PRODUCTION OF MUON PAIRS WITH LARGE INVARIANT MASSES IN HADRON COLLISIONS

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Submitted 20 April 1971
ZhETF Pis. Red. 13, No. 11, 653 - 656 (5 June 1971)

Most muons that are not decay products of pions or kaons are probably produced in bremsstrahlung processes [1, 2]. With increasing invariant mass of the pair (defined by $M^2 = (p_{\mu^+} + p_{\mu^-})^2$), the cross section of such processes decreases rapidly. For this region, other pair-production mechanisms were proposed, namely the two-photon [3] and the vector-dominance [4] models. The dominant process, however, is probably annihilation of the virtual particles making up the colliding hadrons. Recently Drell and Yan [5] proposed a concrete calculation of such a process [5], using the parton model [6]. In the present article we present different differential distribution for this process and compare them with experiment [7]. The possibility of investigating this process in apparatus with colliding hadron beams is discussed.

According to the model of [6], experiments on inelastic ep scattering [8] can be interpreted as incoherent scattering by pointlike particles - partons. Let the probability of finding a parton with certain quantum numbers α and a fraction of the total momentum x be $f_\alpha(x)$. Then the cross sections for ep scattering and $\mu^+\mu^-$ production are proportional, respectively, to $F(x) = \nu W_2(x)$ [6] and $\mathcal{F}(x_1x_2)$ [5]:

$$F(x) = x\,\Sigma Q_\alpha^2 f_\alpha(x), \qquad \mathcal{F}(x_1x_2) = \Sigma Q_\alpha^2 f_\alpha(x_1) f_{\bar\alpha}(x_2). \tag{1}$$

Here Q_α is the charge and $\bar\alpha$ denotes a parton with opposite quantum numbers. We have assumed here that the spins of all the partons are the same (we shall henceforth assume them equal to 1/2). If we assume that the momentum distribution of the different partons is the same, i.e., $f_\alpha(x) = p_\alpha\phi(x)$, then these sums can be connected by

$$\mathcal{F}(x_1x_2) = c\,\frac{F(x_1)\,F(x_2)}{x_1 x_2}; \qquad c = \frac{\Sigma Q_\alpha^2 p_\alpha p_{\bar\alpha}}{(\Sigma Q_\alpha^2 p_\alpha)^2}. \tag{2}$$

Comparison with the experimental data [7] shows that this assumption is well satisfied and that c is close to unity. It is still impossible to determine this parameter exactly, owing to experimental uncertainties (uranium target etc). We note that its magnitude gives important information on the structure of the protons. Some estimate of c is obtained under the assumption that the N sorts of charged particles are approximately uniformly represented: $c = [\langle Q^2\rangle N]^{-1}$, where $\langle Q^2\rangle$ is the mean-squared charge of these particles; for quarks, for example, $c = 3/4$.

The differential distribution with respect to the mass M of the pair and it momentum p_L in the lab is of the form (m is the proton mass)

$$d\sigma = \frac{8\pi\alpha^2 c}{3} F\left(\frac{2mp_L}{s}\right) F\left(\frac{M^2}{2mp_L}\right)\frac{dM}{M^3}\,\frac{dp_L}{p_L}. \tag{3}$$

Figures 1a and 1b show the distributions with respect to M (integrated over the region $p_L > 12$ GeV) and with respect to p_L (for M > 1 GeV). In the calculations we used c = 1 and F(x) as shown in Fig. 1c. Besides the region of small masses that lie outside the region of applicability of the model, the agreement is good. It is interesting that for large p_L, according to (3), there is practically no correlation between M and p_L, as was noted also in [7]. The pair momentum is produced in practice only by the incoming parton, and therefore $(d\sigma/dp_L) \sim (1/p_L)F(2mp_L/s)$ - to the momentum distribution of the incoming partons. The dashed and dash-dot curves in Fig. 1a correspond to [3] and [4].

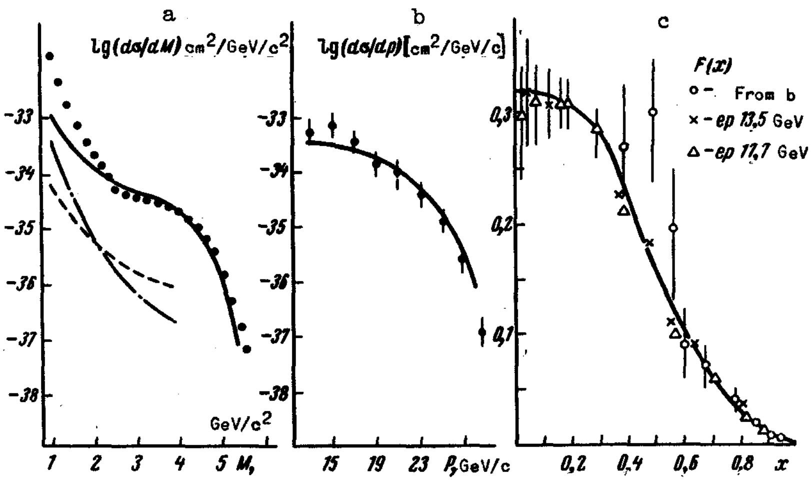

Fig. 1

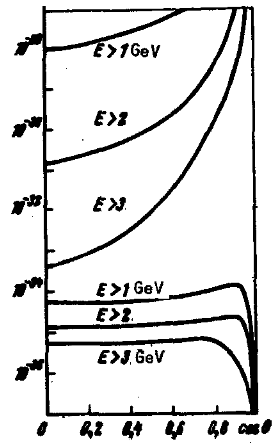

Fig. 2

The $\mu^+\mu^-$ production process can be investigated with installations with colliding hadron beams, since the background of high-energy decay muons is small in the large-angle region. In the region $p_C M \ll \sqrt{s}$ the cross section has the rather simple form $d\sigma = (4\pi\alpha^2 c/3)F^2(0)(dM/M^3)\times [dp_C/(p_C^2 + M^2)^{1/2}]$, where p_C is the pair momentum in the c.m.s. of the colliding hadrons. The distribution with respect to the muon emission angles θ_+ and θ_- in this system and with respect to the transverse momentum k (we neglect the transverse momentum of the pair) is given by $[u_\pm = \tan(\theta_\pm/2)]$

$$d\sigma = \pi\alpha^2 c F\left[\frac{k_\perp}{\sqrt{s}}(u_+ + u_-)\right] F\left[\frac{k_\perp}{\sqrt{s}}\left(\frac{1}{u_+} + \frac{1}{u_-}\right)\right] \times$$
$$\times \frac{(u_+^2 + u_-^2)(1+u_+^2)(1+u_-^2)}{(u_+ + u_-)^6} \frac{dk_\perp}{k_\perp^3} d\cos\theta_+ \, d\cos\theta_- . \qquad (4)$$

Figure 2 shows the cross section of the process in which one muon is emitted at an angle θ and the other falls in a detector with a solid angle $\Delta\Omega = 0.1$ near the angle $\theta = \pi/2$ with an energy higher than the threshold value indicated in the figure. We chose $c = 1$ and $\sqrt{s} = 30$ GeV. For comparison we present the angular distributions of pions having the same energy thresholds. The estimates were based on

$$d\sigma = \frac{\sigma_0 N}{a\sqrt{2\pi}} \exp\left(-\frac{x^2}{2a^2}\right) dx \exp\left(-\frac{p_\perp}{T}\right) \frac{p_\perp dp_\perp}{T^2},$$

$$\sigma_0 = 40 \text{ mb}; \; N = 10; \; x = \lg \operatorname{tg}(\theta/2); \; a = 0{,}6; \; T = 0{,}16 \text{ GeV}.$$

In conclusions, we attempt to answer the question: why does not an analogous mechanism give pions with large transverse momenta? The pions are subject to an intense interaction in the final state, and their transverse is determined more readily by the final "temperature" of the system than by the initial one. Leptons, on the other hand, for example μ^+ and μ^-, do not take part in these processes and carry information on the structure of the particles.

The author is deeply grateful to S. T. Belyaev, L. M. Barkov, I. F. Ginzburg, and V. G. Serbo for very useful discussions.

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POSSIBILITY OF ORIENTING ELECTRON SPINS WITH CURRENT

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Submitted 21 April 1971
ZhETF Pis. Red. 13, No. 11, 657 - 660 (5 June 1971)

It is known that if a polarized beam of electrons is scattered by an unpolarized target, then the spin-orbit interaction leads to scattering asymmetry about the plane containing the directions of the spin and of the initial momentum [1]. The so-called anomalous Hall effect is connected with this asymmetry [2 - 5]. In the scattering of an unpolarized beam by an unpolarized target, a spacial separation of electrons with different spin orientation is produced by the fact that the deflection is correlated with the spin [6]. A predominant deflection of electrons with opposite spins takes place in opposite directions.

When current flows through a conductor, the multiple scattering of the carriers should give rise to a spin flux perpendicular to the current and directed from the interior to the periphery of the conductor. We show in this paper that this leads to accumulation of spin orientation at the surface of the sample, limited by the spin relaxation. As a result there dhould exist at the surface of a current-carrying sample a layer in which the electron spins are oriented (spin layer). The spin-layer thickness is determined by the length of the spin diffusion.

From the phenomenological point of view the phenomenon can be described as follows: We introduce the spin-density vector $\vec{S}$ and the spin-flux density tensor $q_{\alpha\beta}$. The quantity $q_{\alpha\beta}$ gives the flux density of the β-component of the spin in the direction of α. The spin density $\vec{S}$ satisfies the continuity condition

$$\frac{\partial S_\beta}{\partial t} + \frac{\partial q_{\alpha\beta}}{\partial x_\alpha} + \frac{S_\beta}{\tau_s} = 0, \qquad (1)$$

where τ_s is the spin relaxation time. The expression for the spin flux density $q_{\alpha\beta}$ will be written in the form

$$q_{\alpha\beta} = -b_s E_\alpha S_\beta - d_s \frac{\partial S_\beta}{\partial x_\alpha} + \beta_s n \epsilon_{\alpha\beta\gamma} E_\gamma \quad , \qquad (2)$$

where $\epsilon_{\alpha\beta\gamma}$ is an antisymmetrical unit tensor of third rank, $\vec{E}$ the electric field intensity, and n the electron concentration. In expression (2) we confined ourselves to terms linear in the electric field, the spin density, and its first derivatives[1)]. The first term in the right side of (2) describes the drift of the spin due to the electric field, the second describes the spin diffusion, and the third describes the occurrence of a spin flux in a direction perpendicular field, due to spin-orbit interaction. Consequently the coefficients b_s, d_s, and β_s can be called the spin mobility, the spin diffusion coefficient, and the spin-electric coefficient.

1)It is possible to add to Eq. (2) also the terms due to the spin-orbit interaction, containing the expressions $E_\beta S_\alpha$, $\delta_{\alpha\beta}(\vec{E}\cdot\vec{S})$, $\partial S_\alpha/\partial x_\beta$, and $\delta_{\alpha\beta}\mathrm{div}\vec{S}$, which are compatible with the law of transformation of the tensor $q_{\alpha\beta}$. These terms, however, are of no significance in the effect under consideration, and have been omitted for simplicity.