-section in z to the distribution of quarks in the proton and the quark fragmentation functions. From the symmetry of the quark content of the \( \rho^0 \) and the paucity of strange quarks in the proton \( p \), it follows that

\[
\frac{1}{d^2 x} \frac{d\sigma}{dz} (x, z) = D_u^0 (z).
\]

This result applies to electroproduction, muoproduction, and, except for strange quark production, to antineutrino charged current interactions, and to \( e^+e^- \) annihilation, and thus permits direct comparisons of data. It should be noted, however, that the model itself is not considered useful at low z.

In Fig. 4, we present our data as well as results from other experiments, and compare with two models of quark fragmentation. Our data agree in shape with the model of Field & Feynman. At high z, the muoproduction data cannot be compared with the other measurements since the elastic channel was not subtracted from the data. The \( e^+e^- \) data have been divided by two since there are two leading quarks in this process. The agreement of data from different processes lends support to the universal applicability of the quark-parton model.

The dependence of the cross-section on \( p_T \), the transverse momentum with respect to the virtual photon's direction, was determined for those pairs with \( z > 0.4 \) in a manner similar to that described above. The results shown in Fig. 5 are in good agreement with a single exponential in \( p_T^2 \) with \( <p_T> = 0.52 \pm 0.03 \text{ GeV} \). This value is similar to our results for inclusive high z hadron and \( K^0_{S,L} \) production and also to results from \( p^+ + p \to \phi \) production.

The helicity zero contribution to inelastic \( \rho^0 \) production, \( \rho_{00}^0 \), was measured by analyzing the \( \rho^0 \) decay pion angular distribution. This distribution is

\[
W(\cos \theta) = \frac{3}{4} (1 - \rho_{00}^0 + (3\rho_{00}^0 - 1)\cos^2 \theta),
\]

where \( \theta \) is the angle between the direction of the \( \rho^0 \) in the rest frame of the final state hadrons and the direction of the \( n^+ \) in the rest frame of the \( \rho^0 \).
For those pairs with z > 0.4, \( \rho_{oo} \) was determined by weighting each hadron pair by \( \cos^2 \theta \). The resulting mass distribution was analyzed as described above to determine the mean value of \( \cos^2 \theta \) for the \( \rho \) signal. The value obtained for the \( \rho \) contribution was \( \rho_{oo} = 0.41 \pm 0.06 \). This result is insensitive to track losses and radiative effects. The systematic error is estimated to be less than the statistical error. This result suggests that the zero helicity state is more populated than the helicity \( \pm 1 \) states.\(^{19} \)

The ratio of the \( \rho \) production cross-section to the average of the \( \pi^+ \) and \( \pi^- \) production cross-sections for \( z > 0.4 \) was measured. Due to charge conjugation and isospin invariance, this ratio equals the ratio of the cross-sections for \( \rho \) and \( \pi^0 \) production. The charged pion cross-sections were measured in the same \( q^2 \) and \( W \) region as in the \( \rho \) analysis, except that for the \( \pi^+ \) cross-section the region \( W < 3.5 \) GeV was eliminated to facilitate the subtraction of protons.\(^{20} \) Elastic \( \rho^* \) events were not used in either the \( \rho \) or \( \pi^0 \) cross-sections' determinations. The resulting \( \rho^*/\pi^0 \) ratio is \( 0.97 \pm 0.11 \). To approximate the ratio of \( \rho \) production to direct pion production, the pions produced by \( \rho \) decay were subtracted from the pion cross-section and the ratio \( R = \rho^*/\pi^0 \) was found to be \( 2.0 \pm 0.5 \). According to the quark parton model, this result should be directly comparable to measurements of \( R \) in pp collision at high \( p_T \) or in e^+e^- annihilation. Our value of \( R \) is greater than that obtained at the ISR in high \( p_T \) production \((0.9 \pm 0.2)\)\(^{21} \), and less than the value measured in the e^+e^- annihilation \((3.1 \pm 0.6)\)\(^{14} \). It is also less than the value of three suggested by spin statistics. The product of \( R \) and \( \rho_{oo} \) is the ratio of helicity zero \( \rho \) production to \( \pi^0 \) production. This is measured to be \( 0.82 \pm 0.26 \), which is consistent with unity.

Using the vector-pseudoscalar ratio from this analysis and the SU(3) breaking from our \( K_s \) analysis\(^1 \), the Field and Feynman model of quark fragmentation\(^2 \) predicts the ratio of \( K^+ \) to \( K^0 \) plus \( \bar{K}^0 \) production to be 1.5. This ratio was measured to be \( 1.1 \pm 0.4 \) by our observation of \( K^*(890) \) in the \( K_s \) \( \pi^0 \) channels.

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Figure Captions:
Fig. 1. Cross-section for elastic $\rho^0$ production as a function of $Q^2$ in three $W$ regions. The data from references 5, 6, 7 and 22 are also shown.
Fig. 2. Slope parameter $A$ as obtained from least-squares-fits of the $t'$ distribution to $e^{At'}$ as a function of $Q^2$. The data from references 5, 6, 7, and 22 are included.
Fig. 3. $\pi^+\pi^-$ mass distribution after removal of the elastic events. The curves were determined by the fitting procedure described in the text.
Fig. 4. $z$-distribution of the $\rho^0$ cross-section shown in comparison with other experimental results and with the fragmentation function, $D^0_{\rho}$, from Field and Feynman from $\pi'$ (solid curve) and without $\pi'$ (dashed curve) and from B. Andersson et al., without $\pi'$ production (dashed-dotted curve).
Fig. 5. $p_T^2$ distribution for inelastically produced $\rho^0$ mesons.
Fig. 1

Fig. 2