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Наблюдение скейлинга в среднем в реакциях $\pi^- p \to \{ {}^{\gamma}_{\pi^0} \} + X$ при 5 ГэВ/с

Неинвариантные распределения продольных ($p_{||}$) и поперечных ($p_{\perp}$) импульсов в реакциях $\pi^- p \to \gamma + X$ и $\pi^- p \to \pi^0 + X$ при 5 ГэВ/с представлены в переменных скейлинга в среднем $\xi = p_{||}/\langle p_{||} \rangle$ и $\eta = p_{\perp}/\langle p_{\perp} \rangle$. Исследуется зависимость формы этих распределений от множественности вторичных заряженных частиц, а также от начальной энергии. На основе сравнения с данными для π^+ - и π^--мезонов при 13-300 ГэВ/с показано, что форма распределений $(1/\sigma)d\sigma/d\xi_{\pi^0}$ и $(1/\sigma)d\sigma/d\eta_{\pi^0}$ не зависит от энергии. С помощью интегральных уравнений, связывающих спектры продольных и поперечных импульсов π^0-мезонов с соответствующими спектрами γ-квантов, показано, что распределения $(1/\sigma)d\sigma/d\xi_{\gamma}$ и $(1/\sigma)d\sigma/d\eta_{\gamma}$ также не зависят от энергии. Анализ этих распределений в событиях заданной топологии показал, что их форма не зависит от множественности вторичных заряженных частиц. Делается вывод о том, что характеристики исследуемых распределений согласуется с предсказаниями гипотезы скейлинга в среднем.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

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Amaglobeli N.S. et al. **E1 - 10776**

The Evidence for Scaling in the Mean in the Reactions $\pi^- p \to \{ {}^{\gamma}_{\pi^0} \} + X$ at 5 GeV/c

The noninvariant distributions of longitudinal and transverse momenta have been studied in the reactions $\pi^- p \to \gamma + X$ and $\pi^- p \to \pi^0 + X$ at 5 GeV/c. It has been shown that in the variables $p_L/\langle p_L \rangle$ and $p_T/\langle p_T \rangle$ the shape of these distributions does not depend upon the initial energy and the multiplicity of secondary charged particles.

The analysis performed shows the extension of the validity region of scaling in the mean both for the energy range (5-300 GeV) and for the type of particles.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

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I. According to the predictions of the scaling in the mean hypothesis[1] one-particle inclusive distributions of longitudinal and transverse momenta in multi-particle production reactions should obey the following relations:

$$\frac{1}{\sigma}\frac{d\sigma}{d\xi} = \phi_L\left(\xi = \frac{p_L}{\langle p_L \rangle}\right), \qquad (1)$$

$$\frac{1}{\sigma}\frac{d\sigma}{d\eta} = \phi_T\left(\eta = \frac{p_T}{\langle p_T \rangle}\right), \qquad (2)$$

where the functions ϕ_L and ϕ_T are independent of the initial energy, the multiplicity of secondary particles, and also the type of colliding particles. Here and below p_L and p_T are longitudinal and transverse components of the momentum in c.m.s.

The check up of relations (1) and (2) in the reactions $pp \to \pi^-$ at 13-300 GeV/c [1], $\pi^- p \to \pi^{\pm}$ at 40 GeV/c [2], $pp \to K^0_s$ and $pp \to \Lambda$ at 19 GeV/c [3] as well as $pp \to \pi^{\pm}$ at 28.5 GeV/c [4] confirmed their validity for the spectra of not leading particles. The

consequences of the scaling in the mean hypothesis as well as the questions of the relation of this hypothesis with the earlier scaling relations[5] have been considered in refs.[6] .

In the present paper we consider the question of displaying of scaling in the mean in the reactions

$$\pi^- p \to \gamma + X \qquad (3)$$

and

$$\pi^- p \to \pi^\circ + X \qquad (4)$$

at 5 GeV/c. The experimental data are based on statistics including 7940 gamma-quanta detected with a JINR one-meter propane bubble chamber[7] . The processing of gamma-quanta events and the analysis of invariant differential cross sections of reaction (3) have been described earlier[8].

The basic results of the experimental investigation of reaction (4) by the reconstruction of neutral pion kinematic characteristics from the corresponding characteristics of gamma-quanta pairs have been published previously[9]

II. First of all, it is necessary to note that if not identical particles collide, the spectra $d\sigma/dp_L$ are asymmetric with respect to the point $p_L = 0$. Taking into consideration this circumstance the distributions $(1/\sigma)d\sigma/d\xi_\gamma$ will be considered separately for the backward and forward hemispheres. The study of the dependence of relations (1) and (2) upon the multiplicity of secondary particles

requires a preliminary determination of the scales, i.e., the average values of longitudinal and transverse momenta in the events of the given topology. The whole set of values of $\langle|p_L|\rangle$ and $\langle p_T\rangle$ required for further investigations of reaction (3) is presented in Table 1.

Table 1

Prong multiplicity		0	2	4	all
$\langle\|P_L\|\rangle$, GeV/c	$P_L<0$	0.162±0.013	0.117±0.005	0.112±0.007	0.120±0.004
	$P_L>0$	0.254±0.013	0.149±0.005	0.103±0.005	0.147±0.004
$\langle P_T\rangle$, GeV/c		0.192±0.006	0.178±0.003	0.152±0.004	0.172±0.002

Begin with the analysis of longitudinal momenta of gamma-quanta. Figures 1 and 2 show the experimental distributions $(1/\sigma)d\sigma/d\xi_\gamma$ for events of the given topology in reaction (3). Both the Figures show a dense grouping of points with respect to some common curve. This regularity indicates the independence of the shape of the distributions studied upon the multiplicity of charged particles.

Now consider the dependence of $(1/\sigma)d\sigma/d\xi_\gamma$ distributions upon energy. In view of the absence of the corresponding data at other energies, the problem cannot be solved by direct comparison of distributions. In this situation a fact that gamma-quanta from reaction (3) are the products of π° -meson

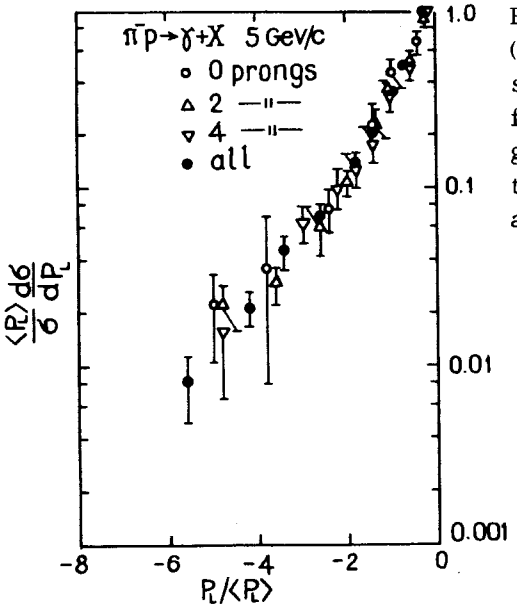

Fig.1. Plot of $(\langle|p_L|\rangle/\sigma)d\sigma/dp_L$ versus $p_L/\langle|p_L|\rangle$ at $p_L<0$ for events of the given topology in the reaction $\pi^- p \to \gamma + X$ at 5 GeV/c.

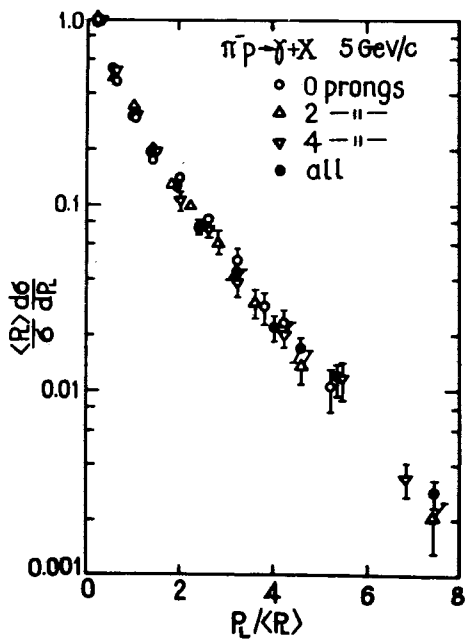

Fig.2. Plot of $(\langle|p_L|\rangle/\sigma)d\sigma/dp_L$ versus $p_L/\langle|p_L|\rangle$ at $p_L>0$ for events of the given topology in the reaction $\pi^- p \to \gamma + X$ at 5 GeV/c.

decay* from reaction (4) can be used. The spectrum of longitudinal moments of gamma-quanta $d\sigma/dp_L$ is related by the integral equation /10/ to a similar spectrum of π°-mesons. This equation, as is shown below, makes it possible to draw a certain conclusion on the dependence of the $(1/\sigma)d\sigma/d\xi_\gamma$ distribution upon energy basing on the studies of the energy dependence of the $(1/\sigma)d\sigma/d\xi_{\pi^\circ}$ distribution. There are no data on $(1/\sigma)d\sigma/d\xi_{\pi^\circ}$ distributions at higher energies yet. However, there is considerable information on the $d\sigma/dp_L$ spectra whose behaviour reveals a number of features: first, as has been shown in refs. /11-15/ , the spectra of longitudinal moments of neutral pions $d\sigma/dp_L$ in $\pi p-$, $Kp-$ and pp-interactions are similar to the spectra of not leading π^+- and π^--mesons; second, to a good accuracy all these spectra are described by the dependence $A\exp(-B|p_L| - Cp_L^2)$. These facts are a sufficient argument to use the corresponding distributions of charged pions instead of the absent $(1/\sigma)d\sigma/d\xi_{\pi^\circ}$ distributions. The data shown in Fig. 3 evidence in favour of the reasonability of such a replacement. As is seen from the Figure, the distribution $(1/\sigma)d\sigma/d\xi_{\pi^\circ}$ in reaction (4) at 5 GeV/c within errors agrees with the curve describing the corresponding distribution of negative pions in pp-interactions at 13-300 GeV/c.

*Under estimates a fraction of gamma-quanta from other sources ($\eta \to \gamma\gamma$, $\Sigma^\circ \to \Lambda^\circ\gamma$, ...) does not exceed 1%.

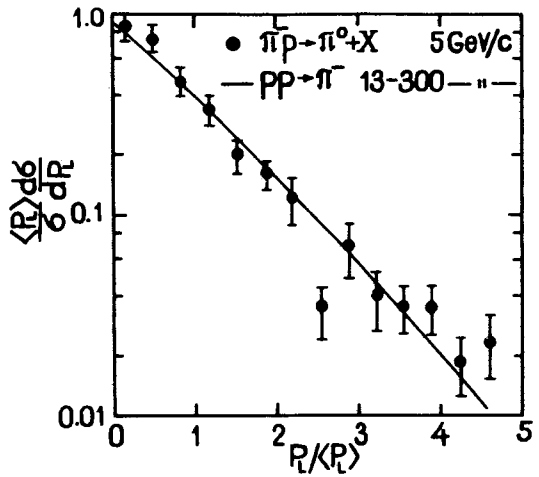

Fig. 3. Plot of $\langle|p_L|\rangle/\sigma)d\sigma/dp_L$ versus $p_L/\langle|p_L|\rangle$ at $p_L > 0$ in the reaction $\pi^- p \to \pi^\circ + X$ at 5 GeV/c. The curve represents the results of fitting the pp data[1].

Reduce, according to the above said plan, the integral equation taken from ref.[10] to the form relating the distributions of longitudinal momentum of gamma-quanta and neutral pions in the representation of scaling in the mean variables

$$\frac{1}{\sigma}\frac{d\sigma}{d\xi_\gamma} = \langle|p_L|\rangle \int \frac{\phi^\pi_L(\xi_{\pi^\circ})d\xi_{\pi^\circ}}{\langle|q_L|\rangle\sqrt{\xi^2_{\pi^\circ}+m^2/\langle|q_L|\rangle^2}}, \qquad (5)$$

where $\phi^\pi_L(\xi_{\pi^\circ})=(1/\sigma)d\sigma/d\xi_{\pi^\circ}$, p_L (q_L) is the longitudinal component of the gamma-quantum momentum (a π°-meson), m is π°-meson mass. The integration limits depend on ξ_γ and are as follows:

$$f(\xi_\gamma)/\langle|q_L|\rangle, \infty \quad \text{for} \quad \xi_\gamma > 0$$

and

$$-\infty, f(\xi_\gamma)/\langle|q_L|\rangle \text{ for } \xi_\gamma<0,\ f(\xi_\gamma)=\xi_\gamma\langle|p_L|\rangle - m^2/(4\xi_\gamma\langle|p_L|\rangle).$$

In eq. (5) the only parameter depending on energy is $\langle|p_L|\rangle$ (here $\langle|q_L|\rangle$ can be expressed by $\langle|p_L|\rangle$ according to the relation $\langle|q_L|\rangle = 2\langle|p_L|\rangle$). The calculation of the right-hand side of eq. (5) with the function ϕ^π_L obtained in ref.[1] for the distribution $(1/\sigma)d\sigma/d\xi_\pi$- has shown that increasing $\langle|p_L|\rangle$ from 0.150 up to 0.300 GeV/c leads to the variation of the distribution $(1/\sigma)d\sigma/d\xi_\gamma$ that does not exceed 7%. If one neglects the weak dependence upon $\langle|p_L|\rangle$, it will follow from eq. (5), that if one of the distributions does not depend upon energy, the second one behaves similarly.

To determine quantitative characteristics of the $(1/\sigma)d\sigma/d\xi_{\pi^\circ}$ distribution, the experimental data shown in Figs. 1 and 2 were fitted by the right-hand side of eq. (5) with the function

$$\phi^\pi_L(\xi_{\pi^\circ}) = a_1 \exp(-a_2|\xi_{\pi^\circ}| - a_3\xi^2_{\pi^\circ}), \qquad (6)$$

where a_i are free parameters. This parametrization is of the same form as for the similar distribution of charged pions in refs.[1,2].

The values of the parameters a_i obtained by the fit are presented in Table 2. For the sake of comparison Table 2 includes also the parameters of $(1/\sigma)d\sigma/d\xi$ distributions

for not leading π^+- and π^--mesons from refs.[1,2] as well as the values of χ^2 obtained by fitting our data with the help of these parameters.

Table 2

		a_1	a_2	a_3	χ^2/number of points
$\pi^-p \to \pi^0$ 5 GeV/c	$\xi_{\pi^0}<0$	0.96±0.05	0.98±0.04	0.00 - fix.	54/73
	$\xi_{\pi^0}>0$	I.04±0.03	I.05±0.02	0.00 - fix.	
$pp \to \pi^-$ 13 - 300 GeV/c		0.9I±0.I5	0.83±0.04	0.03±0.0I	I27/73
$\pi^-p \to \pi^-$ 40 GeV/c $\pi^-p \to \pi^+$	$\xi_\pi<0$	I.20±0.04	I.36±0.04	-0.07±0.0I	I2I/73
	$\xi_\pi>0$	I.I8±0.04	I.34±0.05	-0.07±0.0I	

The data presented in Table 2 permit one to make the following conclusions: 1) The parameters of the distributions $(1/\sigma)d\sigma/d\xi_{\pi^0}$ for the backward and forward hemispheres coincide with each other within error limits. This fact indicates that the use of scaling in the mean variables leads to symmetrization of the longitudinal momenta spectrum; 2) The parameters of the distributions $(1/\sigma)d\sigma/d\xi_{\pi^0}$ within two-fold and three-fold errors coincide with the parameters of the distributions $(1/\sigma)d\sigma/d\xi$ for π^+- and π^--mesons at higher energies. This coincidence due to the above-said considerations evidences in favour of the energy-independence of the distribution $(1/\sigma)d\sigma/d\xi_{\pi^0}$ and consequently of the independence of the distributions $(1/\sigma)d\sigma/d\xi_\gamma$ upon energy.

III. Now we proceed to the analysis of transverse momenta spectrum of gamma-quanta. Figure 4 shows the experimental distributions $(1/\sigma)d\sigma/d\eta_\gamma$ for reaction (3). It is seen that in the whole range of variation $\eta_\gamma = p_T/\langle p_T\rangle$, the data for various topologies within errors coincide. This shows the independence of the shape of distributions under study upon the multiplicity of charged particles.

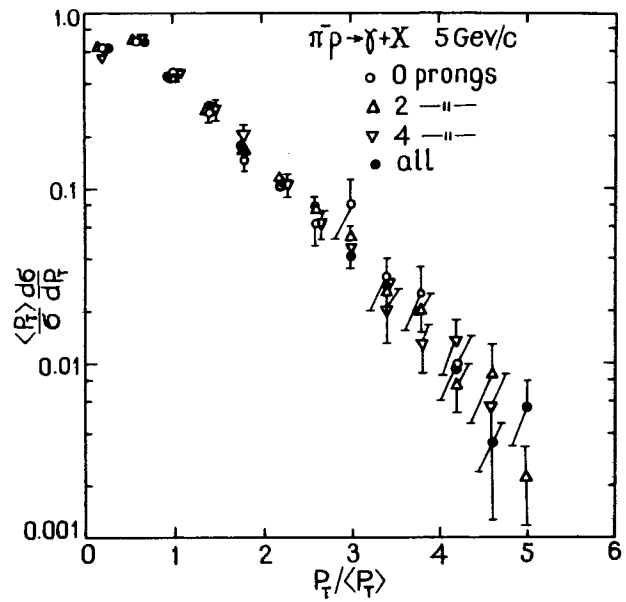

Fig. 4. Plot of $(\langle p_T\rangle/\sigma)d\sigma/dp_T$ versus $p_T/\langle p_T\rangle$ for events of the given topology in the reaction $\pi^- p \to \gamma + X$ at 5 GeV/c.

Consider the dependence of these distributions upon energy. The absence of the corresponding information at other energies makes us use the same way of consideration as for the distributions of longitudinal momenta. Proceeding from the integral equation[10] relating the spectra of transverse momenta of gamma-quanta and π°-mesons it is possible to obtain an integral equation for the corresponding distributions in the representation of scaling in the mean variables. The quantities $\langle p_T \rangle_\gamma$ and $\langle p_T \rangle_{\pi^\circ}$ are included in this equation as parameters. The weak dependence of $\langle p_T \rangle$ upon energy leads to the fact that the energy-independent distribution $(1/\sigma)d\sigma/d\eta_{\pi^\circ}$ will produce the energy-independent distribution $(1/\sigma)d\sigma/d\eta_\gamma$. To estimate energy dependence of the distribution $(1/\sigma)d\sigma/d\eta_{\pi^\circ}$ on the basis of the same facts as for longitudinal momentum distributions it is possible to use the corresponding distributions of charged pions.

Figure 5 shows the experimental distribution $(1/\sigma)d\sigma/d\eta_{\pi^\circ}$ for reaction (4) as compared with the curve describing the analogous distributions of negative pions in pp-interactions at 13-300 GeV/c. The coincidence of experimental data with the curve (χ^2 / the number of points = 2.8/14) shows the independence of the distribution $(1/\sigma)d\sigma/d\eta_{\pi^\circ}$ upon energy and hence the independence upon energy of the distributions $(1/\sigma)d\sigma/d\eta_\gamma$.

IV. In conclusion let us summarize the basic results of this investigation.

1. The regularity which agrees with the predictions of the scaling in the mean

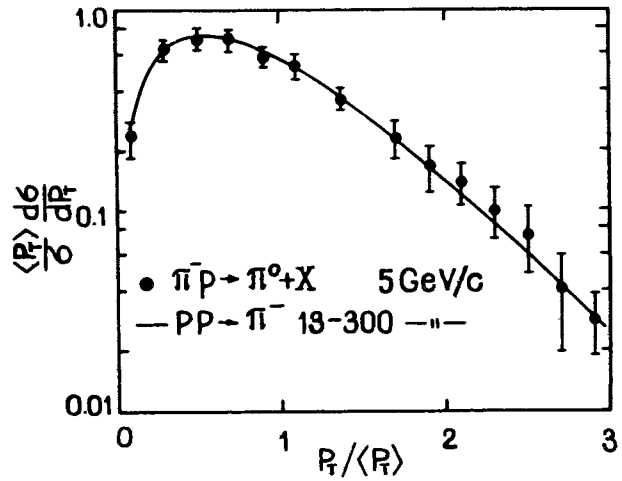

Fig. 5. Plot of $(\langle p_T \rangle/\sigma)d\sigma/dp_T$ versus $p_T/\langle p_T \rangle$ in the reaction $\pi^- p \to \pi^\circ + X$ at 5 GeV/c. The curve represents the result of fitting the pp data[1].

hypothesis observed in the spectra of longitudinal and transverse momenta of π°-mesons and gamma-quanta.

2. The analysis performed shows the extension of the validity region of scaling in the mean both for the energy range (5-300 GeV) and for the type of particles.

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