Observation of slow-pion production in nucleus-nucleus interactions

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The production of slow $\pi^{\pm}$ mesons in nucleus-nucleus interactions has been observed in a nuclear emulsion. The spectrum has the typical evaporation shape, with a temperature $T = 3.5 \pm 0.4$ MeV and a threshold $V = 0.2 \pm 0.3$ MeV, at pion energies up to 13 MeV. Most of the pion production occurs in central collisions.

The most thorough study of the production of slow pions in hadron-nucleus interactions in emulsions was carried out in Refs. 1, where the energy spectra of the $\pi^{\pm}$ mesons and the relative frequencies of their emission from nuclei were reported, and the results of the measurements were analyzed theoretically. Those experiments yielded information on the nuclear interaction of slow pions with energies close to the Coulomb potentials of the parent nuclei. A procedure for detecting soft $\pi^{\pm}$ mesons with a magnet-free hadron spectrometer was described in Ref. 2.

1. We have observed the production of slow pions in an interaction with emulsion nuclei of neon and magnesium ions accelerated to an energy of 4.1 GeV/nucleon at the accelerator of the Joint Institute for Nuclear Research. A scan along the track of the projectile nucleus revealed 1128 interactions (stars) formed by the accelerated neon and magnesium ions. All of the black and black-gray tracks which appeared in the stars were traced a distance up to 3 mm from the interaction point. Stoppings of the $\pi^{\pm}$ mesons were detected on the basis of the characteristic configuration of the decay $\pi^{+} \to \mu^{+} \to e^{+}$; the stoppings of π^{-} mesons were detected on the basis of the σ_{π^-} stars formed in the capture of stopped π^{-} mesons by a nucleus. We considered only those captures of π^{-} mesons by nuclei which led to the emission of charged particles. The multiplicity spectrum of the particles from the σ_{π^-} stars is known; the fraction of stoppings of π^{-} mesons which form zero-prong stars is[3] $26.8 \pm 1.0\%$. The charged-particle multiplicity which we found for the charged particles produced in the capture of π^{-} mesons by emulsion nuclei agrees well with existing data.[3,4] We can thus reliably introduce a correction for zero-prong σ_{π} stars. The actual range of $\pi^{\pm}$ mesons before stopping was found as the sum of the lengths of the segments of the broken line which constitutes the path traced out by the $\pi^{\pm}$ meson from the point at which it is emitted from a star to the point at which it stops. The pion energy was calculated from tabulated range-energy values.[5]

2. We detected 89 slow pions with energies up to 13 MeV: 12 π^{+} mesons and 77 π^{-} mesons. After correcting for the zero-prong stars, we found 110 slow pions among the 1128 nucleus-nucleus interactions. For each pion we measured, in addition to its kinetic energy, the angle (θ) at which it was emitted from the star, reckoned from the

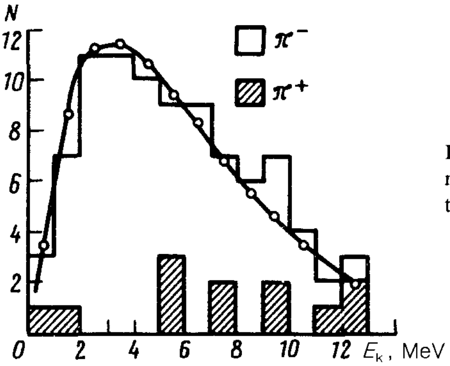

FIG. 1. Energy spectrum of the pions produced in nucleus-nucleus interactions. The solid line is the result of a calculation from the evaporation model.[6]

direction of the incoming projectile nucleus. The average rapidity calculated from these measurements is $\langle y\rangle = 0.035$, and the angular distribution has a front-back asymmetry $N_f/N_b = 1.6 \pm 0.4$. The average longitudinal velocity found from the rapidity can be used to transform to the center-of-mass system. The distribution in $\cos\theta$ then becomes essentially isotropic. The pion energy spectrum in this system differs insignificantly from that in the laboratory system (because of the small average translation velocity); this spectrum is shown in Fig. 1. The solid line here corresponds to the evaporation spectrum[6]

$$dN \approx \frac{E_k - V}{T^2} \exp\left(-\frac{E_k - V}{T}\right) dE_k\,,$$

where E_k is the kinetic energy of the pion, T is the excitation temperature of the system, and V is the potential barrier. A fit using the two parameters T and V yields best values $T = 3.5 \pm 0.4$ MeV and $V = 0.2 \pm 0.3$ MeV. The soft-pion energy spectrum observed here thus has the characteristic Maxwellian (evaporation) distribution. The temperature T is characteristic of evaporation processes which are observed in the interaction of hadrons with emulsion nuclei (Ref. 7, for example). The ratio of the numbers of slow negative and slow positive pions is $R = 8.2 \pm 2.4$, in agreement with the corresponding ratio in hadron-nucleus interactions. If the experimental spectrum is put in the form $f \sim \frac{E}{p}\frac{dN}{dE_k} \sim \exp(-E_k/T_0)$, the slope parameter turns out to be T_0

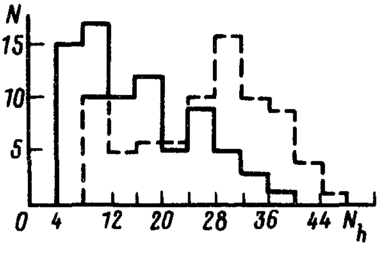

FIG. 2. Multiplicity spectrum of the h particles which appeared in nucleus-nucleus interactions. Dashed histogram—Sample of events with slow pions; solid histogram—events without slow pions.

= 5.0 ± 1.0 MeV over the energy range up to 13 MeV. We established that most of the slow ions are produced in central interactions, in which a nucleus is destroyed (breaks up). For this purpose we measured the multiplicity spectrum of the *h* particles (black and gray tracks); the result is shown in Fig. 2. Events with observable slow pions are shown by the dashed histogram; events without such pions are shown by the solid histogram. The dashed histogram, which corresponds to events including slow pions, is seen to be shifted up the multiplicity scale.

We do not have an explanation for the appearance of "evaporation" pions in nucleus-nucleus interactions, but there is the possibility that part of the reason the spectrum has this Maxwellian shape is an influence of the Coulomb field of the moving nucleus on the kinetic energy of the slow pions which have been emitted.

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