Origin of "direct" leptons

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Experiments are analyzed on processes of the type $p+N\to l^{\pm}+X$, in which "direct" leptons with large transverse momenta are detected. It is shown that an appreciable contribution to such processes is made by the decays $\psi(3105)\to l^{+}+l^{-}$.

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In a large number of experiments performed at Serpukhov,[1], Fermilab,[2], and CERN ISR[4] there was observed the formation of "direct" leptons in the process

$$p+N\to l^{\pm}+X\ , \tag{1}$$

where $l^{\pm}$ is the detected lepton and X are undetectable particles. By "direct" leptons are meant leptons produced in the decay of certain objects with lifetimes $\tau<10^{-12}$ sec. The observed yield of leptons with large transverse momenta ($k_{\perp}>1.5$ GeV/c) cannot be explained on the basis of calculations within the framework of parton models of the Drell-Yan type,[5] where the production of $l^{+}l^{-}$ pairs is due to electromagnetic annihilation of partons and antipartons belonging to the colliding hadrons.

We present below arguments favoring an appreciable contributions to the lepton yield from the decays of the $\psi(3105)$ meson into $l^{+}l^{-}$. We assume that the invariant differential ψ-meson production cross section can be described in factorized form

$$\frac{E\,d\sigma}{d^3p}=A\exp(-\beta p_{\perp})\exp(-\alpha x_E)\ , \tag{2}$$

where $p_{\perp}$ is the transverse momentum of the ψ meson. The scaling variable[1)] x_E is chosen in the form $x_E=E^*/E_{max}$, where E^* is the energy of the ψ particle in the c. m. s. and E^*_{max} is the maximum possible value of E^*. The parameters β and α in (2) characterize the effective regions of the values of $p_{\perp}$ and x_E making the main contribution to the ψ-meson production cross section, and can be obtained from data on ψ-meson production at 250 GeV[6] and 1500 GeV.[7] The results of these experiments can be well fitted to formula (2) with the parameters $\alpha=8$, $\beta=2$ (GeV/c)$^{-1}$, and $A=5.1\times10^{-32}$ cm^2/GeV^2.

The use of the variable x_E instead of the Feynman variable $x=2p^*_{\parallel}/\sqrt{s}$, where $p^*_{\parallel}$ is the longitudinal momentum of the ψ meson in the c. m. s., explains the rapid growth of the ψ-meson production cross section when the energy changes from $E=30$ GeV[8] to $E=1500$ GeV (with allowance for extrapolation of the data of[6,7] into the region of values where no measurements were

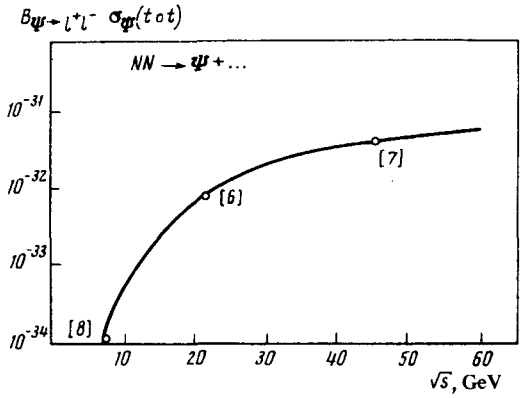

FIG. 1. Cross section for ψ-meson production with decay via the l^+l^- channel in the model with x_E dependence of the ψ distribution.

made). The available experimental points and the predictions of formula (2) for the total cross section of the inclusive process $N+N\to\psi+$ (hadrons) with the decay $\psi\to l^++l^-$ are shown in Fig. 1.

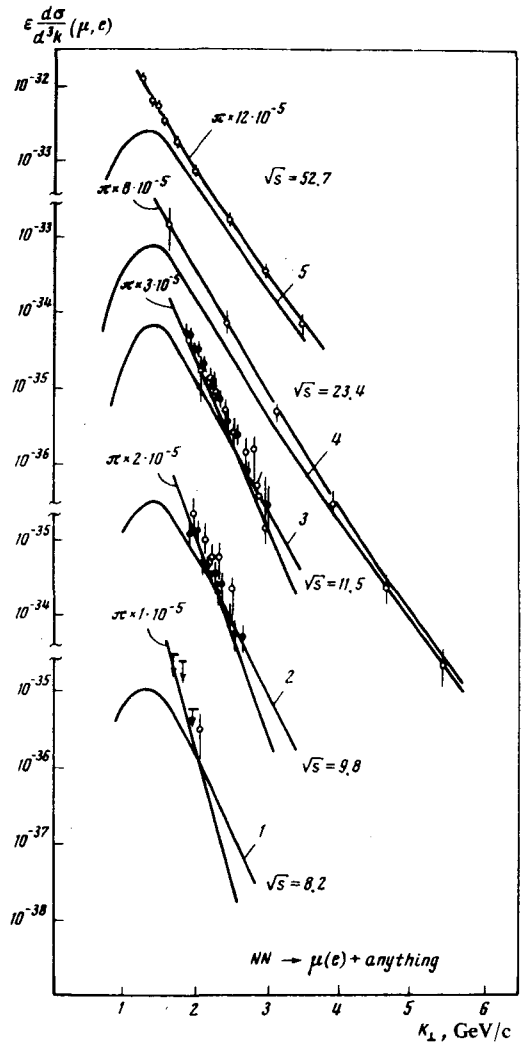

FIG. 2. $\epsilon d\sigma/d^3k$ for leptons from the $\psi\to l^+l^-$ decay. The energies of the primary protons are: 1—35 GeV, 2—50 GeV, 3—70 GeV, and 5—1500 GeV.

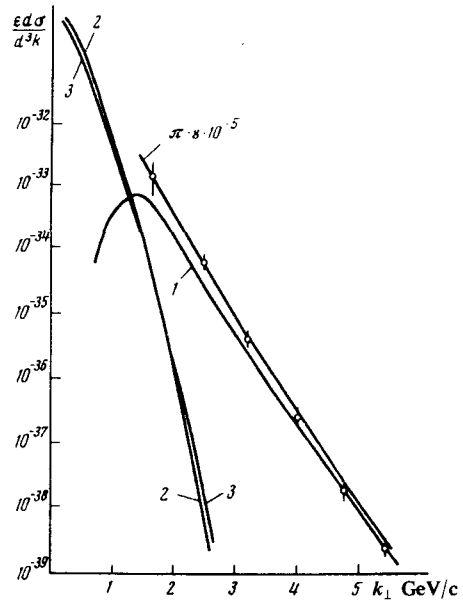

FIG. 3. Invariant differential cross section of lepton production at angles $\theta^*\sim90°$ in the c.m.s. at $E_p=300$ GeV, as a function of their transverse momentum $k_\perp$. The leptons are produced in the following decays: 1) $\psi\to l^+l^-$; 2) $\rho^0\to l^+l^-$, x_E-dependence of the $\rho^0(\omega)$ spectra; 3) $\rho^0\to l^+l^-$, "y"-dependence of the $\rho^0(\omega)$ spectra.

Figure 2 shows the results of calculations of the invariant differential cross sections of the process (1) under the assumption that the source of the "direct" leptons are the decays $\psi(3105)\to l^+l^-$. As seen from Fig. 2, in the region $k_\perp\gtrsim1.5$ GeV/c an appreciable fraction of the "direct" leptons can be attributed to the $\psi\to l^+l^-$ decay.

Let us estimate now the contribution made to the yield of the "direct" leptons by the decays of the light vector mesons ρ^0, ω, and ϕ. According to the predictions of the quark model of multiple production,[9] meson resonances should be produced predominantly at high energies. The average multiplicities are then $\langle n_{\rho^\pm}\rangle=\langle n_{\rho^0}\rangle=\langle n_\omega\rangle\sim0.1\langle n_{ch}\rangle$, where $\langle n_{ch}\rangle$, is the average multiplicity of the charged pions. At an energy $E=300$ GeV we have $\langle n_{ch}\rangle\sim8$.[10] It follows from the results of the experiment[6] the contribution of the ϕ meson can be neglected. An upper bound for the cross section of vector mesons in NN collisions is obtained by assuming that $\sigma_{\rho^0}\approx\sigma_{\rho^\pm}\approx\sigma_\omega\approx\sigma_{in}(NN)/4$, where $\sigma_{in}(NN)$ is the total cross section of the inelastic NN collisions. Using these estimates for the absolute normalization of the lepton spectra from the decays of the ρ^0 and ω mesons produced in NN collisions at $E=300$ GeV, taking into account the experimentally measured $\rho^0(\omega)$ meson distribution with respect to $p_\perp$,[6] and varying the dependence on the "longitudinal" variables (there are no data on the spectra of ρ^0 and ω with respect to $p_\parallel$), namely of the type (2) or in the form $\sqrt{1-y^2/y^2_{max}}$, where y is the rapidity of the $\rho^0(\omega)$ meson in the c.m.s. (this does not contradict the experiments at energies $E=12$ and 24 GeV[11]), we determined the upper bound of the contribution of $\rho^0(\omega)$ to the invariant cross section for lepton production in the process (1) with large $k_\perp$ and

with emission angles $\theta^* \sim 90^\circ$. The results of the calculations are shown in Fig. 3 for $E = 300$ GeV. It is seen from Fig. 3 that in the region $k_\perp \gtrsim 1.5$ GeV/c the contribution of the $\rho^0(\omega)$ mesons is appreciably smaller (by 1.5–2 orders of magnitude) than the contribution from the $\psi(3105)$ meson. The suppression of the contribution of these mesons to the yield of the "direct" mesons, besides the rather small value of their relative probability of decays via the l^+l^- channel, is also explained by the purely kinematic effect of the shift of the maximum of $k_\perp$ distribution of the leptons from the $\rho^0(\omega)$ decay towards smaller $k_\perp$, by an amount $\Delta k_\perp = (m_\psi - m_{\rho/\omega})/2$.[12]

It can thus be concluded that the contribution of the $\psi(3105) - l^+l^-$ decays to the yield of the "direct" leptons is appreciable in the region $k_\perp \gtrsim 1.5$ GeV/c. It is presently impossible to estimate the contribution of other heavy mesons, such as $\psi(3695)$, since we do not have the necessary quantitative data on their production cross sections.

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[1)]We note that at $m_\perp \ll |p_z|$ the variable x_E goes over into the usual Feynman variable $x = |p_z^*/p_{max}^*$.

[1]G. B. Bondarenko *et al.*, Proc. 16-th Internat. Conf. on High Energy Physics, Vol. 2, 329 (1973); V. V. Abramov *et al.*, Preprint IFVÉ, SÉF 74-83, Serpukhov, 1974; B. A. Dologoshein, Lepton Production in Hadron-Hadron Interactions, Proceedings (Trudy), 8-th School on Elementary Particle Physics, Erevan, 1975.

[2]I. P. Boymond *et al.*, Phys. Rev. Lett. **33**, 112 (1974).

[3]J. A. Appel *et al.*, *ibid.* **33**, 722 (1974).

[4]F. W. Busser *et al.*, High Transverse Momentum Electrons at the CERN ISR, Report at Internat. Conf. on High Energy Phys., Palermo, 23–26 June 1975; Phys. Lett. **53B**, 212 (1974).

[5]S. D. Drell and T. M. Yan, Phys. Rev. Lett. **25**, 316 (1970). Yu. A. Golubkov *et al.*, Yad. Fiz. **18**, 393 (1973) [Sov. J. Nuc. Phys. **18**, 203 (1974)]; G. B. Farrar, Nucl. Phys. **B77**, 429 (1974); M. Einhorn and R. Savit, Phys. Rev. **D10**, 2785 (1974).

[6]B. Knapp *et al.*, Preprint FNAL, 1975.

[7]F. W. Busser *et al.*, Observation of J(3.1) Production in Proton-Proton Collisions at the CERN ISR, Report at In. Conf. on High Energy Phys. Palermo, 23–28 June, 1975.

[8]I. I. Aubert *et al.*, Phys. Rev. Lett. **33**, 1404 (1974).

[9]V. V. Anisovich and V. M. Shekhter, Nucl. Phys. **B55**, 455 (1973).

[10]M. Anttinucci *et al.*, Nuovo Cimento Lett. **6**, 121 (1973).

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

[12]Yu. A. Golubkov, A. A. Ivanilov, Yu. P. Nikitin, and R. V. Rozhnov, ZhETF Pis. Red. **17**, 158 (1973) [JETP Lett. **17**, 110 (1973)].