Therefore, since the fifth band in Pd is already so dominant (contributing 90% to the unenhanced magnetic moment density) and is essentially of pure $l=2$ character, the effect of exchange enhancement is simply to populate more spin-up states with nearly the same spatial character as the unenhanced spin density. As a consequence, the form factor of Pd will not be appreciably affected by exchange enhancement. The only effect of the enhancement will be to make the localized fifth-band spin-density contribution even more dominant than it is for the unenhanced values calculated from Eq. (2). As seen from Table I, the fifth-band form factor is in somewhat better agreement with experiment than is f_{tot}; its mean square deviation is 0.021.

We conclude that the very good agreement between these APW results and experiment confirm the need for, and the validity of, energy-band calculations of magnetization densities and neutron form factors of metals.

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Evidence for ρ^0 Production at Large Transverse Momentum*

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We have extracted the ρ^0 inclusive cross section from π^+p interactions at 6 and 22 GeV/c as a function of the longitudinal variables y^* and x, and the transverse momentum P_T. The ratio of ρ^0 to π inclusive cross sections is found to be rising linearly with P_T^2, and at $P_T \simeq 1$ GeV/c the ρ^0 and π^- inclusive cross sections are equal. The implications of this observation for direct lepton production are discussed.

Recently several experiments[1] have reported the ratio of directly produced leptons to pions at large transverse momentum (P_T) to be $\sim 10^{-4}$ independent of the charge of either the lepton or the pion. Vector mesons are a source of leptons; however, the assumption that the measured cross section for inclusive ρ^0 production[2,3] relative to inclusive π production is independent of P_T does not account for the relatively large numbers of leptons observed. Here we present an analysis of the reaction

$$\pi^+ + p \rightarrow \rho^0 + \text{anything} \qquad (1)$$

at 6 and 22 GeV/c with the aim of measuring the ratio of ρ^0 to π production at $P_T \simeq 1$ GeV/c.

The data come from exposures at the Brookhaven National Laboratory (BNL) 80-in. hydrogen bubble chamber. A total of 67 000 events at 6 GeV/c and 71 000 events at 22 GeV/c were measured on the BNL flying spot digitizer. A description of the single-particle spectra has been previously reported[4] including a description of the weight given to ambiguous fast positive tracks.[5]

To determine the total cross section for Reaction (1), the $\pi^+\pi^-$ invariant-mass spectra for all $\pi^+\pi^-$ combinations, shown in Fig. 1, are fitted by a Breit-Wigner function, with fixed mass and width, plus a polynomial background. The total cross

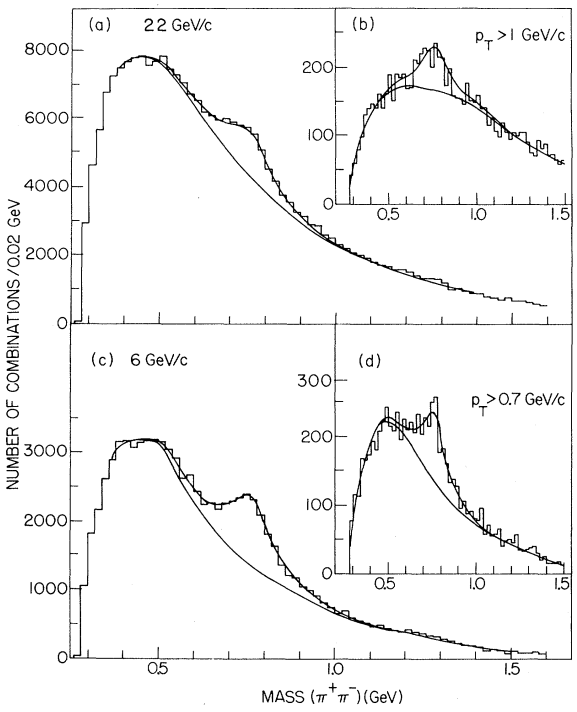

FIG. 1. $\pi^+\pi^-$ effective mass for the reaction $\pi^+ + p \rightarrow \rho^0 +$ anything at 22 and 6 GeV/c for (a), (c) all events, (b), (d) high transverse momentum. The curves are results of fits described in the text.

section for Reaction (1) is 3.34 ± 0.36 mb at 6 GeV/c and 6.03 ± 0.71 mb at 22 GeV/c.[7] However, the ratio of the cross sections ρ^0 to $\pi^\pm$ remains relatively constant: $\rho^0/\pi^+ = 0.076$ and 0.1, $\rho^0/\pi^- = 0.238$ and 0.232, for 6 and 22 GeV/c, respectively. In the following discussion, the ρ^0 cross section is presented as a function of y^*, x, and P_T, i.e., the center-of-mass rapidity, the Feynman scaling variable, and the transverse momentum, respectively. Each of these variables is calculated for each $\pi^+\pi^-$ combination and the cross section as a function of these kinematic variables is found from a fit to the $\pi^+\pi^-$ mass spectrum of events falling in each bin of, for example, P_T. As an example, the events for relatively large P_T are shown in Figs. 1(b) and 1(d).

Figure 2(a) presents $d\sigma/dy^*$ for Reaction (1) at both momenta. For $y^* < 0$, the target-fragmentation region, the 22-GeV/c data for Reaction (1) are compared with those from $p + p \rightarrow \rho^0 +$ anything at 24 GeV/c.[2] The data from these two reactions agree in shape and magnitude.

The invariant cross sections[8] as a function of x are displayed in Fig. 2(b) for both momenta. An approximate scaling between 6 and 22 GeV/c

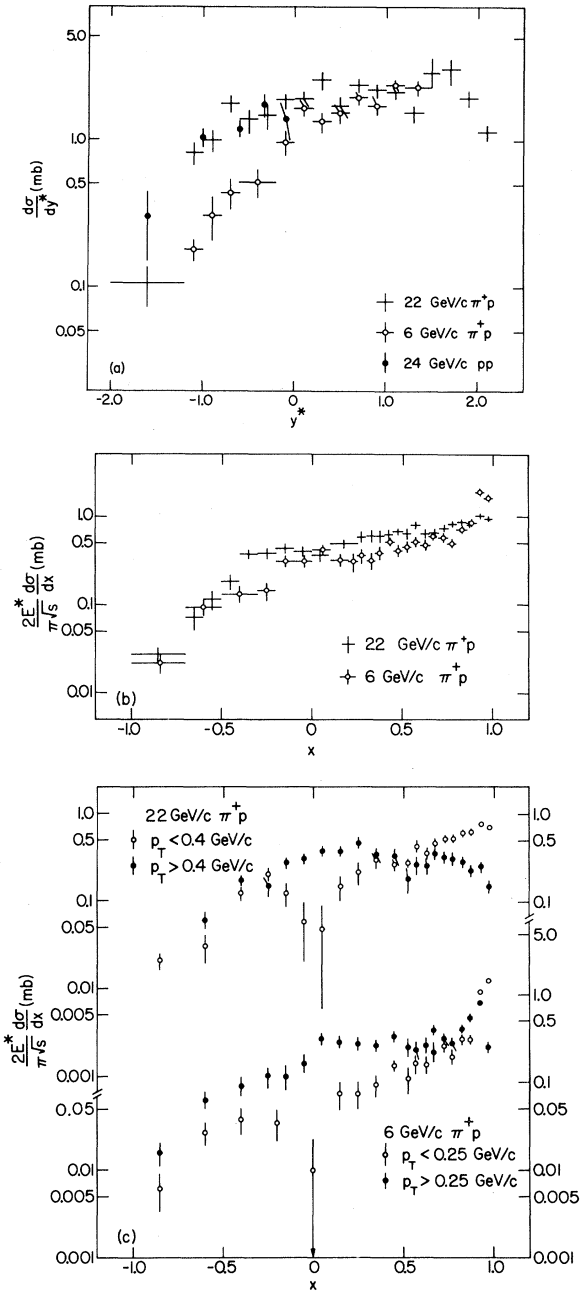

FIG. 2. (a) Center-of-mass rapidity distributions for the reaction $\pi^+ + p \rightarrow \rho^0 +$ anything at 6 and 22 GeV/c, and for $p + p \rightarrow \rho^0 +$ anything at 24 GeV/c (Ref. 2). (b) Invariant cross section as a function of x for 6 and 22 GeV/c. (c) Same as (b) but for low and high P_T regions.

is observed to within 1 standard deviation. The cross section decreases exponentially in the target-fragmentation region $x < -0.5$ but is approximately constant for $x > -0.2$. The increasing cross section for $x > 0.80$ is due to quasi-two-body exclusive processes.[9]

In Fig. 2(c) the invariant cross section versus x is divided into two regions of P_T. For $|x| \lesssim 0.3$ the invariant cross section does not show a contribution from low P_T. This is in contrast to what is observed in single π inclusive production: For instance, the average P_T decreases as x approaches zero for $\pi^- + p \to \pi^\pm +$ anything at 16 GeV/c.[10]

The cross section for Reaction (1) as a function of P_T is displayed in Figs. 3(a) and 3(b). The $P_T{}^2$ distribution for all x is incompatible with a single exponential. However, this is not surprising since the different x regions exhibit different behavior. For example, we have examined the $N\langle Y_m{}^l\rangle$ moments of the $\pi^+\pi^-$ helicity decay angles as a function of the $\pi^+\pi^-$ mass for the various x regions. For $x > 0.5$ the moments show that the ρ^0 decay is not isotropic, whereas for $|x| < 0.5$ the moments show that the ρ^0 decay is consistent with isotropy. Because of the different processes, the P_T data are divided into two regions: $|x| < 0.5$ and $x > 0.5$ as seen in Fig. 3. For the large-x region, acceptable fits to a single exponential $d\sigma/dP_T{}^2 \sim \exp(-bP_T{}^2)$ were found: $b = 15 \pm 3$ for 6 GeV/c; $b = 12 \pm 3$ for 22 GeV/c. These values are compatible with what would be expected if all the ρ^0's had come from exclusive processes such as $\pi^+ + p \to \rho^0 + \Delta^{++}$. However, for $|x| < 0.5$, the slopes are much less steep: $b = 3.9 \pm 0.4$ for 6 GeV/c; $b = 3.0 \pm 0.6$ for 22 GeV/c. The average P_T for ρ^0 was found to be 390 MeV/c at 6 GeV/c and 460 MeV/c at 22 GeV/c. This is higher than that of the individual pions, especially for $|x| < 0.5$.[11] Figure 3(a) also shows that $2(d\sigma/dP_T{}^2)$ for $\pi^+ + p \to \rho^0 +$ anything and that $x < 0$ is quite similar to $d\sigma/dP_T{}^2$ for $p + p \to \rho^0 +$ anything at 24 GeV/c.[2]

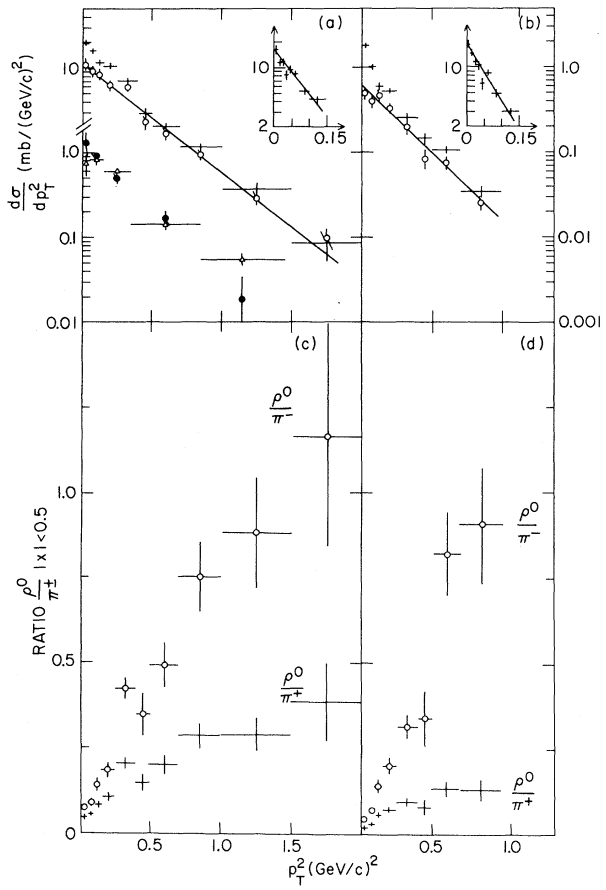

FIG. 3. (a),(b) Transverse-momentum-squared distributions for the reaction $\pi^+ + p \to \rho^0 +$ anything at 22 and 6 GeV/c, respectively, for all x (+), for $|x| < 0.5$ (○), for $x > 0.5$ (insets). (a) also displays a comparison of $2d\sigma(\pi^+ + p \to \rho^0 + \text{anything})/dP_T{}^2$ for $x < 0$ at 22 GeV/c (△) with $d\sigma(p + p \to \rho^0 + \text{anything})/dP_T{}^2$ at 24 GeV/c (Ref. 2) (●). The curves are results of fits described in the text. (c), (d) Ratio of cross sections, $R^\pm = [d\sigma(\rho^0)/dP_T{}^2]/[d\sigma(\pi^\pm)/dP_T{}^2]$, versus $P_T{}^2$ from the reactions $\pi^+ + p \to \rho^0 +$ anything and $\pi^+ + p \to \pi^\pm +$ anything at 22 and 6 GeV/c for the central region, $|x_{\rho^0, \pi^\pm}| < 0.5$.

To determine the amount of ρ^0 production relative to pion production as a function of $P_T{}^2$, the ratio $(R^\pm)$ of $d\sigma(\rho^0)/dP_T{}^2$ to $d\sigma(\pi^\pm)/dP_T{}^2$ is presented in Figs. 3(c) and 3(d) for the central region, $|x| < 0.5$.[12]

R^+ and R^- both increase linearly approximately by 1 order of magnitude as $P_T{}^2$ increases from 0 to 1 (GeV/c)^2. R^+ is naturally lower than R^- because the $\pi^+ p$ initial state leads to more π^+'s than π^-'s in the final state. Since R^- is increasing so rapidly with P_T, one may conclude that ρ^0 production is more important at large P_T than at low P_T.

An attempt was made to measure the cross sections for the other vector mesons, ω and φ. Because we do not see the missing neutrals, the inclusive cross section $\pi^+ + p \to \omega +$ anything cannot be measured in the bubble chamber. However, the semi-inclusive cross section for $\pi^+ + p \to \pi^+ + p + \omega$ is measured to be 482 ± 47 μb at 6 GeV/c and 31 ± 8 μb at 22 GeV/c.[13] By comparison, the cross section for $\pi^+ + p \to \pi^+ + p + \rho^0$ is 1180 ± 79 μb at 6 GeV/c and 600 ± 63 μb and 22 GeV/c.[13] Since the ratio $\sigma(\pi^+ + p \to \pi^+ + p + \omega)/\sigma(\pi^+ + p \to \pi^+ + p + \rho^0)$ decreases from 6 to 22 GeV/c from 0.41 to 0.05, we cannot infer a large ω^0 inclusive cross section relative to ρ^0. An estimate for $\sigma(\pi^+ + p \to \varphi +$ anything) was found by considering all charged tracks to be $K^\pm$. This procedure gives an upper limit of 60 μb for the inclusive φ cross section at 22 GeV/c. Therefore the ρ^0 seems to be the

largest constituent of vector-meson production.

Now we will discuss the implications of the rising ratio $R^{\pm}$ to lepton production. At higher energies and larger P_T, $R^{\pm}$ may continue to increase, as is suggested by our data. The upper limit for the ratio would occur when all the π's come from ρ^0 production. In this case a Monte Carlo study[14] shows R can go as high as 3 at $P_T \simeq 1$ GeV/c at our energies and

$$\frac{d\sigma}{dP_T{}^2}(\text{leptons}) = \frac{d\sigma}{dP_T{}^2}(\pi)\frac{\Gamma(\rho \to l^+ + l^-)}{\Gamma(\rho \to \pi^+ + \pi^-)};$$

that is, the shape of the two differential cross sections would be identical,[15] with the ratio of the magnitudes being just the ρ^0 branching ratio for the particular lepton, $\sim(4-8)\times 10^{-5}$. The ρ^0 could then account for a large part of the observed direct lepton production.

An increasing cross section for ρ^0 inclusive production is observed in $\pi^+ p$ interactions from 6 to 22.5 GeV/c. For $x<0$ the data for Reaction (1) are compatible with $p+p \to \rho^0 + \text{anything}$ at 24 GeV/c, showing that factorization is not valid. The ratio of the cross section for inclusively produced ρ^0's to π^-'s increases linearly with $P_T{}^2$ so that $R^- \simeq 1$ at $P_T = 1$ GeV/c. This new observation means that vector mesons are an important component of the spectra of large-transverse-momentum processes and may help to explain the high rate of "directly" produced leptons.

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Note added.—After completion of this work, we learned of the observation at BNL and at Stanford Linear Accelerator Center[16] of a narrow state which couples strongly to lepton pairs produced in pp interactions with a cross section $\sim 10^{-34}$ cm^2. This can be compared to π production cross section in pp interactions of $\sim 10^{-26}$ cm^2. Therefore, the ratio of e/π from this narrow state will be of the order of 10^{-8}.

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[5]A π^+ weight was assigned to an ambiguous positive track equal to the number of times the track received a π^+ interpretation, consistent with ionization and/or kinematics, divided by the total number of interpretations for the event.

[6]A mass of 760 MeV and a width of 150 MeV were used.

[7]To estimate the ρ^0's lost as a result of the weighting procedure, we substituted the pion mass for all the proton tracks and calculated a new "π^+""π^-" effective mass. This procedure led to an additional $(14\pm4)\%$ correction to the ρ^0 cross sections at 22 GeV/c which was found to be independent of the inclusive variables within our statistics. These errors on the ρ^0 cross sections reflect the normalization uncertainty. The errors on the data presented in the figures are only statistical.

[8]The E^* in the invariant cross section was the average c.m. energy for events in the ρ^0 region for each x bin.

[9]The cross section for $\pi^+ + p \to \rho^0 + \Delta^{++}$ is 362 ± 47 μb at 6 GeV/c and 55 ± 13 μb at 22 GeV/c. The cross section for $\pi^+ + p \to A_1{}^+ + p$ (with ρ^0 decay) is 280 ± 79 μb at 6 GeV and 140 ± 32 μb at 22 GeV/c.

[10]M. Deutschmann *et al.*, Nucl. Phys. B70, 189 (1974).

[11]The ρ^0 average transverse momentum for $|x|<0.5$ is 430 and 510 MeV/c for 6 and 22 GeV/c, respectively.

[12]The ratios $\rho^0/\pi^{\pm}$ for all x have the same behavior as for $|x|<0.5$.

[13]The ω cross section has been corrected for all decay modes. For $|x|<0.5$, $\sigma(\pi^+ + p \to \pi^+ + p + \omega) = 143\pm32$ μb at 6 GeV/c and 18 ± 13 μb at 22 GeV/c; $\sigma(\pi^+ + p \to \pi^+ + p + \rho^0) = 110\pm32$ μb at 6 GeV/c and 100 ± 32 μb at 22 GeV/c.

[14]ρ^0 events were generated at our energies with the observed x and P_T distributions and allowed to decay isotropically into pions, muons, or electrons.

[15]No significant difference was found in our Monte Carlo study for $d\sigma/dP_T{}^2$ for e, μ, or π.

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