Correlations between secondary particles in $\pi^- A$ interaction at 3.7 GeV/c

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Correlations are investigated between π^- mesons emitted backwards in $\pi^- A$ interactions at 3.7 GeV/c, on the one hand, and the fast positive particles traveling forward. It is observed that the correlation parameter R is independent of either the energy of the backward emitted π^- meson or of the momentum of the forward-moving particle.

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Much interest is being paid of late to the study of nuclear reactions at high energies with emission of baryons into the rear hemisphere, as well as of cumulative[1] pions.[1-4] The overwhelming majority of the data on cumulative particles were obtained in the inclusive approach, in the investigation of the reactions

$$a + A \to b + \dots , \qquad (1)$$

where a is a certain particle, A is a nucleus, b is a particle emitted backward in the laboratory system. Reaction (1) is characterized by nuclear scaling, i.e., asymptotic independence of the inclusive spectra of the particles "b" of the energy and of the sort of the incident particle, as well as independence of the form of the spectra on the atomic mass of the target nucleus.[2]

There are many different theoretical models for the description of the reaction (1). 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 measurement of the doubly inclusive cross sections, which yield information on the correlations of the secondary particles.

We have continued the investigation of the reaction

$$a + A \to b + c + \dots , \qquad (2)$$

where a is a negative pion with momentum 3.7 GeV/c, A is the nucleus Al, Cu, or Pb, and b is a negative pion emitted backward with a laboratory energy 30–350 MeV. In [3] we investigated the reaction (2), in which the particle "b" was a fast proton ($T_b > 50$ MeV, where T_b is the kinetic energy), and c was a forward-emitted positive particle (p or π^+) 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). The investigated backward-emitted π^- mesons are only partially cumulative. However, the available experimental data[4] show no noticeable changes of the π^--meson spectrum at the boundary of the cumulativity region.

To measure the correlations we used the same photographs of the $\pi^- A$ events as in

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[5], obtained with a TISS track spark spectrometer.[5] The efficiency of the installation has imposed restrictions on the kinetic energy T_b and on the emission angle $\theta(\cos\theta=z)$ of the particle "b" (π^- meson). In the angle interval $-1<z<-0.8$ we reduced the tracks of π^- mesons with $30<T_b<350$ MeV. Accordingly, in the intervals $-0.8<z<-0.6$; $-0.6<z<-0.4$; $-0.4<z<-0.2$ the values of T_b varied in the ranges 30–310, 30–250, and 30–250 MeV.

We represent the cross sections of reactions (1) and (2) in the form of normalized invariant functions

$$\rho(\mathbf{P}_b) = \frac{1}{\sigma_{a\,A}^{in}} E_b \frac{d\sigma}{d^3P_b}, \tag{3}$$

$$\rho_2(\mathbf{P}_b, \mathbf{P}_c) = \frac{1}{\sigma_{a\,A}^{in}} E_b E_c \frac{d\sigma}{d^3P_b\, d^3P_c}. \tag{4}$$

Here E_b, $\mathbf{P}_b$, E_c, and $\mathbf{P}_c$ are respectively the total energy and momentum of particles b and c, σ_{aA}^{in} is the total inelastic cross section for the interaction of the particle a with the nucleus A. We represent the correlation in the form

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

$R=0$ in the absence of correlations, when $\rho_2(\mathbf{P}_b,\mathbf{P}_c)=\rho(\mathbf{P}_b)\rho(\mathbf{P}_c)$. Integrating over the region of the momenta Ω_c of the particle c:

$$\int_{\Omega_c} (R(\mathbf{P}_b, \mathbf{P}_c)+1)\rho(\mathbf{P}_b)\rho(\mathbf{P}_c)\frac{d^3P_c}{E_c} = \int_{\Omega_c} \rho_2(\mathbf{P}_b, \mathbf{P}_c)\frac{d^3P_c}{E_c}$$

and replacing R by its average $\bar{R}$ over Ω_c, we obtain:

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

In the absence of correlations ρ^* coincides with ρ.

The inclusive $\rho(P_b)$ spectra are customarily represented in the form

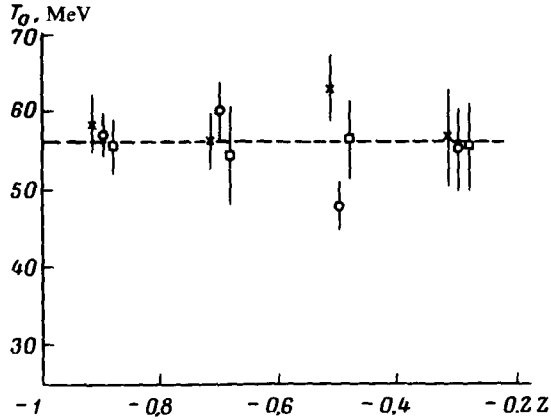

FIG. 1. Dependence of T_0 on the cosine z of the π^--meson emission angle: ×–Al, o–Cu, □–Pb. The dashed line corresponds to $T_0 = \bar{T}_0$.

$$\rho(P_b) = \rho(T_b) = C\exp\left(-\frac{T_b}{T_0}\right), \tag{7}$$

where T_0 is the spectrum slope parameter. Plots of ρ^* against the kinetic energy T_b were prepared for the nuclei Al, Cu, and Pb in four angle intervals of the backward emitted π^- meson. $\rho^*(T_b)$ is well approximated by the relation

$$\rho^*(T_b) = C\exp\left(-\frac{T_b}{T_0}\right) \tag{8}$$

with $\chi^2/\nu \sim 1$ for all spectra. Accurate to $\sim 10\%$, no dependence of the parameter T_0 on the atomic number of the target nucleus and on the angle was observed (see Fig. 1), whereas it is known[2] that T_0 of the protons from reaction (1) increases with increasing z.

The mean value $\bar{T}_0 = 56.1 \pm 1.2$ MeV is close to the slope parameters of the known inclusive spectra of the π^- mesons from the reaction $p+A \to \pi^{\pm} + \ldots$ (in the region $T_\pi = 100$–700 MeV, $z = -1$) at an initial momentum 6 GeV/c,[4] namely $T_0^{Al} = 55.6 \pm 1.2$ MeV and $T_0^{Cu} = 59.5 \pm 1.4$ MeV. This allows us to state that the slope parameter T_0 is insensitive to the presence of the forward-moving fast particle or, equivalently, that $\bar{R}(T_b, \Omega_c) \sim \rho^*(T_b)/\rho(T_b)$ is independent of T_b. T_0 remained constant also with decreasing region of integration Ω_c ($P_L < 1.3$ GeV/c, $1.3 < P_L < 2$ GeV/c, and $P_L > 2$ GeV/c). The accuracy of this statement is $\sim 10\%$ for each nucleus at $-1 < z < -0.2$ and $30 < T_b < 250$ MeV.

We have also compared the result obtained for $\bar{T}_0$ with the slope parameters of the inclusive spectra of the π^- mesons from the reaction $p+p \to \pi^- + \ldots$ ($P_{lab} = 19.2$ GeV/c). The known data on the inclusive spectra of the π^- mesons emitted forward[6] were recalculated into the antilaboratory system. In the region far from the kinematic boundary, these spectra are described by relation (7) with $\chi^2/\nu \sim 1$ and yield $T_0 = 52.8 \pm 1.3$ MeV for $z = -0.85$ and $T_0 = 57.8 \pm 1.0$ MeV for $z = -0.70$. The inclusive spectra of the pions in the fragmentation region for pp interactions have a scaling

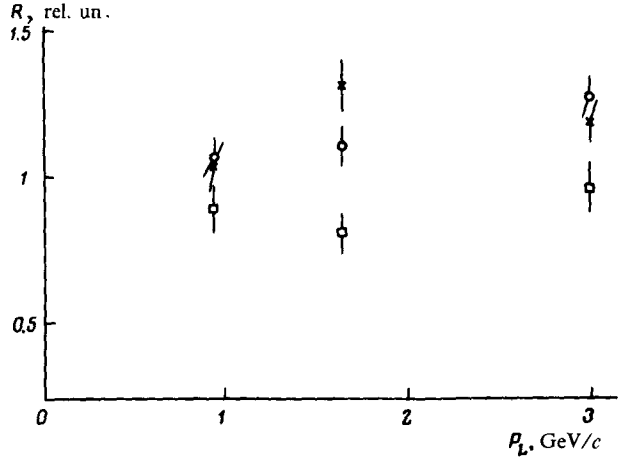

FIG. 2. The correlation parameter R as a function of the longitudinal momentum P_L of the forward emitted positive particle; $30 < T_b < 250$ MeV, $-1 < z < -0.2$; ×–Al, o–Cu, □–Pb.

behavior starting with $P_{\text{lab}} \sim 10$ GeV/c. On the other hand, the available experimental data at 6 and 8.4 GeV/c[4] reveal a weak dependence of T_0 on the initial energy. We can therefore conclude that the slopes of the spectra of the investigated π^- mesons have close values for nuclei and for hydrogen.

Since $\bar{R}(T_b, \Omega_c)$ does not depend on T_b, we can integrate with respect to T_b to

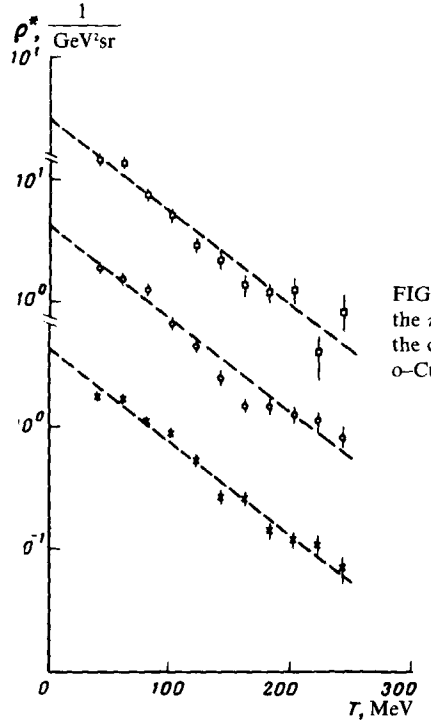

FIG. 3. Dependence of the function ρ^* on the kinetic energy T of the π^- mesons ($-1 < z < -0.2$). Dashed line–approximation of the data by the relation (8) with fixed value of $T_0 = \bar{T}_0$: ×–Al, o–Cu, □–Pb.

increase the statistical accuracy in the study of the $R(P_c)$ dependence. Figure 2 shows a plot of $\bar{R}$ against the longitudinal momentum of a particle with P_{cL}. The absence of data on the inclusive backward emission of π^- at an initial momentum 3.7 GeV/c makes it impossible to obtain the absolute values of R. For the investigated π^- mesons no dependence of $\bar{R}$ on P_{cL} has been observed, whereas for protons a decrease of $\bar{R}$ has been observed with increasing P_{cL}.[3]

The differences in the dependence of $\bar{R}$ on P_{cL} and in the angular dependence of T_0 seem to offer evidence that the mechanisms that produce the investigated π^- mesons in the reaction (2) differ from those producing the cumulative protons.

Figure 3 shows the spectra of ρ^* averaged over z (in the region $-1 < z < -0.2$). As noted above, the slope parameter of the spectrum does not depend on z; the value of C as approximated by (8) increases by a factor 2–2.5 times when z changes from -1 to -0.2. The absolute value of the functions ρ^* remains constant or decreases somewhat with increasing atomic number A, whereas a rising $C(A)$ dependence is observed for protons.[3]

[1)]By "cumulative" we mean particles whose momenta lie in a region kinematically forbidden for the production of such particles on a free nucleon. Any baryon emitted into the rear hemisphere in the laboratory system is cumulative.

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