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STUDY OF THE INVARIANT CROSS SECTION FOR INCLUSIVE REACTION $\pi^- p \to \gamma + ...$ AT 5 GeV/c

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STUDY OF THE INVARIANT CROSS SECTION FOR INCLUSIVE REACTION $\pi^- p \to \gamma + \ldots$ AT 5 GeV/c

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БИБЛИОТЕКА

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Исследование инвариантной структурной функции реакции $\pi^- p \to \gamma + ...$ при 5 ГэВ/с

Измерено инвариантное дифференциальное сечение $f(x, p_\perp)$ реакции $\pi^- p \to \gamma + ...$ при 5 ГэВ/с в широкой области x и $p_\perp$. Найдена аппроксимирующая формула для $f(x, p_\perp)$. Показано, что функция $f(x, p_\perp)$ не факторизуется по переменным x и $p_\perp$. В некоторых областях фазового пространства наблюдается масштабно-инвариантное (скейлинговое) поведение дифференциального сечения. Анализ асимметрии спектра продольных импульсов γ-квантов свидетельствует о подобии механизмов образования нейтральных и заряженных пионов в центральной области. Результаты анализа качественно согласуются с предсказанием кварковой модели адронов.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

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Study of the Invariant Cross Section for Inclusive Reaction $\pi^- p \to \gamma + ...$ at 5 GeV/c

The invariant differential cross section $f(x, p_\perp)$ of the reaction $\pi^- p \to \gamma + ...$ at 5 GeV/c is measured in a large range of x and $p_\perp$. An approximating formula is found for $f(x, p_\perp)$. The function $f(x, p_\perp)$ is shown to be not factorized with respect to x and $p_\perp$. In some regions of the phase space the scale-invariant behaviour is observed for the differential cross section. The analysis of asymmetry of the longitudinal momentum spectrum of γ-quanta indicates similarity of the production mechanisms of neutral and charged pions in the central region. The results are in qualitative agreement with predictions of the quark model of hadrons.

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1. In the present paper we report the results of measurement of the invariant differential cross section $Ed^3\sigma/d^3p$ for the reaction

$$\pi^- p \to \gamma + ... \qquad (1)$$

at 5 *GeV/c*. A simple formula is obtained which describes the experimental data in the region $-0.7 \le x \le 1.0$ and $0.0 \le p_\perp \le 0.8$ *GeV/c*. Here $x = p_L^*/p_m^*$, p_L^* and $p_\perp$ are the longitudinal and transversal components of the momentum in c.m.s., resp., p_m^* is the maximum value of p_L^*. The problem of scale-invariant behaviour is studied for the differential cross section in different regions of the phase space. The asymmetry of the longitudinal momentum spectrum is analysed for the forward $(x>0)$ and backward $(x<0)$ hemispheres. Results are compared with predictions of the quark model of hadrons.

The measurement of the cross section $Ed^3\sigma/d^3p$ as a function of x and $p_\perp$ makes it possible, first, to check thoroughly the hypotheses of scaling /1/ and of limiting fragmentation /2/, predictions of which have been formulated just for the differential cross section at fixed points (regions) of the phase space. Second, at present the differential cross section of reaction (1) is measured only at energies 18.5 /3/, 40 /4, 5/, 100 /6/ and 205 /7/ *GeV*. The distribution of the type $E^* dN/dx dp_\perp$ has been analysed only at 40 *GeV* (collaboration of the two-meter propane bubble chamber of the JINR). In this situation the analytical description of the cross section as a function of x and $p_\perp$ is of the independent interest. Third, the obtained approximating function allows the comprehensive information to be suitably given for reaction (1) at 5 *GeV/c*.

Table 1

$\langle p \rangle_\gamma^{lab.}$ GeV/c	$\langle p_L \rangle_\gamma^{lab.}$ GeV/c	$\langle p \rangle_\gamma^{c.m.s.}$ GeV/c	$\langle p_L \rangle_\gamma^{c.m.s.}$ GeV/c	$\langle p_\perp \rangle_\gamma$ GeV/c	$\langle p_\perp^2 \rangle_\gamma$ $(GeV/c)^2$
0.531	0.476	0.242	0.060	0.172	0.050
0.009	0.003	0.003	0.003	0.002	0.001

2. The system of processing of events with γ-quanta and some inclusive distributions are published in paper /8/. Recall the main characteristics of the experiment. The statistics includes 7940 γ-quanta with average weight 6.21±0.06. The average number of γ-quanta $\langle n_\gamma \rangle$ and the total inclusive cross section $\sigma(\gamma)$ are 2.58±0.07 and 61.4±2.1 *mb*, resp. The average momentum characteristics of γ-quanta are given in *Table 1*.
Following the relations found by G.Kopylov /9/ one can calculate the corresponding characteristics for π^0-mesons

$$\langle p_L \rangle_{\pi^0}^{c.m.s.} = 2\langle p_L \rangle_\gamma^{c.m.s.} = 0.120 \pm 0.006 \ GeV/c,$$

$$\langle p_\perp^2 \rangle_{\pi^0} = 3\langle p_\perp^2 \rangle_\gamma - m_{\pi^0}^2/2 = 0.141 \pm 0.003 \ (GeV/c)^2.$$

Now we proceed to analyse the differential cross section of reaction (1). In terms of the variables x and $p_\perp$ it has the form

$$E d^3\sigma / d^3p = (E^*/\pi p_m^*) d^2\sigma / dx\, dp_\perp^2 = f(x, p_\perp)^{*)}.$$

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*) For simplicity we omit the dependence on s (the c.m. total energy squared).

The experimental data in the integral form

$$(1/\Delta p_\perp^2) \int_{\Delta p_\perp^2} f(x, p_\perp) dp_\perp^2 \qquad (2)$$

for a set of intervals $\Delta p_\perp^2$ are plotted in *Fig. 1*.

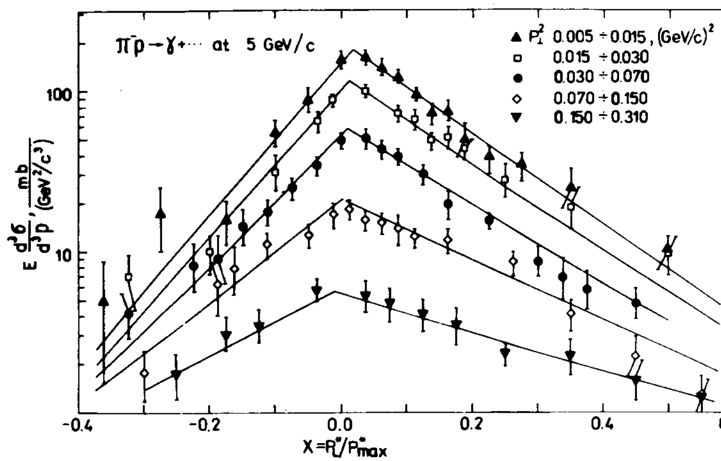

Fig. 1.

In the distribution $f(x, p_\perp)$ certain regularities are observed. At fixed $p_\perp$ the data are consistent with the exponential dependence $A \exp(-B|x|)$, the slope parameter B being smaller in the forward hemisphere $(x > 0)$ that in the backward one $(x < 0)$. With increasing $p_\perp$ the parameter B decreases. Keeping in mind the above characteristics of $f(x, p_\perp)$ and requiring B to be positive *) at any $p_\perp$, the approximating function can be represented as follows

---

*) The positiveness of B ensures the continuous decrease of $f(x, p_\perp)$ with aproaching of x and $p_\perp$ to the kinematical limit.

$$f(x, p_\perp) = a_1 \exp(-B|x| - a_4 p_\perp),$$
$$B = a_2 \exp(-a_3 p_\perp^2), \qquad (3)$$

where a_i are free parameters.

The experimental distributions shown in *Fig. 1* were approximated by the corresponding integrals of function (3) (solid lines in *Fig. 1*). The results of approximation are given in *Table 2*.

Figures 2 and *3* show the experimental distributions

$$F_1(x) = \int f(x, p_\perp)\, dp_\perp^2, \quad F_2(p_\perp^2) = \int f(x, p_\perp)\, dx$$

and the corresponding integrals of function (3). The comparison of the approximating function with the experimental distributions $F_1(x)$ and $F_2(p_\perp^2)$ indicates that function (3) is the adequate image of the invariant differential cross section of reaction (1) at 5 *GeV/c*.

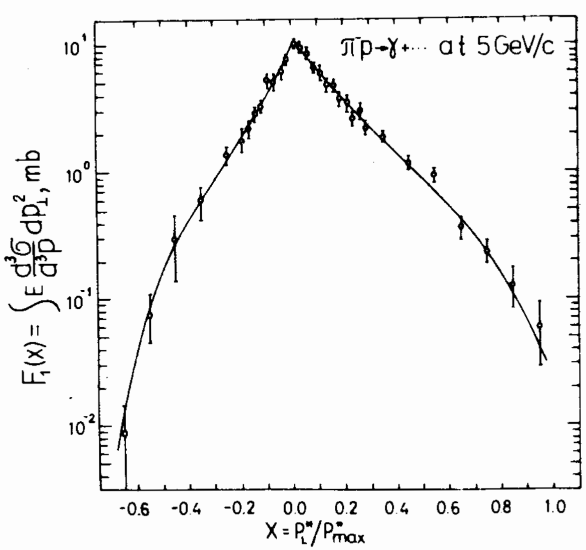

Fig. 2

Table 2

	a_1 (mb GeV^{-2}c^3)	a_2	a_3 (GeV/c)$^{-2}$	a_4 (GeV/c)$^{-1}$
$x < 0$, 36 points, $\chi^2 = 18$	354 ±30	11.60±0.80	4.07±0.87	8.68±0.33
$x > 0$, 57 points, $\chi^2 = 43$	551±38	7.02±0.36	4.46±0.65	9.97±0.27

Table 3

$p_\perp$ (GeV/c) middle of interval	B, $x < 0$		B, $x > 0$	
	5 GeV/c	40 GeV/c	5 GeV/c	40 GeV/c
0.05	11.5±0.80	26.7±4.3	6.94±0.36	19.3±1.2
0.15	10.6±0.76	11.9±2.1	6.35±0.34	11.5±0.9
0.25	9.0±0.80	5.9±1.8	5.30±0.35	6.4±1.0
0.35	7.3±0.90	3.9±2.7	4.06±0.39	3.5±1.4

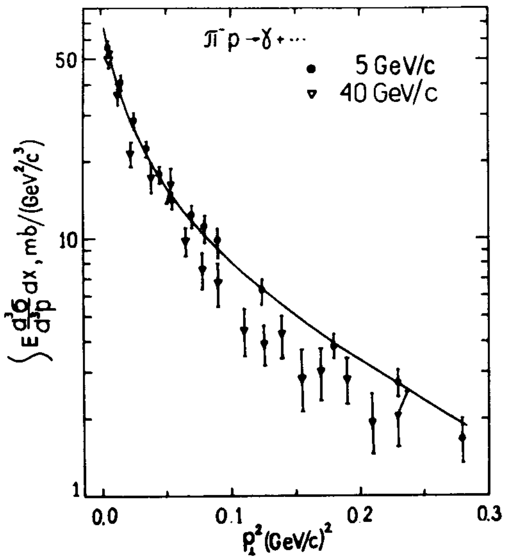

Fig. 3

The slope parameter $B = \partial \ln f(x, p_\perp)/\partial x$ is an important characteristic of the distribution $f(x, p_\perp)$. When B does not depend on $p_\perp$, the function $f(x, p_\perp)$ can be represented in the form $\phi_1(x)\phi_2(p_\perp)$, i.e., it is factorized with respect to x and $p_\perp$.

In the reaction

$$pp \to \gamma + \ldots \qquad (4)$$

at 500 - 1500 *GeV/c* the $p_\perp$ independence is determined for B. However, even at 69 *GeV/c* /11/ in reaction (4) and at 40 *GeV/c* in reaction (1) the factorization is not observed. The same holds for the distribution $f(x, p_\perp)$ at 5 *GeV/c* since in our case $B = a_2 \exp(-a_3 p_\perp^2)$. These facts indicate that with growing energy the mechanism of γ -quanta production becomes more simple.

3. In our previous paper /8/ it has been shown that in reaction (1) at 5 *GeV/c* the distributions of type

$\int (Ed^3\sigma/d^3p)\,dp_\perp^2$ are compatible with the scale-invariant behaviour both in the central region and in both the regions of fragmentation. The measurement of the differential cross section throughout the whole phase space allows one to raise the question about the check of the scaling hypothesis in full correspondence with its formulation, i.e., for fixed $x, p_\perp$. Unfortunately, due to the lack of data on $f(x, p_\perp)$ at higher energies, the direct comparison is impossible. Nevertheless, using the results of measurement for B and $F_2(p_\perp^2)$ at 40 *GeV/c* /4, 5/ certain conclusions can ba made about the energy dependence of $f(x, p_\perp)$. In *Table 3* the slope parameters at 5 and 40 *GeV/c* are presented for some intervals of $p_\perp$.

In both the cases the slope parameters depend on $p_\perp$ and for them there are observed the following relations: $B_{40} > B_5$ for $p_\perp \le 0.15$ *GeV/c*, $B_{40} \approx B_5$ for $p_\perp \approx 0.20$ *GeV/c*, and $B_{40} \lesssim B_5$ for $p_\perp \gtrsim 0.25$ *GeV/c*. On the other hand, the distribution $F_2(p_\perp^2)$ in the range $p_\perp \lesssim 0.25$ *GeV/c* with increasing momentum from 5 till 40 *GeV/c* remains constant within errors (see *Fig.3*). This means that for any fixed $p_\perp$ in the range $p \lesssim 0.25$ *GeV/c* the equality

$$\int A_{40} e^{-B_{40}|x|}dx = \int A_5 e^{-B_5|x|}dx$$

holds. Hence on the basis of the relation between B_{40} and B_5 one can estimate the ratio between A_{40} and A_5. The above presented facts and arguments allow the following conclusions to be made: a) In the range $p_\perp \simeq 0.20$ *GeV/c*, where $B_5 \simeq B_{40}$, the values of $f(x, p_\perp)$ at 40 *GeV/c* and 5 *GeV/c* should coincide for all $|x|$.
b) In the range $p_\perp \le 0.15$ *GeV/c*, where $B_5 < B_{40}$, the functions should intersect at some intermediate values of $|x|$, for $|x| \approx 0$ the value of $f(x, p_\perp)$ being larger at 40 *GeV/c* than at 5 *GeV/c*. This indicates that locally (in some regions of x and $p_\perp$) the differential cross section of reaction (1) at 5 *GeV/c* is in agreement with the scale-invariant behaviour.

4. Now let us analyse the distribution $d\sigma/dp_L^*$. The study of such distributions for charged mesons has resulted in the following experimental facts [12-16]:
a) The spectrum $d\sigma/dp_L^*$ in the central region is of the exponential form $\exp(-B|p_L^*|)$.
b) When the colliding particles are non-identical (πp, Kp, etc.) the distribution $d\sigma/dp_L^*$ is asymmetric about $p_L^* = 0$ (the parameter B is larger for $p_L < 0$ than for $p_L > 0$).
c) In the reference frame moving with definite velocity along the momentum direction of a projectile the symmetry is achieved.

To specify the moving reference frame the parameter $R = -p_T/p_B$ is introduced, where $p_T(p_B)$ is the momentum of the target particle (projectile) in the reference frame under consideration. The parameter R_{SYMM} providing the distribution symmetry depends weakly on energy in the interval 5 - 60 *GeV*. For pp-interactions $R_{SYMM} = 1.0$ and increases with decreasing mass of a projectile. For instance, for Kp-, πp-, γp-interactions the value of R_{SYMM} equals approximately 1.5, 1.75 and 2.0 (or larger), resp. The first evidence for the connection of asymmetry of the secondary pion spectra with the internal structure of hadrons has been obtained in paper [12]. By the naive quark model of hadrons [17] the particle interaction in the first approximation can be treated as the free collision of a quark of the projectile with a quark of the target. The produced pions give the dominant contribution to the central region. In the c.m.s. of colliding quarks, where $R_{SYMM} = 1.5$ (for πp-, Kp-interactions), the distribution $d\sigma/dp_L$ should be symmetric. To interpret more detailed characteristics of the multiparticle production within the quark model, it is necessary, apparently, to take account of interactions due to the quark rescattering [18, 19].

No analysis of the asymmetry of inclusive spectra of γ-quanta has been made so far. Note that both in the published data on spectra $d\sigma/dp_L^*$ (for pp-interactions at 200 [20] and at 300 [21] *GeV/c* and for $\pi^- p$-interactions at 40 *GeV/c* [22]) and in our case one can distinguish the general specific feature. In the central region the slope parameter $B = |\partial \ln(d\sigma/dp_L^*)/\partial p_L^*|$, unlike the case of charged pions, depends on p_L^* decreasing with increasing $|p_L^*|$. This fact, evidently, is a reflection of the kinematics of decay $\pi^\circ \to 2\gamma$. Denoting the distribution $d\sigma/dp_L^*$ in the backward and forward hemispheres by $\phi_B(p_L)$ and $\phi_F(p_L)$, resp., we obtain that the spectrum symmetric about $p_L = 0$ should obey the condition $\phi_B(-p_L) = \phi_F(p_L)$. The sum

$$\chi^2 = \Sigma \frac{(\phi_B(-p_L) - \phi_F(p_L))^2}{(\Delta\phi_B(-p_L))^2 + (\Delta\phi_F(p_L))^2} \quad (5)$$

has the minimal value in the system where $d\sigma/dp_L$ is symmetric.

In our case the symmetrization of spectra was carried out for $|p_L^*| \le 0.380$ ($|x| \le 0.26$). The value of χ^2 for values of $\tilde{R}$ (1.4 - 2.1) was calculated by using both the experimental distributions and the approximating function (3). The analysis of the R-dependence of χ^2 revealed that the minimum position of χ^2 is the same for both the cases and corresponds to $R_{SYMM} = 1.77 \pm 0.18$. This value is consistent with the parameter R_{SYMM} obtained by analysing the charged pion spectra and somewhat exceeds the value following from the quark model ($R_{SYMM} = 1.5$). On the other hand, according to formulae from ref. [9], the symmetric distribution $d\sigma/dp_L$ for γ-quanta is connected with that for π°-mesons. Thus, one observes the coincidence of the reference frames where the longitudinal momentum spectra of π°- and $\pi^\pm$-mesons are symmetric. This fact shows a similarity of the production mechanisms for neutral and charged pions in the central region and is in qualitative agreement with predictions of the quark model of hadrons.

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