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DIFFERENTIAL AND INTEGRAL CHARACTERISTICS OF π-MESONS IN HIGH ENERGY N-N COLLISIONS

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The phenomenological expression for inclusive single-particle cross section of pion production in N–N collisions is suggested giving a good description of experimental data at energies exceeding 5 GeV. This expression is used for calculation of average meson multiplicities of different charge sign, average meson kinetic energies and transverse momenta The calculated quantities are in good agreement with experiment.

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At present there is the extensive information on meson production in high energy nucleon interactions. These are the great deal of numerical data spread in various publications and related to separate, often spaced far apart regions of kinematic variables. In many cases extrapolation of these data or interpolation to intermediate regions are associated with considerable difficulties. Needless to say that the information on meson production in N-N collisions in a broad kinematic range is of great importance in many theoretical and applied problems.

The purpose of our investigation is to "assemble" the known experimental data into a compact phenomenological expression convenient for practical use. As a basis we take inclusive single-particle meson production cross section $d^3\sigma/dp^3$. Using this cross section one can derive other differential and integral characteristics of the interaction.

We approximate the known experimental data by relativistically invariant expression

$$E\,\frac{d^3\sigma(x, p_\perp, s)}{dp^3}\left[\frac{\text{mb}}{\text{GeV}^2/c^3}\right] = a(1-x)^b\left[\frac{p_\perp^2 s^{c(1+x)}}{(p_\perp+1)^4}\,e^{-1,3p_\perp^2}+\frac{ds^{f(1-x)}}{(x+1)^g}\,e^{-hp_\perp^2}\right], \quad (1)$$

where $x \equiv |x|$[1]. Coefficient values for p-p collisions are presented in Table I. The corresponding coefficients for n-n collisions are derived from charge symmetry considerations

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[1] Here we use the same notation as in the previous paper [1] devoted to the investigation of nucleon spectra in N–N collisions. In what follows T is the kinetic energy of projectile in the laboratory coordinate system.

(in Table I π^+ and π^- mesons must be interchanged). For the description of p-n interactions the coefficients average between those for p-p and n-n interactions will be used.

As seen from Figs. 1–3 accuracy of the approximation (1) is quite sufficient.

In Fig. 4 we compare with experiment the average multiplicities of created mesons,

TABLE I

Coefficients for spectra of π-mesons created in inelastic p-p collisions

Coeff.	$pp \to \pi^+ + \ldots$	$pp \to \pi^- + \ldots$	$pp \to \pi^0 + \ldots$
a	23	8	38
b	3	4	4
c	0.04	0.15	0.
d	2.0	3.5	0.9
f	0.06	0.12	0.09
g	1.6	1.3	0.2
h	11	11	11

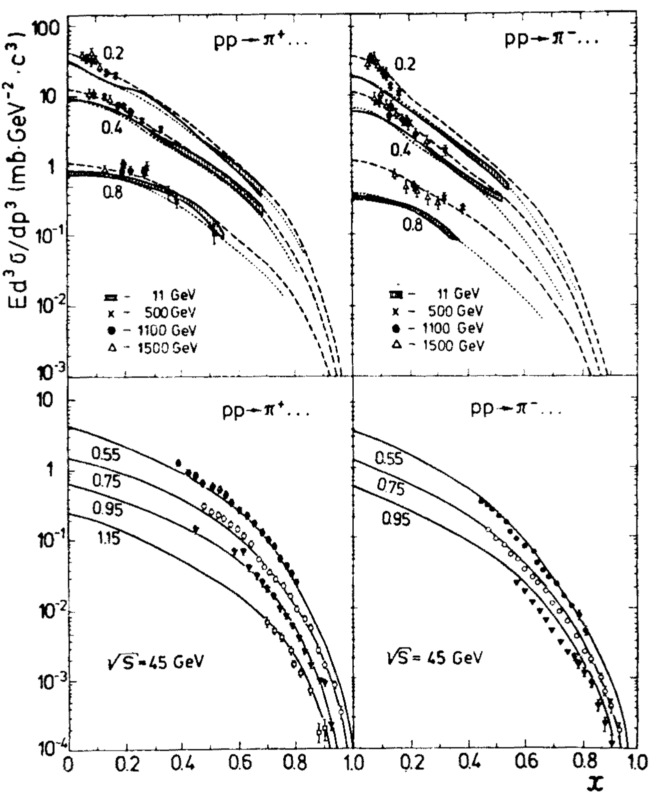

Fig 1. Differential distribution of charged mesons in p-p collisions. Dotted and dashed lines are the calculations for $T = 11$ and $T = 1100$ GeV, respectively, solid curves for $T = 1078$ GeV. Near the curves the $p_\perp$ values are sited. Experimental data are taken from [2, 26]

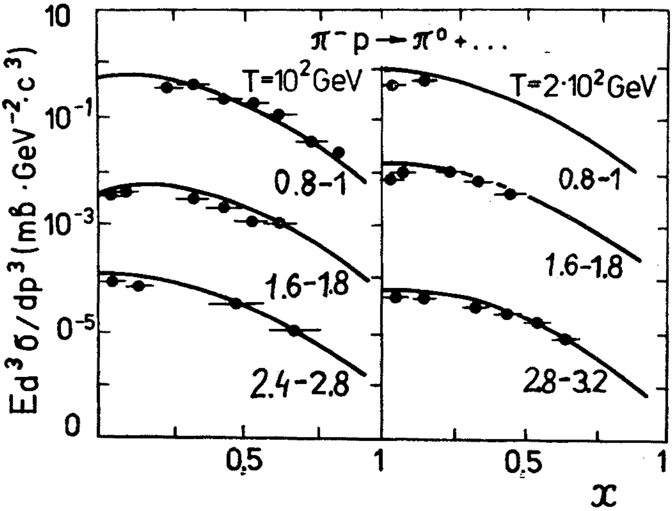

Fig. 2. Differential distribution of π^0 mesons in p-p collisions. Curves and the points correspond to calculations and experimental data [3], respectively. Near the curves $p_\perp$ values are sited

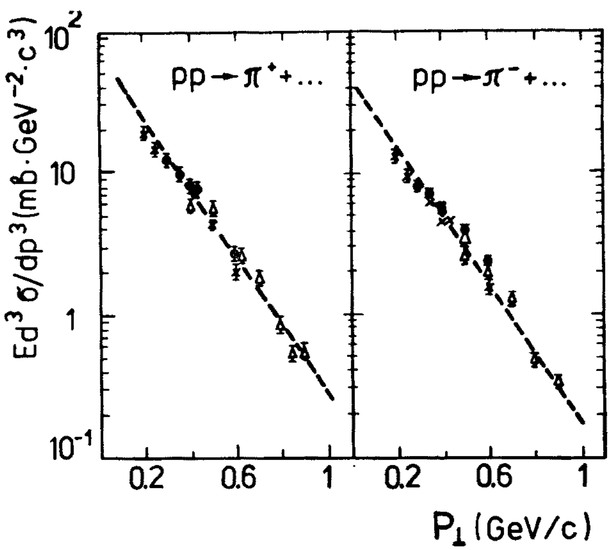

Fig. 3. Transverse momentum distribution of charged mesons created in p-p collisions at $x = 0$. Calculations for $T = 1100$ GeV are shown by the dashed lines. The corresponding experimental points [2] for $T = 500$, 1100 and 1500 GeV are marked by ×, ●, △, respectively

calculated by expression (1)[2]. To complete the picture Fig. 4 includes also the multiplicities of secondary protons. Calculations give a good fit to experimental data. As it is confirmed by experiment the average multiplicities of π^+ and π^0 mesons are approximately equal and considerably exceed the number of created π^- mesons. The difference between $\langle n_{\pi^+} \rangle$

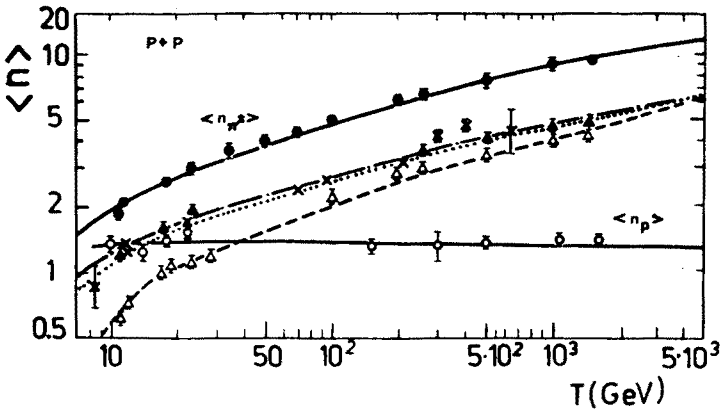

Fig. 4. Average particle multiplicity in inelastic p-p collisions. Solid curves correspond to calculated values of $\langle n_p \rangle$ and $\langle n_{\pi^\pm} \rangle$; dot-and-dashed, dotted and dashed lines correspond to $\langle n_{\pi^+} \rangle$, $\langle n_{\pi^0} \rangle$ and $\langle n_{\pi^-} \rangle$, respectively. The corresponding experimental data are shown by the marks ○, ●, ▲, ×, △ [4–17]

and $\langle n_{\pi^-} \rangle$ remains actually constant in a wide range of energies from $T \simeq 10$ GeV to $T \sim 10^3$ GeV. The number of created π^0 mesons is about 50–60% of the number of charged mesons (see Table II). This is in good agreement with average experimental data presented recently [4, 10], but somewhat exceeds the results of earlier measurements [18, 19] (the difference is less than 20%).

TABLE II

Average multiplicity ratio for neutral and charged π-mesons in inelastic p-p interactions

T, GeV	$\langle n_{\pi^0} \rangle / \langle n_{\pi^\pm} \rangle$	
	Theory	Experiment[1]
10	0.58	0.57 ± 0.04
20	0.57	0.59 ± 0.04
100	0.55	0.58 ± 0.04
500	0.53	0.57 ± 0.05
10^3	0.52	0.56 ± 0.08
$1.5 \cdot 10^3$	0.51	0.55 ± 0.08

[1] Experimental data are taken from the curves $\langle n(T) \rangle$, which are approximating the measurement results from [4, 10].

[2] For the formulae expressing multiplicity and other integral characteristics by the cross section $d^3\sigma/dp^3$ see Ref. [1].

In the range of approximation (1) the average transverse momenta of π mesons are charge independent. Their magnitude is approximately one-third less than the proton transverse $\langle p_{\perp p} \rangle$ momenta and slowly increases at increasing primary energy T (see Table III).

The comparison of the calculated values of average kinetic energy of π mesons with the few presently known experimental data values is shown in Fig. 5. Compared to the

TABLE III

Average transverse momentum of π-mesons in p-p collisions

T, GeV	10	20	10^2	10^3	$4.1 \cdot 10^3$
$\langle p_{\perp\pi} \rangle$ Calculation	306	317	323	332	340
MeV/c Experiment[1]	307 ± 6	310 ± 4	340 ± 10	—	270 ± 30

[1] See compilations [20, 21].

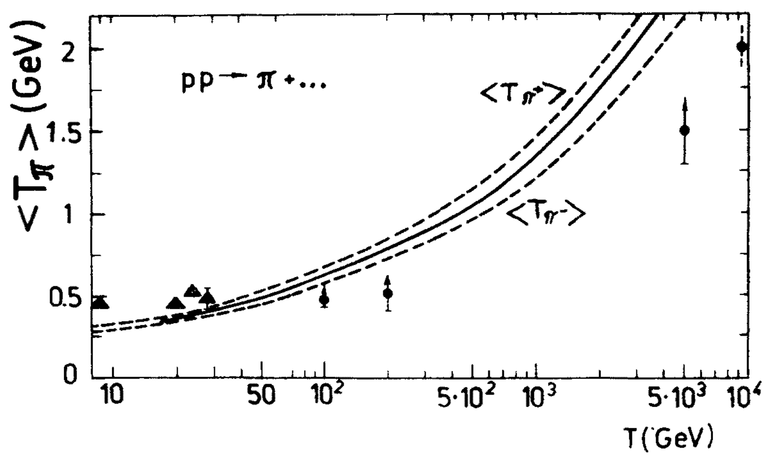

Fig. 5. Average kinetic energy of mesons at p-p collisions (C. M. S). Solid curves correspond to calculations for $\pi^{\pm}$-mesons, the upper and lower dashed lines correspond to calculations for π^{+}-mesons and π^{-}-mesons, respectively. Experimental data for p-p interactions and interactions of protons with light nuclei are denoted by the marks ▲ and ●, respectively [21, 24]

average energy of secondary protons the quantity $\langle T_\pi \rangle$ is considerably less energy dependent: T^α, $\alpha = 0.3$. There is no contradiction between this conclusion and the results of direct measurements of $\langle T_\pi \rangle$, however, there is lack of corresponding experimental data yet. In the whole region $T \gtrsim 5$ GeV $\langle T_{\pi^+} \rangle > \langle T_{\pi^-} \rangle$. The energy of π^0 mesons is $\langle T_{\pi^0} \rangle \simeq \langle T_{\pi^+} \rangle$.

As to the share of energy taken by π mesons

$$\langle K_\pi \rangle = \langle n_\pi \rangle \{ \langle T_\pi \rangle + M_\pi \} / \sqrt{s} \tag{2}$$

TABLE IV

Share of energy taken by π^- and π^0 mesons $\langle K_\pi \rangle$ in p-p collision (C.M.S.)

$pp \to \pi^- + \ldots$			$pp \to \pi^0 + \ldots$		
T, GeV	Calcul.	Exper.	T, GeV	Calcul.	Exper.[1]
9	0.07	0.13 ± 0.03	9	0.12	0.15 ± 0.02[2]
18	0.08	0.11 ± 0.06	20	0.13	0.16 ± 0.02[2]
68	0.09	—	68	0.14	0.12 ± 0.01
205	0.10	—	205	0.15	0.14 ± 0.02
250	0.11	0.12 ± 0.04	300	0.16	0.17 ± 0.03
10^3	0.13	0.11 ± 0.08	10^3	0.17	0.17 ± 0.01

[1] See compilations [20, 21, 24]. [2] For interactions $p + {}^{12}C$.

TABLE V

Relative inelasticity of p-p interactions for neutral and charged mesons (C.M.S.)

T, GeV	$\langle K_{\pi^0} \rangle / \langle K_{\pi^\pm} \rangle$
10	0.59
20	0.59
10^2	0.57
10^3	0.56
$5 \cdot 10^3$	0.55

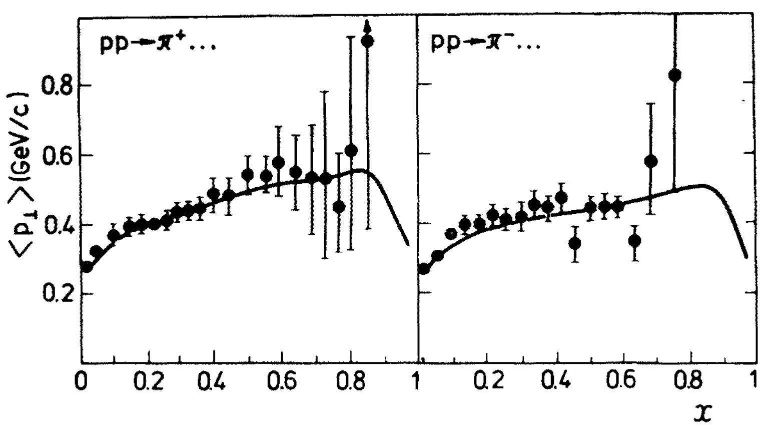

Fig. 6. Average transversal momentum of π^+ and π^- mesons in p-p inclusive reaction at energy $T = 68$ GeV. The curves are results of our calculations, the points are experimental data from Refs [27, 28]

it is almost the same for π^+ and π^0 mesons and is considerably less for π^- mesons. This is in good agreement with known experimental data (see Table IV).

The share of energy consumed on neutral meson production is approximately twice less than that for the charged meson creation (see Table V). The comparison of experimental data with calculations supports the applicability of the expression (1) for the description of differential as well as integral characteristics of created mesons. With the expression for nucleon spectra presented in Ref. [1] it gives a complete inclusive description of secondary nucleons and π mesons in inelastic N-N reactions.

Taking into account the energy, momentum and charge conservation laws these expressions enable not only to obtain the information about average inclusive quantities but to perform the statistical Monte-Carlo simulation of separate inelastic N-N collisions as well (cf. Refs. [25, 26]).

In this approach one can obtain secondary particles multiplicity distributions, various correlations of charged and neutral secondaries (as an example Fig. 6 shows the theoretical and experimental x-$p_\perp$ correlations) and many other quantities.

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