Collective nature of the baryon cumulative effect on nuclei

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Experimental data are presented on deep-inelastic pion-nucleus interactions with emission of protons in the rear hemisphere, and also with emission of Λ hyperons and protons; these data point to a collective nature of the nuclear scaling mechanism.

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The "cumulative" effect is one of the most interesting phenomena of high-energy nuclear physics. Possible mechanisms that lead to the knockout of fast "cumulative" baryons in a direction opposite to the primary particle (a process kinematically forbidden for collisions with free nucleons) have been extensively discussed in the last few years.[1-7] The various models are checked, without exception, by using inclusive distributions of fast protons with kinetic energy $E_k > 30$ MeV emitted into the rear hemisphere relative to the beam. The sensitivity of such distributions is insufficient to give preference to any concrete interaction variant. More definite conclusions can be obtained by investigating the properties of the reaction products that accompany the emission of "cumulative" particles.

In this paper we present the results of investigations of the reactions

$$\pi^- + A \to kp_{\rm rear} + X, \quad (k = 1,2\ldots) \tag{1}$$

$$\pi^- + A \to kp + \Lambda + X, \quad (k = 1,2\ldots) . \tag{2}$$

The work was performed with the 105-cm freon bubble chamber of our institute using a beam of π^- mesons with momentum 3.9 GeV/c ($\bar{A} = 22.5$).[8,9]

Table I lists the measured cross sections of the reaction (1) on the average nucleus

TABLE I.

n_p	σ, mb	σ/σ_{inel}, %
1	79 ± 3	21.0 ± 0.9
2	21 ± 2	5.7 ± 0.6
3	5 ± 1	1.4 ± 0.3
> 3	< 1	< 0.3
≥1	106 ± 4	28.4 ± 1.1

of the freon mixture with emission of one, two, three, and more fast ($E_k > 30$ MeV) protons into the rear hemisphere. As seen from the table, the fraction of events with emission of two or more protons backwards is more than 20% of the cross section of the reaction (1). "Multiple cumulative" protons were observed also in Ref. 10.

In reaction (1) are observed correlations of the "cumulative" protons with close momenta. Figure 1 shows the distribution, in the relative momentum, of two fast (E_k

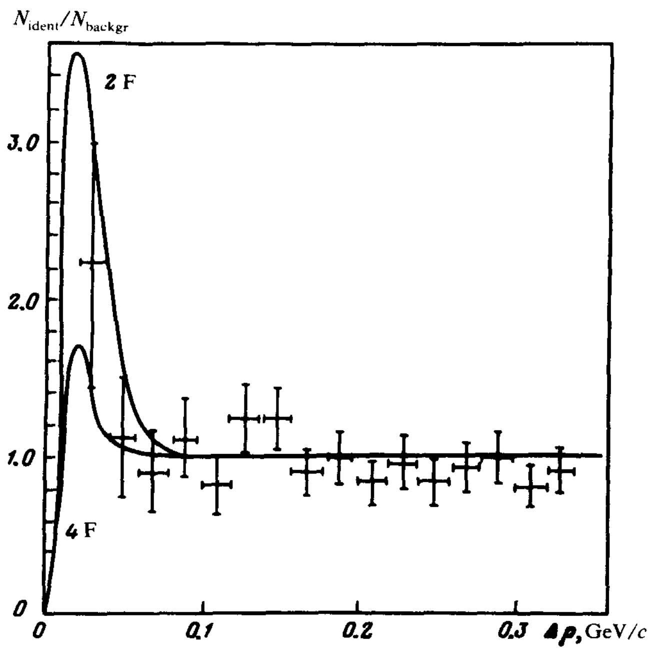

FIG. 1. Two-proton relative-momentum distribution divided by the background distribution.

> 50 MeV) protons ($\Delta p = |\mathbf{p}_1 - \mathbf{p}_2|/2$), divided by the background distribution. Not a single event with $\Delta p < 20$ MeV/c was recorded. The curves in the same figure for the interaction regions 2 and 4 F were calculated with account taken of the Coulomb and nuclear pp potential.[11] The background was obtained by combining the protons from

different events. The character of the correlations indicates that the dimensions of the region from which the protons are emitted is comparable with the dimensions of the nucleus.

For reaction (1), the average number of protons emitted into the rear hemisphere ($\bar{n}_p$) is proportional to the total number of fast protons in the star (N), namely $\bar{n}_p = (0.28 \pm 0.01)N$ ($\chi^2 = 5.1$ at six degrees of freedom). The appearance of an average of one fast proton in the rear hemisphere is accompanied by the emission of two or three other fast protons.

Of undisputed interest are the reactions investigated in practice, with formation of cumulative hyperons. The first data were obtained at the Institute of Theoretical and Experimental Physics[12] and at our Institute.[9] The advantages of the reaction (2) are, first, that the registration of the Λ hyperon makes it possible to extend the measured energy range of the secondary baryons. In our case we registered Λ hyperons with kinetic energy up to 2 GeV. Second, owing to the properties of the Λ hyperon, its source can be taken to be, with high degree of reliability, the primary interaction act in the nucleus. The hyperon is definitely "evaporative" or a "spectator," as can always be suspected when protons are registered.

Figure 2 shows the dependence of the multiplicity of fast protons ($E_k > 30$ MeV)

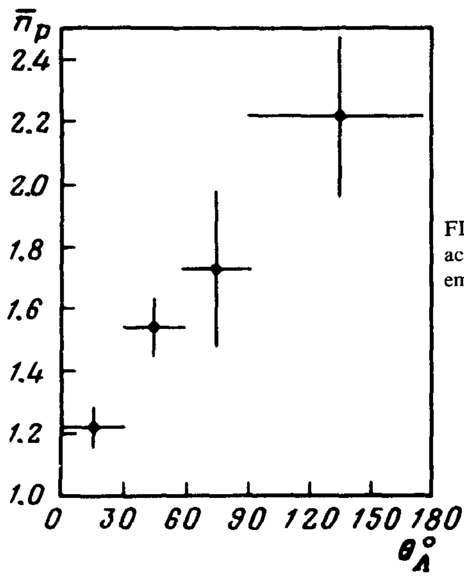

FIG. 2. Dependence of the average number of fast protons accompanying the production of the Λ hyperon on the emission angle θ_Λ in the lab.

in the reaction (2) on the Λ-hyperon emission angle in the laboratory frame. The dependence is close to linear. Hyperon emission in the angle region that is kinematically forbidden for the production on a free nucleon is accompanied on the average by the emission of more than one fast proton. No strong change was observed in the function $\bar{n}_p(\theta_\Lambda)$ on going from the forbidden to the allowed region; such a change might indicate a change in the interaction mechanism.

In contrast to the noted close connection between the emission of the Λ hyperon and the emission of nuclear nucleons, the connection between the Λ hyperon and the relativistic (mesic) component of the reaction products is weakened. This manifests itself, in particular, in the fact that the average cosine of the emission of the Λ hyperon does not depend, within the limits of experimental error, on the multiplicity of the relativistic charged particles n_s (Fig. 3a). A dependence on n_s does exist for the K^0 meson (Fig. 3b).

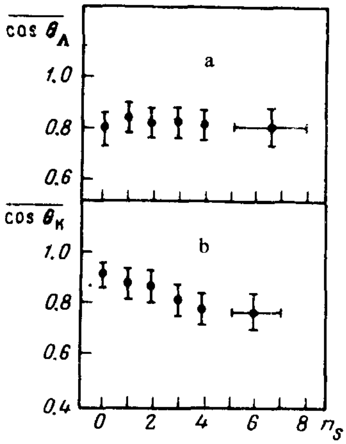

FIG. 3. Dependence of the average cosine of the Λ-hyperon (a) and K^0-meson (b) emission angle on the number of emitted relativistic particles.

Just as for the reaction (1), multiple cumulative processes were observed for the reaction (2). The probability of emission of at least one fast proton into the rear hemisphere in reaction (2) is 45%. In not less than 20% of the cases is the emission of such a proton accompanied by emission of one additional fast proton. In 10% of the cases, simultaneous emission of a Λ hyperon and a fast proton is observed in the angle region which is kinematically forbidden for collisions with a free nucleon.

The presented experimental results allow us to conclude that processes with backward emission of fast baryons are essentially multiple processes and involve several nucleons of the nucleus or the entire nucleus. It appears that to describe them we must resort to collective models of the type in Refs. 6 and 7, and not models with single-particle exchange.[1-4]

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