Direct lepton yields from vector-meson decay*

K. Raychaudhuri and H. Weisberg
Department of Physics, University of Pennsylvania, Philadelphia, Pennsylvania 19174
(Received 22 September 1975)

Lepton yields from vector-meson decay for $p_T \lesssim 1$ GeV/c are reasonably well determined by existing vector-meson production data and are small compared with $l/\pi = 1 \times 10^{-4}$. A class of reasonable extrapolations to higher p_T gives yields that remain small, but a rise in l/π cannot be ruled out. Vector-meson polarization effects are discussed.

Direct lepton production, with $l/\pi \sim 1 \times 10^{-4}$ for transverse momentum $0.8 < p_T < 5.5$ GeV/c and incident momentum $10 < P_{\text{inc}} < 2000$ GeV/c, has been observed in a number of recent experiments.[1] The source of these leptons and the reason for the constancy of l/π are not known. In another recent experiment,[2] ρ^0 production in 6- and 22-GeV/c π^+p collisions was measured up to $p_T \sim 1.3$ GeV/c. The experimenters note that the ratio of ρ^0/π^- rises linearly with p_T^2 over the range covered and they suggest that, if this ratio continues to rise, then the ρ^0 could account for a large part of the observed direct lepton production, through the decay $\rho^0 \to l^+l^-$.

We have calculated e/π^- yields at center-of-mass rapidity $y = 0$, for various parameterizations of the measured ρ production. Our emphasis is on the kinematic region where the lepton yields are constrained by measured vector-meson production. Thus we do not consider extrapolations to $p_T > 2$,[3] nor do we consider J (ψ) production.[3,4]

In our calculations, we have assumed that the ρ^0 and π^- inclusive cross sections have the factorized form $E d\sigma/d^3P = f(y)g(p_T)$.[5] Figure 1(a) shows the π^- p_T distribution for $|x| < 0.5$,[6] where $x \equiv p_l(\text{c.m.})/p_l(\text{max})$. These data are well fitted over the measured range by the sum of two Gaussians $g(p_T) = A\exp(-Bp_T^2) + A'\exp(-B'p_T^2)$. However, we have instead parameterized the pion p_T distribution by the form $g(p_T) = A\exp(-Bm_T)$, with $m_T = (p_T^2 + m_\pi^2)^{1/2}$. This form fits the measured points equally well. In addition this form (with m equal to the produced particle mass) is known[7] to give a good description of π, K, and p production at $y = 0$ and $p_T < 1.5$ GeV/c in 12- and 24-GeV/c pp collisions, and furthermore it reproduces the known $\exp(-Bp_T)$ behavior of particle production in 24-GeV/c pp collisions at intermediate p_T;[8] we see no reason why the shape should be different in πp collisions.

Figure 1(b) is the p_T dependence of inclusive ρ^0 production for $|x| < 0.5$.[2] Here and in the remainder of Fig. 1 we show three parameterizations of ρ^0 production, all of which are consistent with the data over the measured p_T region but imply rather different behavior at large p_T: (i) (dashed line) the Gaussian form $A\exp(-Bp_T^2)$, (ii) (solid line) the single exponential form $A\exp(-Bm_T)$ with m_T

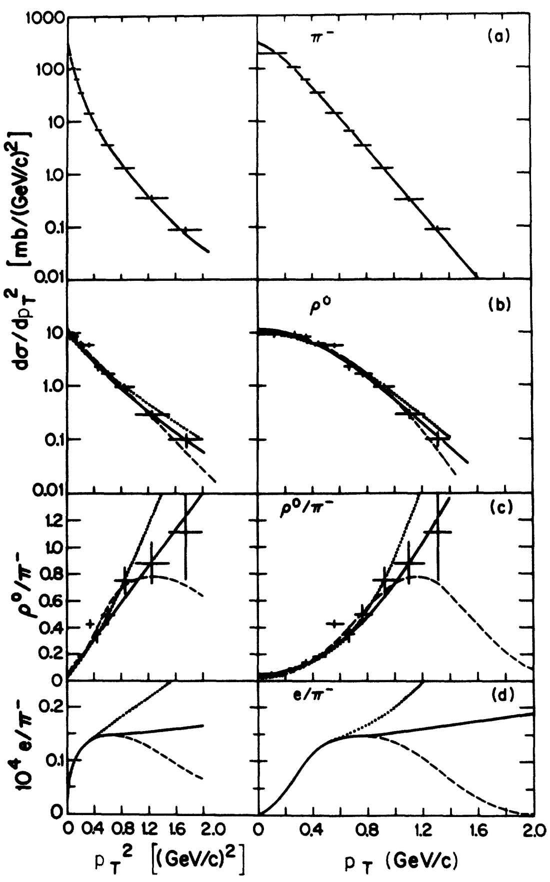

FIG. 1. p_T and p_T^2 distributions for 22-GeV/c π^+p collisions (data from Ref. 2). (a) π^- production for $|x| < 0.5$. The curve is the function $g(p_T) = \text{const}\exp[-6.93(p_T^2 + m_\pi^2)^{1/2}]$. (b) ρ^0 production for $|x| < 0.5$. The curves are $g(p_T) = \text{const}\exp(-3.0p_T^2)$ (dashed line), $\text{const}\exp[-6.3(p_T^2 + m_\rho^2)^{1/2}]$ (solid line), and $\text{const}\exp[-5.5(p_T^2 + m_\rho^2)^{1/2}]$ (dotted line). (c) The ratio of ρ^0 and π^- production for $|x| < 0.5$. (d) Calculated values, at $y = 0$, for e/π^- for electrons from ρ^0 decay.

$= (p_T^2 + m_\rho^2)^{1/2}$, and (iii) same as (ii) but with a smaller B parameter. Figure 1(c) then gives the corresponding ρ^0/π^- ratios for $|x| < 0.5$, and Fig. 1(d) gives the resulting e/π^- ratios at $y = 0$.[9]

It can be seen that all three parameterizations reproduce the dramatic rise in ρ^0/π^- for $p_T \leq 1$ GeV/c, and that in all three cases the ratio e/π^- rises to $\sim 0.15\times10^{-4}$ at $p_T = 1$. But at higher p_T, e/π^- is free to rise, fall, or remain the same.

If ρ^+, ρ^0, and ρ^- are produced equally and are unpolarized, then the ratio(electrons from ρ^0 decay)/(all π^-) cannot exceed half the $\rho^0 \to e^+e^-$ branching ratio, or 0.22×10^{-4}. However, polarization effects can enhance this ratio and in fact it is possible to construct a model[10] in which $l/\pi = 1\times10^{-4}$ from ρ decay alone. In terms of the ρ^0 density matrix elements the pion decay angular distribution[11] is

$$W(\theta,\varphi) = \rho_{11}\sin^2\theta + (1-2\rho_{11})\cos^2\theta - \rho_{1,-1}\sin^2\theta\cos2\varphi - \sqrt{2}\,R_e\,\rho_{10}\sin2\theta\cos\varphi, \tag{1a}$$

while that for the leptons is

$$W(\theta,\varphi) = \rho_{11}(1+\cos^2\theta) + (1-2\rho_{11})\sin^2\theta + \rho_{1,-1}\sin^2\theta\cos2\varphi + \sqrt{2}\,R_e\,\rho_{10}\sin2\theta\cos\varphi + O\left(\frac{m_l^2}{P_l^2}\right)\ . \tag{1b}$$

In our case the pion cross section is known and we are only concerned with possible enhancements of lepton production. Equation (1b) provides us with an *upper bound* of a factor of 1.5 for this enhancement at large p_T, for $\rho_{11} = \frac{1}{2}$ in the helicity frame (ρ_{10} and $\rho_{1,-1}$ do not affect the single-lepton yield significantly). Figure 2 shows the calculated effect in our model for ρ_{11} (helicity) $= \frac{1}{2}$. The effect for any other value of ρ_{11} is

$$l(\rho_{11})/l(\tfrac{1}{3}) = 3(1-2\rho_{11}) + 2(3\rho_{11}-1)f\,,$$

where $l(\rho_{11})$ is the lepton yield as a function of ρ_{11} and $f = l(\frac{1}{2})/l(\frac{1}{3})$ is the quantity plotted in Fig. 2; $\rho_{11} = \frac{1}{3}$ corresponds to complete isotropy.

The $\rho_0 \to \pi^+\pi^-$ decay angular distributions in 12- and 24-GeV/c pp collisions have been measured[12] and are consistent with isotropy. We find ρ_{11}(helicity) $= 0.33 \pm 0.03$ from the 24-GeV/c data, implying that in fact the spin effects are completely negligible, at least at small p_T.

To compare with direct lepton measurements, we need to consider three factors:

(i) The lepton yields were measured mainly in pp rather than πp collisions. In similar calculations we find that the l/π yield from ρ^0 production in pp collisions at 24 GeV/c (see Ref. 12) and $p_T \lesssim 1$ GeV/c is typically a factor of 2 smaller than shown here.

(ii) Other vector mesons will contribute. φ production seems to be strongly suppressed[2,13] and, despite its relatively large branching ratio into l^+l^-, does not seem to be an important lepton source. Using the upper limit[2] of 60 μb for φ production in 22-GeV/c π^+p collisions and assuming the same momentum distribution as for the ρ, the φ contribution to e^-/π is <0.07 times that of the ρ. Inclusive ω^0 production has not been measured, but semi-inclusive ω^0 and ρ^0 production in 12- and 24-GeV/c pp collisions have been found to be equal,[12] suggesting that inclusive ω^0 and ρ^0 production are also equal.

(iii) Much of the lepton production data are taken at much higher incident energy than the vector-meson production measurements of Refs. 2 and 12. However, ρ^0 production in π^+p collisions at 8, 16, and 23 GeV/c (see Ref. 14) and 205 GeV/c (see Ref. 15) has recently been reported, and the ratio of total cross sections for ρ^0 and π^- production appears to be the same over the whole energy range,[14] suggesting that e/π ratios at small p_T do not change much with energy.

Thus for comparison with the lepton-production experiments in pp collisions one should multiply the e/π^- ratios of Fig. 1(d) by a factor of ~1.5. For $p_T \leq 1$ GeV/c, the resulting ratios are well determined, the principal uncertainty being the lack of information on ω^0 production. Thus vector-meson decay cannot explain that part of the copious direct lepton production which has been reported[1] at low p_T. The bulk of the data, how-

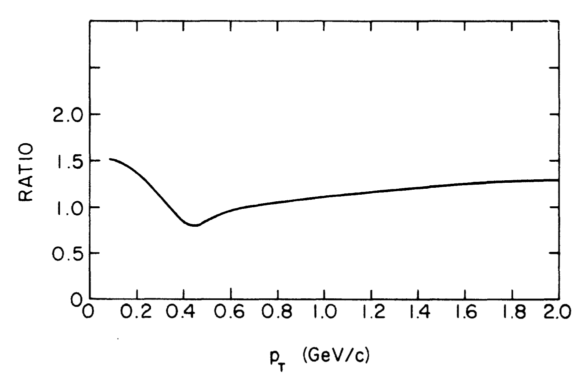

FIG. 2. The ratio of lepton yield for a $1+\cos^2\theta$ decay angular distribution to that for isotropic decay, for $g(p_T^2) = \exp[-6.3(p_T^2 + m_\rho^2)^{1/2}]$.

ever, are at high p_T. These data still can be explained by vector-meson decay, but only if the high energy, high p_T behavior of vector-meson production is quite different from that of the other hadrons. Explicit measurements of inclusive ρ^0 and ω^0 production and decay distributions at high energy and p_T are needed for a conclusive comparison with the high p_T data.

We thank Professor Chang and Professor Langacker for helpful comments.

---

*Work supported by the E.R.D.A.

[1]For an experimental review and references see the talk of B. Pope, International Conference on High Energy Physics, Palermo, 1975 (unpublished).

[2]H. A. Gordon *et al.*, Phys. Rev. Lett. 34, 284 (1975).

[3]M. Bourquin and J. M. Gaillard, paper submitted to the International Symposium on Leptons and Photons at High Energies, Stanford, California, 1975 (unpublished).

[4]G. R. Farrar and R. D. Field, Phys. Lett. 58B, 180 (1975).

[5]We studied the error expected from the factorization assumption by analyzing $pp \to \pi^-$ at 24 GeV/c [V. Blobel *et al.*, Nucl. Phys. B69, 454 (1974)], where the doubly differential distribution at $y=0$ is available, and find that the error is everywhere less than a factor of 1.5. Furthermore, we make the factorization assumption both for ρ and for π production, so the error will tend to cancel in the ratios ρ/π and l/π.

[6]We thank the authors of Ref. 2 for providing numerical values. The requirement $|x|<0.5$ excludes the pion fragmentation region where there is a significant departure from factorization.

[7]V. Blobel *et al.*, Nucl. Phys. B69, 454 (1974).

[8]U. Amaldi *et al.*, Nucl. Phys. B86, 403 (1975).

[9]The electron yields for Fig. 1(d) were obtained by Monte Carlo integration, using the y distribution from Ref. 2 for $f(y)$, and the parameterizations of $g(p_T)$ described in the text. The ρ^0 was assumed to decay isotropically. The pion inclusive cross section at $y=0$ was taken to be $E\, d\sigma/d^3p = 100 \exp(-6.93\, m_T)$, where the normalization has been determined from the data of D. J. Crennell *et al.*, Phys. Rev. Lett. 28, 643 (1972).

[10]G. Chu and J. Koplik, Phys. Lett. 55B, 466 (1975).

[11]K. Gottfried and J. D. Jackson, Nuovo Cimento 33, 309 (1964).

[12]V. Blobel *et al.*, Phys. Lett. 48B, 73 (1974).

[13]F. W. Büsser *et al.*, Phys. Lett. 53B, 212 (1974); J. A. Appel *et al.*, Phys. Rev. Lett. 35, 9 (1975).

[14]M. Deutschmann *et al.*, CERN Report No. 75-29 (unpublished).

[15]F. Winkelmann *et al.*, Phys. Lett. 56B, 101 (1975).