Correlations between the secondary particles in π^-A interactions at 3.7 GeV/c

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We investigate the correlations between the protons emitted forward in π^-A interactions at 3.7 GeV/c and the fast positive particles that move forward. It is observed that the correlation parameter R does not depend on the energy of the backward-emitted proton. The dependence of R on the p_L of the forward-moving particles and on the atomic number A is determined.

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It was observed in[1] that the cross section of deep-inelastic nuclear reactions

$$a + A \to b + \dots, \tag{1}$$

(where a is a certain particle, A is the nucleus, and b is a proton (deuteron, etc.,) emitted backward (in the rest frame of the nucleus), with energy $T \geq 50$ MeV) do not depend on the atomic number A of the nucleus. This phenomenon, called nuclear scaling,[1,2] has attracted great interest to the study of these reactions. A brief review of the experimental situation is given in[2].

To describe the deep-inelastic reactions and to explain the nuclear scaling, a number of theoretical models have been proposed,[3] based on various ideas. To verify the validity of any particular model and for a deeper understanding of the process, the inclusive data alone are insufficient. The next step in the development of the inclusive approach to multiple reactions is the measurement of the doubly inclusive cross sections, which yield information on the correlations of the secondary particles. We have investigated the reaction

$$a + A \to b + c \dots, \tag{2}$$

where a is a π^- meson with momentum 3.7 GeV/c, A are the nuclei Al, Cu, and Pb, b is a proton emitted backward in the lab frame, c is a positive particle (p or π^+) emitted forward with $p_L > 0.6$ GeV/c and $p_T < 0.6$ GeV/c (p_L and p_T are the longitudinal and transverse momenta).

It is convenient to represent the cross sections of reactions (1) and (2) in the form of the normalized invariant functions

$$\rho(\mathbf{p}_b) = \frac{1}{\sigma_{aA}^{in}} \frac{E_b}{p_b^2} \frac{d\sigma}{dp_b d\Omega_b}, \tag{3}$$

$$\rho_2(\mathbf{p}_b, \mathbf{p}_c) = \frac{1}{\sigma_{aA}^{in}} \frac{E_b E_c}{p_b^2 p_c^2} \frac{d\sigma}{dp_b d\Omega_b dp_c d\Omega_c}. \tag{4}$$

To represent the correlations it is customary to use the function

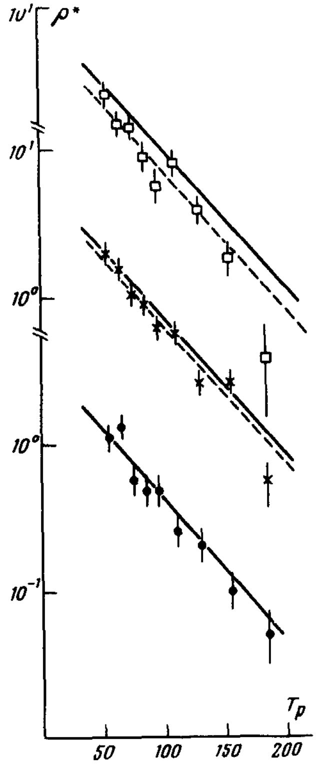

FIG. 1. Dependence of the function ρ^* on the kinetic energy T (MeV) of the protons emitted forward in the angle interval $1 \leq \cos\theta_p < -0.9$, ●—Al, x—Cu, □—Pb.

$$R(\mathbf{p}_b, \mathbf{p}_c) = \frac{\rho_2(\mathbf{p}_b, \mathbf{p}_c)}{\rho(\mathbf{p}_b)\rho(\mathbf{p}_c)} - 1 \cdot \tag{5}$$

We shall also use the function

$$\rho^*(\mathbf{p}_b) = \frac{\int_{\Omega_c} \rho_2(\mathbf{p}_b, \mathbf{p}_c)\frac{d^3 p_c}{E_c}}{\int_{\Omega_c} \rho(\mathbf{p}_c)\frac{d^3 p_c}{E_c}} = \{\bar{R}(\mathbf{p}_b, \Omega_c) + 1\}\,\rho(\mathbf{p}_b)\,, \tag{6}$$

where the integration is carried out in a certain kinematic region for the particle c, and $\bar{R}$ is the value of R [Eq. (5)] averaged over Ω_c. In the absence of correlations ($R = 0$), ρ^* coincides with ρ.

To measure the correlations we used photographs obtained with the aid of a tracking spark spectrometer. The installation and the experimental details are described in[4]. In the reduction we measured the tracks of the forward-moving positive particles with $p_L > 0.6$ GeV/c and $p_T < 0.6$ GeV/c (the presence of such a particle was the condition for the triggering of the spectrometer)

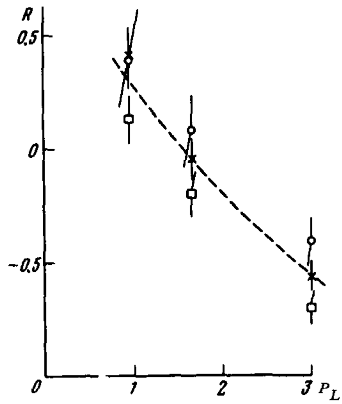

FIG. 2. Dependence of the correlation parameter R of p_L (GeV/c) of a positive particle emitted forward. ○—Al, x—Cu, □—Pb. The dashed line corresponds to the value of $R(p_L)$ averaged over the nuclei.

and of all the particles emitted backwards in the lab system. We measured altogether 4200 events without and 16100 particles with backward emission of particles. In the subsequent reduction, we took into account the efficiency and the resolution of the spectrometer and introduced a correction for the small ($\lesssim 3\%$) π^+ admixture in the backward-emitted positive particles.

Figure 1 shows a plot of ρ^* against the kinetic energy of the protons (T) emitted backward in the angle region $-1 \leq \cos\theta < -0.9$ [here Ω_c (see (6)) corresponds to $p_L > 0.6$ GeV/c and $p_T < 0.6$ GeV/c]. The solid lines in Fig. 1 show the relation

$$\rho(T) = C \exp\{-T/T_0\}, \tag{7}$$

which was obtained for the inclusive reaction (1) from the data of[5] where a stands for a π^- meson with momentum 3.5 GeV/c, and b stands for a proton emitted at an angle 162° ($\cos 162° \cong -0.95$). The fact that ρ and ρ^* have identical dependences on T means that $\bar{R}(T_b, \Omega_c)$ is independent of T. Nor did we observe a dependence of R on T_b when the region of integration of Ω_c with respect to p_L was decreased ($p_L < 1.3$ GeV/c and $p_L > 2$ GeV/c). The accuracy of this statement is ~20% for $50 < T_b < 150$ MeV when averaged over the nuclei. The dashed lines in Fig. 1 correspond to the relations $\rho^* = \bar{R}(\Omega_c)\rho(T_b)$, where $\bar{R}$ was obtained by area normalization. We have here $\bar{R}_{\rm Al} = 0.0 \pm 0.09$, $\bar{R}_{\rm Cu} = -0.10 \pm 0.06$; $\bar{R}_{\rm Pb} = -0.25 \pm 0.06$. Attention is called to the decrease with increasing A of the nucleus.

Since $\bar{R}(T_b, \Omega_c)$ does not depend on T_b within the limits of the statistical accuracy, we can integrate with respect to T_b in the study of the $R(p_c)$ dependence. A plot of $R(p_{cL})$ is shown in Fig. 2. It is seen that R decreases when p_L and A of the nucleus increase. R is in this case practically independent of p_T (with the possible exception of R for the Pb nucleus, which exhibits a certain growth with increasing p_T in the region $p_L > 1.3$ GeV/c).

It was also observed that the spectrum of the protons emitted backward in the investigated reaction does not depend on their number in the region $50 < T_p < 150$ MeV. The statistical accuracy is in this case ~30% in the comparison with $n_p = 1$ and $n_p = 2$ and not better than 50% for $n_p \geq 3$.

The observed facts can be understood assuming independent backward emission of fast protons in deep inelastic nuclear reactions, which constitute a fraction of all the inelastic processes (they do not include, of course, the so-called quasi-free reactions). This hypothesis agrees with the independence of the spectrum of the protons of their number and of the presence of a forward particle and its momentum. On the other hand, the behavior of $R(p_L)$ is explained by the fact that the relative contribution of deep-inelastic reactions to the production of forward-emitted fast particles decreases with increasing p_L.

In the discussion of the dependence of R on the atomic number of the nucleus one must bear in mind the dependence of the parameter C (7) on the initial energy, obtained in[5] for the inclusive reaction (1). The data of[5] show that the value of C first increases with increasing p_0, and then assumes a constant value at $p_0=p^*(A)$. The results are $p^*(\mathrm{Al})=3$ GeV/c, $p^*(\mathrm{Cu})=4$ GeV/c, and $p^*(\mathrm{Pb})=5$ GeV/c. The forward emission of a sufficiently rapid particle makes the energy remaining for the formation of the remaining particles less than the initial energy, and this leads in turn to a decrease of ρ^* in comparison with ρ for the inclusive process. At $p_0=3.7$ GeV/c this can manifest itself strongly for the Pb nucleus and somewhat more weakly for Cu and quite weakly for Al.

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