Pion and kaon production in collisions of relativistic nuclei with an energy of 3.65 GeV/nucleon

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The cross sections for the production of $\pi^{\pm}$ and $K^{\pm}$ mesons have been measured over the momentum interval 0.5–1.1 GeV/c at an angle of 24° in collisions of carbon nuclei with carbon and lead nuclei. A comparison is made with corresponding data on collisions of relativistic deuterons with nuclei.

There have been only a few experimental studies of the production of strange particles in collisions of relativistic nuclei (see the review by Stock[1]). Charged kaons have been measured only at an energy 2.1 GeV/nucleon, i.e., below the threshold for the production of K^- mesons in nucleon-nucleon collisions. In the present letter we

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report the first measurements under identical experimental conditions of the cross sections for the production of strange and nonstrange, positive and negative mesons at energies above the production thresholds in *NN* collisions. In order to search for possible differences in the meson production mechanism in collisions of nuclei with nuclei and collisions of nucleons with nuclei, we made a comparison with data on the collisions of deuterons with nuclei at an identical energy per nucleon[2] under the assumption that the deuteron can be treated as consisting of two weakly bound nucleons.

The measurements were taken at the KASPIĬ apparatus of the Institute of Nuclear Research, Academy of Sciences of the USSR,[3] positioned in the extracted beam of relativistic nuclei of the High-Energy Laboratory of the Joint Institute for Nuclear Research. The experimental apparatus is described in Ref. 4. The magnetic channel of the apparatus was used as a secondary-particle spectrometer. The measurements were taken over the meson momentum interval 0.5–1.1 GeV/*c* by a time-of-flight technique with the help of a Čerenkov counter made of a material equivalent to Plexiglas, operated in a total-internal-reflection regime. The particle production angle was 24°. The intensity of the primary beam was varied from 10^7 to 10^8 nuclei/cycle. The thicknesses of the carbon and lead targets were 8 g and 12 g, respectively. For monitoring we used

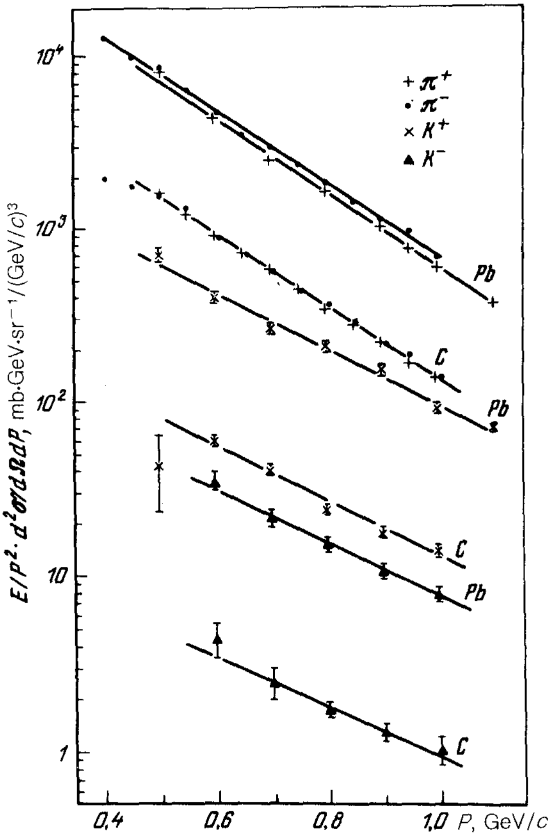

FIG. 1. Behavior of the Lorentz-invariant cross sections for meson production in collisions of carbon nuclei with an energy of 3.65 GeV/nucleon with nuclei as functions of the meson momentum in the laboratory coordinate system. The curves are labeled with the type of meson and the target material. The production angle is 24°. The curves are drawn through the experimental points.

a device calibrated at a reduced intensity. The absolute error of the measurements of the intensity of the primary flux of the nuclei was 15–20%. In calculating absolute cross sections we made corrections for the decay of the mesons over the baseline of 18 m, for scattering in air and in the detector material, and for absorption of the primary and secondary beams in the target. The less than 10% admixture of muons and electrons in the pion peak was ignored.

Figure 1 shows spectra of the invariant cross sections for meson production versus the laboratory momentum. All the spectra are exponential. For pions, the slope parameter is 200 ± 4 MeV/c—the same for the carbon and lead target nuclei, and the same for positive and negative pions. This parameter value also agrees with the corresponding value for measurements[2] in a beam of deuterons with an energy of 3.65 GeV/nucleon. The slopes of the $K^{\pm}$ spectra are the same for the different target nuclei, within the errors. The average slope parameter is 270 ± 10 MeV/c. The reason why the slope parameter is larger for the K^+ spectra than for the pion spectra may be the small value of the cross section for the interaction of K^+ mesons with nucleons and thus the greater sensitivity of the shape of their spectra to the early stage of the collision.[5] The agreement of the slopes of the K^+ and K^- spectra can be explained,

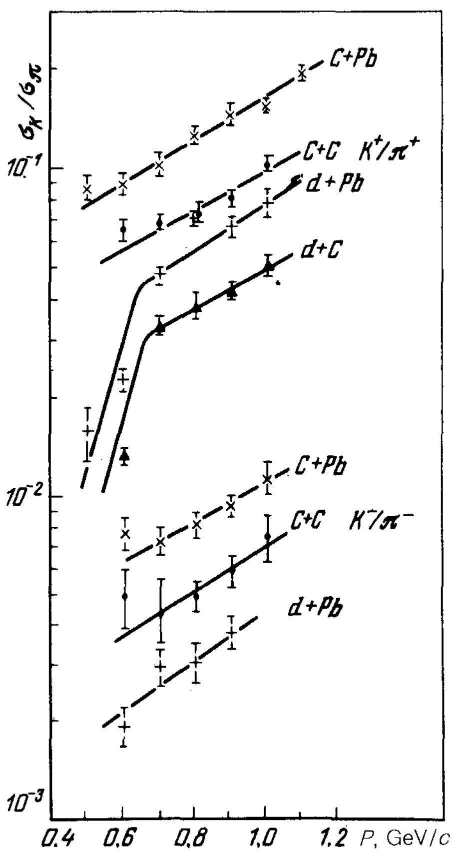

FIG. 2. Ratios of the cross sections for the production of K^+/π^+ and K^-/π^- mesons versus the meson momentum in the laboratory coordinate system. The curves are labeled with the combination of colliding nuclei; the curves are drawn through the experimental points.

despite the large cross section for the interaction of K^- mesons with nucleons, on the basis of a suppression of multiple scattering by the strong absorption of K^- mesons. The result that the shapes of the pion and kaon spectra are independent of the mass of the target nucleus over the meson momentum interval studied is apparently evidence that the meson production mechanism is determined by the general properties of the nuclear medium, not by the individual features of the colliding nuclei.

Effects of meson absorption in the nuclear medium can be traced clearly by examining the ratios of the yields of the various mesons. Figure 2 shows curves of the ratio of invariant K^+/π^+ and K^-/π^- cross sections for the reactions C + C, C + Pb and also d + C, d + Pb. The observed behavior of the ratios as functions of the target mass number can be linked with differences in the extent to which the mesons which are produced are absorbed as they move from the production point to the place where they escape from the nucleus. We know that K^+ mesons are the particles which have the highest penetrating ability in nuclear matter; K^- mesons and pions are absorbed more strongly. The observed cross section σ can be expressed in terms of the cross section in the absence of absorption (σ_0), the absorption length λ, and the effective path length in the nuclear matter, L:

$$\sigma = \sigma_0 \exp(-L/\lambda), \qquad (1)$$

where $\lambda = (\rho\sigma_{hN}^{abs})^{-1}$, σ_{hN}^{abs} is the cross section for the absorption of mesons by nucleons, and $\rho = 0.17\ \mathrm{fm}^{-3}$ is the nuclear density. As was shown by Rundrup,[6] the effective path length of a meson in a nucleus is described approximately by $L = 0.7(R_A + R_B)$, where R_A and R_B are the radii of the colliding nuclei, and $R = 1.15A^{1/3}$ fm. Since we are concerned with the passage of a meson through a nuclear system formed in a collision, these estimates of the absorption cross section should be made at the energy of the meson in the c.m. frame of the colliding nuclei. Since this energy is smaller for kaons in collisions with carbon nuclei, and since the cross section of K^-N absorption is larger, there is essentially no A dependence of the ratio K^-/K^+, and there is essentially no increase in the ratio K^-/π^- at large A.

We took the cross sections for the absorptions of kaons by nucleons from the review by Dover and Walker.[7] We took the reactions $K^-N \to \pi Y$ into account, and we took an average over the protons and neutrons in the nucleus. At the energies under consideration here, the absorption of K^+ mesons can be ignored.

The pion absorption length $\lambda = 5$ fm was found from the relation for the cross section for the absorption of pions by nuclei:

$$\sigma_{\pi N}^{abs} = \pi R^2 [1 - \exp(-d/\lambda)], \qquad (2)$$

where $d = (4/3)R$ is the average path traversed by the pions which are incident on the nucleus which corresponds to the best fit of the experimental data for aluminum, copper, and gold at energies of 180–280 MeV (Ref. 8). Since we have no data for higher energies, we used the value given above for the absorption length; our reasoning is that the mean free path of pions varies slowly at energies above the Δ resonance according to the calculations of Ref. 9. After correcting for the absorption, we find that the ratios of the kaon and pion production cross sections are independent, within the measurement error, of the mass number of the target nucleus for a given projectile nucleus. We might also note that the approach taken here leads to a good description of the change in the ratios of the multiplicity of π^- mesons to the number of protons involved in the collision (π^-/Z) for Ne + NaF and Ne + Pb at 2.1 GeV/nucleon in Ref. 10 and also K^+/π^+ and K^-/π^- for p + Be and p + Cu at 12.3 GeV/c (Ref. 11).

Absorption effects thus explain the difference between the behavior of the cross sections for the production of $\pi^\pm$ mesons and that of the cross sections for the production of $K^\pm$ mesons as functions of the mass of the target nucleus. In the parametrization $\sigma \sim A^\alpha$, where A is the mass number of the target nucleus, the values of the parameter α for d and C beams are the same: 0.56 ± 0.01 for $\pi^\pm$ and 0.71 ± 0.01 for $K^\pm$. After we allow for the absorption of mesons in the nuclei, we find a common value (for pions and kaons) for the parameter in the functional dependence $\sigma_0 \sim A^{\alpha_0}$: $\alpha_0 = 0.7 \pm 0.02$.

It is interesting to note the dependence of the meson production cross sections on the mass of the impinging nucleus: $\sigma \sim B^\beta$, where B is the mass number of the projectile nucleus. Regardless of the mass of the target nucleus, the value of the parameter β is 0.69 ± 0.02 for the $\pi^\pm$ mesons and 1.1 ± 0.1, ranging up to 1.5 at small momenta, for the $K^\pm$ mesons. In other words, it can be seen from Fig. 2 that as we switch from a beam of deuterons to a beam of carbon nuclei, the $K^\pm$ production cross section increases considerably more rapidly, by a factor of more than two, than the cross section for the production of pions at the same target nuclei. A comparison with scaling of the average numbers of nucleons in the d, a, and C projectile nuclei which have interacted, on the basis of Ref. 12, yields $\beta = 0.77 \pm 0.01$. The apparent reason for the smaller value of β for the pion is their absorption in nuclei. There are several possible reasons why the differential cross sections for the $K^\pm$ mesons increase more rapidly than $B - 1$. An increase in the density in the interaction region may give rise to effects of a production of $K^\pm$ at clusters in the impinging nucleus or through a cascading through intermediate π, N, and Δ. Furthermore, the reactions $\pi^- + Y \rightarrow K^- + N$ may be important in the production of K^- mesons.

In summary, this experiment has revealed an increase in the cross section for the production of strange particles, specifically $K^\pm$ mesons, in comparison with that for pions, measured in a common experiment, as we go from accelerated relativistic deuterons to carbon nuclei. Whether the observed effect is a consequence of quark effects or a consequence of an increase in the role played by cluster effects and secondary effects with increasing density of the nuclear matter in the compression zone should be revealed by new and more comprehensive measurements and by an analysis of additional mechanisms for kaon production.

[1]R. Stock, Phys. Rep. **135**, 261 (1986).

[2]Yu. K. Gavrilov *et al.*, in: Proceedings of the Seventh International Seminar on Problems of High-Energy Physics (in Russian), OIYaI, Dubna, 1984, D1, 2-84-599, p. 227.

[3]S. L. Golubev and A. B. Kurepin, in: Proceedings of a Conference on Research in the Field of Relativistic Nuclear Physics (in Russian), JINR, Dubna, 1982, D2-82-568, p. 67.

[4]Yu. K. Gavrilov *et al.*, Preprint P-0359, Institute of Nuclear Research, Academy of Sciences of the USSR, Moscow, 1984.

[5]S. Nagamiya, Phys. Rev. Lett. **49**, 1383 (1982).

[6]J. Rundrup, Phys. Lett. **B99**, 9 (1981).
[7]C. B. Dover and G. E. Walker, Phys. Rep. **89**, 1 (1982).
[8]K. Nakai *et al.*, Phys. Rev. Lett. **44**, 1446 (1980).
[9]M. M. Nesterov and N. A. Tarasov, Yad. Fiz. **37**, 308 (1983) [Sov. J. Nucl. Phys. **37**, 184 (1983)].
[10]S. Nagamiya *et al.*, Phys. Rev. **C24**, 971 (1981).
[11]G. J. Marmer *et al.*, Phys. Rev. **179**, 1294 (1969).
[12]N. Angelov *et al.*, Preprint R1-80-473, Joint Institute for Nuclear Research, 1980.

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