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Spectra of $\pi^{\pm}$ mesons in an inclusive reaction $\gamma C \rightarrow \pi X$ induced by bremsstrahlung γ quanta with a maximum energy of 4.5 GeV

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The heretofore unavailable experimental energy and angular distributions of the inclusive-photopion yields over a broad range of energies and angles of secondary π mesons are presented.

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In our preceding work,[1-4] we investigated many aspects of the inclusive photoproduction of protons by different nuclei irradiated by high-energy, bremsstrahlung, γ quanta with an energy up to 4.5 GeV, which showed that the main systematic features of the cumulative effect[5,6] and of the nuclear scaling[7,8] in the interaction of electromagnetic radiation with the nuclei are correct.

The photoproduction of inclusive π mesons by nuclei, especially at high energies of primary γ quanta and at large angles of secondary π mesons, has not been sufficiently investigated.

In particular, the photoproduction of cumulative π mesons, i.e., π mesons whose production by free nucleons is kinematically forbidden, to our best knowledge, has not been investigated.

We present here the spectra of $\pi^{\pm}$ mesons produced by C^{12} nuclei at a 20°–120° angle, which were irradiated by bremsstrahlung quanta with a maximum energy of 4.5 GeV.

2. We investigated the reaction

$$\gamma + C^{12} \rightarrow \pi^{\pm} + X, \tag{1}$$

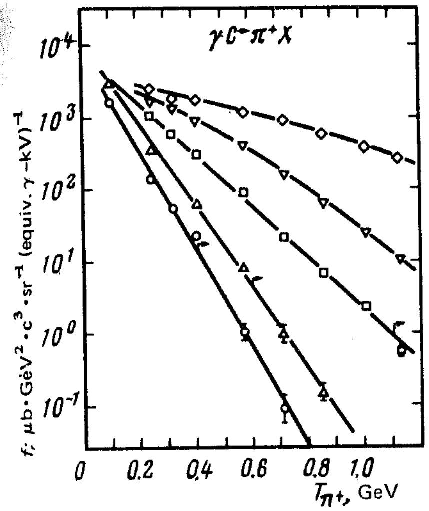

FIG. 1. Energy spectra of π^+ mesons. The experimental points are as follows: ◇, the π-meson angle $\theta_\pi = 20°$; ▽, 40°; □, 60°; △, 90°; and ○, 120°.

where X is a residual system. According to the kinematics, the π-meson spectra belong both to the cumulative and noncumulative regions.

The measurements were performed using the "Deuteron" apparatus that was placed in the beam of the G-3 Erevan Electron Synchrotron. This apparatus was described in detail in Ref. 9.

The π mesons were identified[9] by a magnetic spectrometer using the time-of-flight method.

This spectrometer made it possible to measure the particle momentum in the range $p = 0.18-1.4$ GeV/c with a relative error $\Delta p/p = \pm 6.5\%$ (at $p \geqslant 1$GeV/c) and the

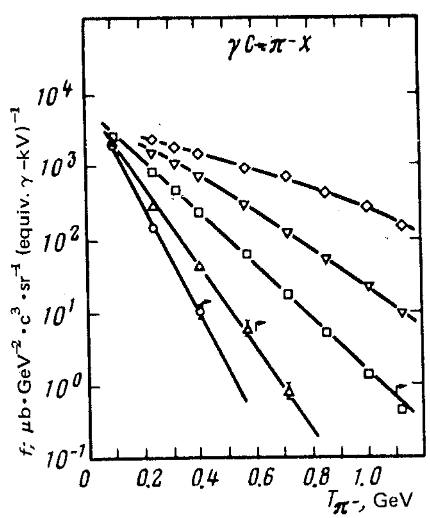

FIG. 2. The same as in Fig. 1 for π^- mesons. The symbols are the same as in Fig. 1.

TABLE I Values of $T_0 \pm \Delta T_0$ (MeV)

	π^+ mesons	π^- mesons
60°	124 ± 2	121 ± 2
90°	76.2 ± 2.6	78.3 ± 1.5
120°	65.1 ± 3.1	57.1 ± 1.8

particle velocity in the range $0.4 \leqslant \beta \leqslant 1$ sec with a spread $\Delta\beta/\beta \leqslant 5\%$. The solid angle of the spectrometer, which was calculated by using the Monte Carlo method, was $\Delta\Omega = 1.26$ msr (at $\Delta p/p = \pm 6.5\%$).

The invariant cross section was determined from the measured yields of the reaction (1).

$$f = E\frac{d^3\sigma}{d^3p\,Q} = \frac{E}{p^2}\,C\,\frac{N_\pi}{\Delta\Omega\,(\Delta p/p)\,p\,N_n Q}, \qquad (2)$$

where N_π is the measured yield of the reaction (1), E and P are the total energy and momentum of recorded π mesons, N_n is the number of nuclei on the γ-quanta path, and C takes into account the corrections due to nuclear absorption and multiple scattering in the detector and target and paraproduction in the target due to in-flight decay and finite efficiency of particle recording.

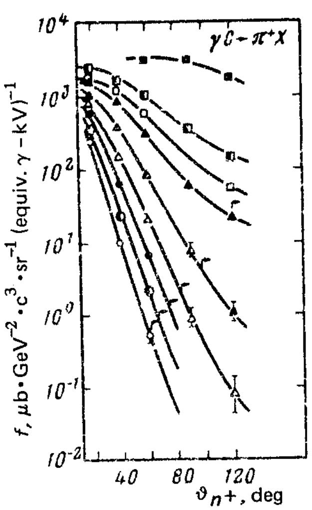

FIG. 3. Angular dependences for π^+ mesons. The experimental points are as follows: ■, (for the kinetic energy of π mesons) $T_\pi = 0.094$ GeV; ■, 0.239 GeV; □, 0.318 GeV; ▲, 0.399 GeV; ▲, 0.567 GeV; △, 0.712 GeV; ●, 0.851 GeV; ●, 1.00 GeV; ○, 1.12 GeV.

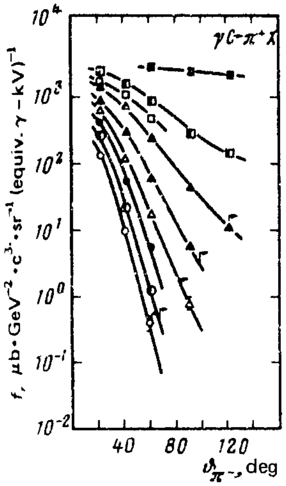

FIG. 4. The same as in Fig. 3 for π^- mesons.

Figure 1 shows the energy spectra of positively charged π mesons. Only statistical errors are shown. The estimates show that the systematic errors do not exceed 20%. The lines were drawn through the experimental points for $\theta_\pi = 60°, 90°$, and 120° by using the least-squares method and they were drawn approximately for $\theta_\pi = 20°$, and 40°. The errors indicate the beginning of the cumulative region.

As we can see, the spectra for $\theta_\pi \geqslant 60°$ and $T_\pi \leqslant 1.1$ GeV are well described by a single exponential curve. At $\theta_\pi \leqslant 40°$ we can see a deviation from the exponential curve (the spectrum drops off more sharply at high energies).

Figure 2 shows analogous data for π^- mesons. As we can see, the spectrum of negatively charged π mesons is identical to that of positively charged mesons.

The invariant cross section for $\delta_\pi \geqslant 60°$ can be represented as follows:

$$f = C\exp(-T/T_0), \qquad (3)$$

where C and T_0 are constants and T is the kinetic energy of π mesons.

Table I gives the values of T_0 determined for different angles from the experimental points by using the least-squares method. As we can see, T_0 decreases with increasing angle and at $\theta_\pi = 120°$ reaches a value $T_0 = 65$ MeV, which is in good agreement with the value $T_0 = 60$–65 MeV determined in analogous processes induced by hadrons.[5,6]

We must emphasize an important fact: the spectra show no singularities when we go from a noncumulative region to a cumulative region. The spectra behaves similarly in the case of photoproduction of protons by nuclei.[1-4]

4. Figures 3 and 4 show angular dependences of π^+ and π^- mesons, respectively.

As we can see, these dependences have a strongly forward direction that increases with increasing energy.

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Deep, inelastic, Compton scattering as a test of the model with integral-charge quarks

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The conditions under which the parton model can be used for the $\gamma N \to \gamma X$ process are investigated. The most suitable characteristic for testing the model with a broken color symmetry are determined. The available experimental data for deep, inelastic, Compton scattering of photons by a proton are analyzed in the context of the unified model with integral-charge quarks.

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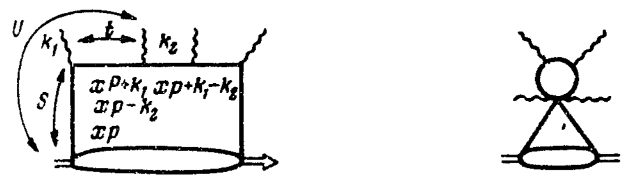
In spite of the fact that the hard processes have recently been intensively investigated theoretically and experimentally, the question whether the color $SU_c(3)$ symmetry is intact or broken has not been answered, and hence the true electric charge of a quark has not been determined unambiguously. Investigations performed within the framework of unified models[1,2] indicate that the data for deep inelastic scattering of leptons and e^+e^- annihilation into hadrons do not favor any one of the existing theories. The measurements of lepton-lepton cross sections and of the anomalous magnetic moment of a muon impose severe constraints on the parameters of the model. The inequality

$$\frac{4\alpha(|q^2| \ll \mu^2)}{3\alpha_s(|q^2| \ll \mu^2)} \leqslant 10^{-4}$$

(α is an invariant singlet charge and α_s is an invariant octet charge) must be satisfied. It was shown[3] that these constraints are satisfied if the current gluon masses are $\mu \lesssim 0.3$ GeV. Investigation of deep inelastic reactions with the participation of real γ quanta is the most promising way of determining the electromagnetic properties of quarks. The processes $\gamma N \to \mu^+\mu^- X$, $\gamma\gamma^* \to$jets, $ep \to e\gamma X$, and $e^+e^- \to \gamma +$jets have been analyzed by many authors.[4–9] Since all the mentioned reactions contain only one real photon, the true charge of a quark, as indicated by Witten,[4] can be determined by a rather imprecise measurement.

We shall formulate in this paper the condition under which the parton model for the $\gamma N \to \gamma X$ reaction can be used, determine whether the experimental data[10] can be explained in the context of QCD and the unified model with integral-charge quarks,[2] and determine the most suitable characteristics for testing the alternative quark models.

To determine the kinematic region of the parton subprocess, we analyze the diagram in Fig. 1(a)



a b

FIG. 1.

where U, t, and S are Mandel'stam variables. The necessary conditions for identifying the parton subprocess in inelastic Compton scattering are

1. $xS \gg m_N^2$ 2. $x(1-y) \gg \dfrac{m_N^2}{S}$, $(t \ll m_N^2)$

3. $(1-y)(1-x) \gg \dfrac{m_N^2}{S}$, $(m_x^2 \gg m_N^2)$ 4. $xy \gg \dfrac{m_N^2}{S}$, $(xU \gg m_N^2)$,

where m_x is the invariant mass of the finite state $\gamma = U/S$ and $x = t/s - U$. To isolate the pionization region, which cannot be calculated in terms of the standard perturbation theory and is described by diagrams such as those in Fig. 1b, we must analyze the jet processes with large $k_\perp$; hence, we obtain the condition

$$5.\ x = \frac{E_1 y}{m_N(1-y)}\left[1-\left(1-\frac{k_\perp^2}{E_1^2 y^2}\right)^{1/2}\right];\quad x \approx \frac{k_\perp^2}{2m_N(1-y)yE_1};$$

$$\left(\frac{k_\perp^2}{E_1^2 y^2} \ll 1\right).$$

