Production of soft pions in hA interactions

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The yields and the transverse dimensions of the region of generation of soft (30- to 60-MeV) π^+ mesons, which are produced in C and Pb nuclei as a result of bombardment with 7.5-GeV/c protons and 5-GeV/c π^- mesons, have been measured. The inclusive characteristics of these mesons are the same as those of hard pions. The transverse dimension of the generation region is $r_\perp^{\rm C} = 0.8 \pm 0.4$ fm and $r_\perp^{\rm Pb} = 2.3 \pm 0.2$ fm, in agreement with the model for a systematic knocking out of particles from the region adjacent to the path of a fast primary particle in the nucleus.

Study of the processes involving the production of soft pions is of interest primarily because of the search for collective pion degrees of freedom in nuclei. It is possible that they manifest themselves in a deep subthreshold pion production,[1] in the production of "evaporative" pions with a temperature of 3.5 MeV in AA interactions,[2] and in the irregular features[3] of the pion spectra at energies of 20 MeV to 100 MeV. There are virtually no published data on the inclusive production of soft pions in nuclear reac-

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tions at high energies and there are no data on the size and shape of the region in which they are generated.

The identical-particle effects[4] were used to measure the size and to determine the shape of the region in which the pions are produced. The use of soft pions has the following characteristic features: (a) The energy of these pions lies below the πN resonance production threshold and hence the nucleus is transparent to them; i.e., there is no distortion of information on the size and shape of the production region; (b) the interference effect may be substantial at any angle of emission of a pion pair.

The experimental setup is shown in Fig. 1.[5] The particle beam was focused on a target A and was monitored by scintillation counters S_1, S_2, and S_3. The counter S_3 defined the working range of the target.

The BAS procedure[6] was ued to record the secondary charged particles emitted from the target. This procedure involved a time-of-flight measurement of the particles moving from the target to a thick (20 cm) scintillator (1-m path length) and the measurement of the energy released in this scintillator. The BAS method was supplemented by an arrangement in which the π^+ mesons stopped in the thick scintillator were identified by recording the delayed (the delay time ranged from 5 μs to 20 μs) signal from the $\mu^+ \to e^+ \nu\tilde{\nu}$ decay. The π^- mesons stopped in the scintillator were captured by a carbon nucleus before they had time to decay into μ^- and ν. The π^+ mesons were detected with an efficiency[7] of $67 \pm 3\%$.

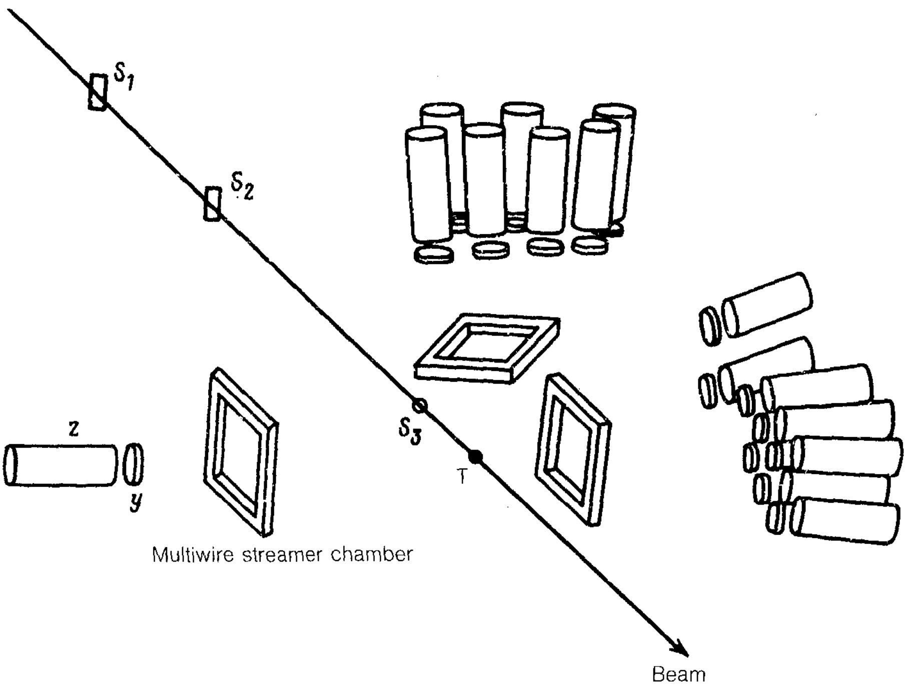

FIG. 1. Experimental arrangement.

Table I

Primary particle, momentum	Target	Invariant cross section, $mb \cdot GeV^{-2} \cdot s^3 \cdot sr^{-1} \cdot nucl^{-1}$
p	Pb	13.0 ± 0.1 ± 2.6
7.5 GeV/c	C	15.0 ± 0.1 ± 2.9
π^-	Pb	11.9 ± 0.1 ± 2.4
5 GeV/c	C	10.4 ± 0.2 ± 2.0

The system consisted of 16 identical BAS channels positioned at angles close to 90° with respect to the direction of the incident particle. We used multiwire streamer chambers to refine the direction of the particles emitted from the target. Such an experimental arrangement enabled us to effectively measure the transverse dimension of the pion generation region.

The values of the invariant cross section $f = Ed\sigma/d^3p$ for the production of π^+ mesons are given in Table I. The first error is a statistical error and the second error is a systematic error which is associated with the measurement accuracy of the secondary-particle energy.

The value of the invariant cross section f for the reaction $p(7.5\ \mathrm{GeV}/c) + \mathrm{Pb} \to \pi^+(90°) + X$ coincides with the extrapolation by the dependence $f = c\exp(-T/T_0)$ of the data, obtained in the case of similar initial conditions in Ref. 8, for pion energies of 0.3–1.3 GeV.

The angular dependence of the yield of π^+ in the angular range measured by us (from 75° to 125°) is in agreement with the dependence obtained previously for the yield of cumulative particles $f = c\exp(-T(1-\beta\cos\theta)/T_0)$, where $T = 89$ MeV, and the parameter β is set equal to 0.62 on the basis of the data[8] on the pion emission at angles of 90° and 168° (see Ref. 5 for a detailed discussion).

The value of α in the approximation A of the dependence of the cross section for the reaction $hA \to \pi X$, $f = cA^\alpha$, is in good agreement with the published data for high-energy secondary pions.[8,9]

In the range under study the value of α does not depend, within the error margin, on the emission angle of π^+, as is also the case for higher-energy secondary pions.[10]

The inclusive data presented above thus imply that there is no distinction between the mechanism for soft pion production and that for hard pion production.

We considered two hypotheses before carrying out the experiment: (a) If the collective effects are appreciable in the production of soft pions, then the transverse dimension of the pion generation region is large, on the order of the nuclear dimen-

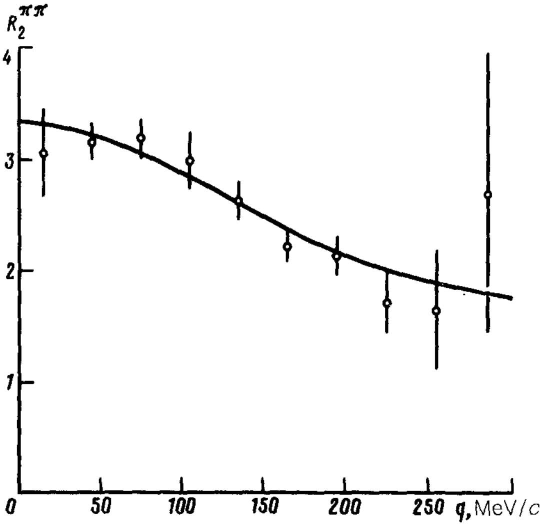

FIG. 2. The correlation function of two π^+ mesons, $R^2_{\pi\pi}$ vs the difference in the transverse components of their momenta ($q_\perp$).

sion; (b) in accordance with the scenario describing the hadron-nucleus reactions at high energies,[11] the transverse dimension of this region is nearly the same as that of the nucleon.

Figure 2 shows the correlation function $R_2^{\pi\pi}$ for two π^+ mesons, plotted as a function of the difference in the transverse components of their momenta. We define $R_2^{\pi\pi}$ as the ratio of the probability for the detection of two π^+ mesons by a pair of channels to the probability for their independent detection by the same channels. This method of defining $R_2^{\pi\pi}$ reduces the π^+ detection efficiency in individuals channels.

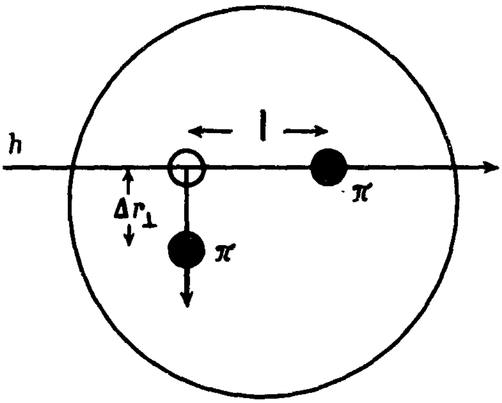

FIG. 3. Spatial description of the production of secondary particles.

The solid curve in the figure shows the result of an approximation using a standard dependence $R_2 = a(1+\exp(-q_\perp^2 r_\perp^2/4))$, with $r_\perp = 2.18$ fm. Since there is no discrepancy, within error limits, in the results obtained for two types of incident particles, we present the results averaged over the initial particle: $r_\perp^C = 0.79 \pm 0.38$ fm and $r_\perp^{Pb} = 2.26 \pm 0.22$ fm.

The transverse dimensions which we have measured are smaller than those obtained in Refs. 12 and 13 under the assumption that the pion source is spherically symmetric. This assumption is consistent with the scenario describing deep inelastic nuclear reactions, according to which the primary fast particle passes through the nucleus without changing its direction appreciably, gradually knocking out the secondary particles from the region adjacent to its path.

The fact that $r_\perp^{Pb}$ is larger than $r_\perp^C$ can easily be explained (see Fig. 3) if we take into account that the first particle has moved by the time the second particle is displaced a certain distance $\Delta r_\perp$, which is greater in the case of a Pb nucleus. In an approximation of a spherical nucleus in the case of a uniform emission of secondary pions along the trajectory of a primary particle we have $\Delta r_\perp^{Pb} - \Delta r_\perp^C = \beta_\pi(\bar{l}_{Pb} - \bar{l}_C) \approx (4/9)\beta_\pi(r_0^{Pb} - r_0^C) = 0.9$ fm, in good agreement with the measured difference in the values of $r_\perp^{Pb}$ and $r_\perp^C$.

The inclusive data and correlation data which have been obtained show that the mechanism for the production of soft pions is the same as that for the production of more-energetic particles in deep inelastic nuclear reactions.

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