RESONANCE PARTICLE PRODUCTION IN INELASTIC N-N AND π-N INTERACTIONS

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Using the considerations connected with the scaling hypothesis and the Regge pole model the phenomenological expressions for differential single-particle inclusive cross-sections of Δ-, ϱ- and ω-resonances produced in N-N and π-N inelastic collisions at high energies are obtained. These expressions describe the known experimental data in a wide energy region from 10 to several thousands GeV.

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Phenomenological expressions describing the differential single-particle inclusive cross-sections of nucleon and π-mesons production at high energies have been obtained in papers [1-3]. Their analytical structure has been defined with regard to known theoretical models, and numerical coefficients have been selected from experimental data. These expressions not only accumulate a great body of experimental data in a wide energy region T[1] from 10 up to several thousands GeV, but provide the possibility to calculate the integral characteristics of secondary particles to analyse the properties of the leading particles [4] etc. From these expressions one can obtain estimations for those regions of kinematic variables, where measurements are still absent, and using the Monte-Carlo method simulate individual acts of inelastic collisions [5][2]. Expressions obtained in [1-3] can also be applied for resonance particle production. At present this fact is particularly important, since the experimental information on resonance production is rather limited and analytical approximate expressions possess a considerable predicting value.

Later on we shall confine ourselves to investigation of the Δ, ρ and ω resonances, being produced up to exremely high energies with large cross-sections and presented by

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[1] Below we always use the centre-of-mass system and the following notation: $\sqrt{s}$ is the total energy of the colliding particles, $E = \mathscr{T}+M$ and $\mathscr{T}$ are, respectively, the total and kinetic energies of the secondary particle considered, $p_{\parallel}$ and $p_{\perp}$ are the longitudinal and transverse momenta of this particle, $x = 2p_{\parallel}s^{-1/2}$. T is the kinetic energy of the projectile in the laboratory system.

[2] Using these expressions one ought to take into consideration, that they are concerned with the total postdecay characteristics and are used at sufficiently large distance from the interaction point.

the greatest amount of experimental data. The approximate expressions are also suitable for other types of resonances. However, because of the lack of experimental data, which can be used for determination of the coefficients, these expressions give only rough, qualitative results.

To describe the spectrum of "conserved"[3] particles we use the expression from paper [1]:

$$E\frac{d^3\sigma}{d^3p}\left[\frac{\text{mb}}{\text{GeV}^2/c^3}\right]=\begin{cases} a(1+b|x|s^{c-x_\perp s^{0.27}})\dfrac{(1-|x|)^{fp_\perp^2}}{(p_\perp^2+\mu^2)^d}e^{q|x|}+us^v(1-|x|)e^{-5p_\perp^2}, 0\leqslant|x|<0.7,\\ A|t|\dfrac{(1-|x|)^{1-\alpha t}}{(m_\pi^2-t)^2}e^{Rt}+\displaystyle\sum_{i=1}^{4}G_i\left(\frac{s}{s_0}\right)^{-\alpha_i}(1-|x|)^{\beta_i-\gamma_i t}e^{R_i t},\ 0.7\leqslant|x|<1, \end{cases} \qquad (1)$$

where $t=-p_\perp^2/|x|-(1-|x|)(M_R^2/|x|-M_a^2)$. Here M_a and M_R are the particle masses in inclusive reaction a+b → R+ ..., parameter $s_0 = 1\ \text{GeV}^2$, m_π – π meson mass.

Expressions (1) can also be applied for description of cross-sections on production of resonances R_a' and R_b' in the reaction a+b → $R_a'(R_b')$+ ... that differ only by one quark from a particle "a" (for example, Δ^{++} in reaction pp → Δ^{++} ...) and particle "b" (Δ^{++} in reaction π^++p → Δ^{++} at $x < 0$), accordingly.

Expression (1) can be used for description of ρ^0- and ω-meson resonances spectra produced in π-p interaction at $x > 0$. The values of parameters for all these reactions are shown in Tables I and II.

TABLE I

Coefficients for "conserved" and "unconserved" resonance particle spectra, described by expression (1) at $|x| < 0.7$

Reaction \ Coefficient		a	b	c	d	f	g	μ^2	u	v
$\|x\| < 0.7$	pp → Δ^+ ...	0.04	22.	0.	3.3	0.09	5.4	1.77	0.1	−1
	pp → Δ^0 ...		1.							
	pp → Δ^{++} ...		20.							
$x > -0.7$	π^+p → Δ^{++} ...	0.3	0.1	−0.2	4.05	1.5	5.9	1.2	6.5	−0.5
	π^-p → Δ^{++} ...	0.1	4.6	0.	4.4	0.07	5.1	1.4	3.2	−0.5
$x < 0.7$	πp → ρ_{cons}	4.8	0.95	−0.04	5.4	0.25	1	1.26	0.65	−0.025
	πp → ρ^0		0.8				0.7		0.65	
	πp → ω		0.5				0.15		0.4	

[3] We call the resonance particle R_a "conserved" in reaction a+b → R_a+ ... if it is emitted in the forward hemisphere ($x > 0$) and possesses the same quark composition as a primary particle "a" (for example, ϱ^+ in reaction π^++p → ϱ+ ...), and also resonance R_b in reaction a+b → R_b+ ... if it is emitted in the backward hemisphere ($x < 0$), and possesses the same quark composition, as a target "b" (Δ^+ in p-p and π^+-p collisions).

TABLE II

Coefficients for "conserved" and "unconserved" resonance particle spectra, described by expression (1) at $|x| \geqslant 0.7$

Equal for all reactions				$\|x\| \geqslant 0.7$		$x \leqslant -0.7$				$x \geqslant 0.7$					
				$pp \to \left\{\begin{matrix}\Delta^+\\ \Delta^0\\ \Delta^{++}\end{matrix}\right\} \ldots$		$\pi^+p \to \Delta^{++} \ldots$		$\pi^-p \to \Delta^{++} \ldots$		$\pi p \to \rho_{cons} \ldots$		$\pi p \to \rho^0 \ldots$		$\pi p \to \omega \ldots$	
	A			24, 5; 1.2[a]		94		38.2		5.8		4.35		2.6	
	R			4		0.01		0.26		0.7		0.7		0.85	
	α			0.4		2.		2.		1.		1.		1.	
i	α_i	β_i	γ_i	G_i	R_i	G_i	R_i	G_i	R_i	G_i	R_i	G_i	R_i	G_i	R_i
1	0	0	1.5	0.4 0.4 0.6	−0.8 −0.8 −0.7	1.5	−0.3	0.18	−0.9	0.6	−0.37	0.6	−0.3	0.68	−0.1
2	0	−0.5	0.85	0.003	−0.9	—	—	0.004	−0.75	0.001	−0.7	0.001	−0.67	0.001	−0.62
3	0.5	−0.5	1.5	—	—	3.0	0.4	8	4.6	4.0	6.0	4.0	6.0	4.0	6.0
4	0	−1	0.2	0.3[b] — —	1.5[b] — —	—	—	—	—	—	—	—	—	—	—

[a] for $pp \to \Delta^0 \ldots$ [b] for $pp \to \Delta^+ \ldots$

For the inclusive spectra of "unconserved" resonance particles (i.e. particles with a different from "a" and "b" particles quark composition, for example, ρ^+ in p-p and π^--p interactions), we use the same expression as in paper [2]:

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

where $R = 0.75\ (\text{GeV}/c)^{-2}$ but values of coefficients b and h may depend on s. The values of parameters are shown in Table III.

In the case of p-p interaction the coefficients for the ρ^0-meson are presented in this Table. However, these coefficients can be used for approximation of inclusive cross--section of $\rho^{\pm}$-mesons if one is restricted to the energy region about several dozens of GeV, since the experimental data show that ρ-mesons spectra do not depend on the charge sign. The data at higher energies are not yet available.

As for ω-meson, available experimental data provide the possibility to define the coefficients only for π-p interaction.

Experimental data for Δ^+ and Δ^0 particles are still unsufficient. The absolute value of Δ^0-resonance production cross-section can be estimated from data in [7]. Proceeding from the identical quark composition of the Δ^+ and p, Δ^0 and n, accordingly, the shape of the Δ^+ spectra can be chosen approximately the same as for the proton spectra and the shape of the Δ^0 spectra the same as for neutron. The corresponding coefficients are presented in Tables I and II. In Fig. 1 the average multiplicities of Δ^{++} and ρ^0 resonances calculated by expressions (1) and (2) are compared with experiment. Within the accuracy of the experimental data available at present there is a good agreement at the region of $T > 10$ GeV. As the primary particle energy increases the average multiplicity of the

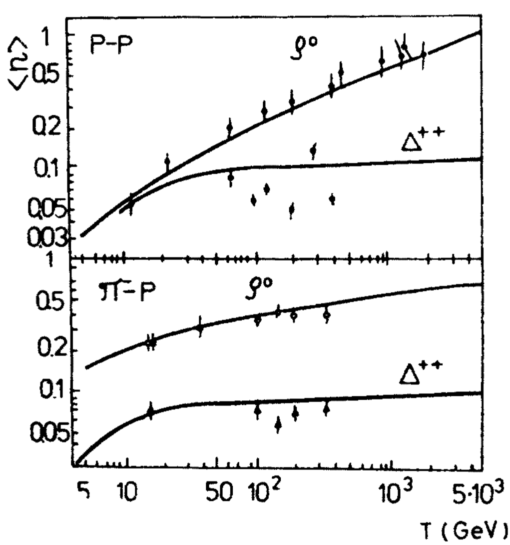

Fig. 1. Average multiplicity of Δ^{++} and ρ^0-resonances in inelastic p-p and π^--p collisions. The curves are the results of calculations, the points correspond to experimental data [6–42]

Δ^{++} resonances rises somewhat slower than the total multiplicity of charged particles $\langle n_{ch} \rangle$ (Table IV). The multiplicity of ρ^0-mesons in π^--p collisions behaves similarly. At the same time in the proton collisions the number of created ρ^0-mesons increases more rapidly than $\langle n_{ch} \rangle$.

Agreement of the calculated and experimental $\rho^{\pm}$ and ω production cross-sections is illustrated by Table V. In the region of several dozens of GeV, where the coefficients of

TABLE III

Coefficients for "unconserved" resonance particle spectra, described by expression (2)

Reaction / Coeffic.	$-1 < x < 1$		$x > 0$		$x < 0$
	$pp \to \rho^0 \ldots$	$\pi^{\pm}p \to \rho^{\pm} \ldots$	$\pi^+ p \to \Delta^{++} \ldots$	$\pi^- p \to \Delta^{++} \ldots$	$\pi p \to \begin{Bmatrix} \rho_{cons} \\ \rho^0 \\ \omega \end{Bmatrix} \ldots$
a	0.2	1.6	1.0	0.4	1.9 (1.6[a])
b	$s^{0.2}$	4.0	3.0	3.0	3.0
c	0.41	0.0	0.0	−0.07	0.0
d	0.75	1.1	4.1	5.4	1.1
f	0.43	−0.01	−0.32	−0.37	−0.01
g	−3.	−3.0	−2.	−1.0	−3.0
h	$2s^{0.2}$	5.0	8.	7.0	5.0

[a] Coefficient for reaction $\pi p \to \omega \ldots$

TABLE IV

The ratio of the average multiplicities of resonance particles and all charged particles $\langle n_R \rangle / \langle n_{ch} \rangle$ in p-p and π^--p collisions at energy T (%)

T [GeV]	p-p		π^--p	
	Δ^{++}	ρ^0	Δ^{++}	ρ^0
10	1.3	1.8	1.5	5.5
10^2	1.6	2.6	1.4	5.4
10^3	1.0	4.3	0.9	5.3
$5 \cdot 10^3$	0.8	6.4	0.8	5.4

TABLE V

Energy dependence of the multiplicities of resonances created in inelastic p-p and π^--p collisions $\langle n(\mathcal{T}) \rangle / \langle n_{tot} \rangle$ $\langle n(\mathcal{T}) \rangle$-average multiplicity of resonance with energy greater than $\mathcal{T}$. $\langle n_{tot} \rangle = \langle n(\mathcal{T} = 0) \rangle$. The initial energy $T = 1000$ GeV

$\mathcal{T}/\mathcal{T}_{max}$	p-p		π^--p		
	Δ^{++}	ρ^0	Δ^{++}	ρ^0	ρ^-_{cons}
0.2	0.961	0.114	0,791	0.332	0.356
0.7	0.633	0.00063	0.437	0.058	0.068

the approximate expressions are being selected, the agreement is satisfactory. At greater energies, where the experimental data are not available the calculated values are considered only to be roughly-qualitative.

Table VI and Fig. 2 show the number of the resonance Δ, ρ particles with kinetic energy higher than $\mathcal{T}$ produced in inelastic p-p and π-p collisions. The corresponding angular distributions are shown in Fig. 3. As one can see, the majority of the Δ^{++} resonances have kinetic energy $\mathcal{T} > 0.2 \cdot \mathcal{T}_{max}$ and are emitted at a narrow angle with respect to the

TABLE VI

Meson resonance production cross-section in π^+p collision at 15 GeV

$\sigma_{inel.}$ (mb) \ Particle	ρ^0	ρ^+	ρ^-	ω
experiment [36]	4.8±0.4	5.3±0.9	2.3±0.5	4.0±0.7
calculation	4.95	5.43	2.2	3.94

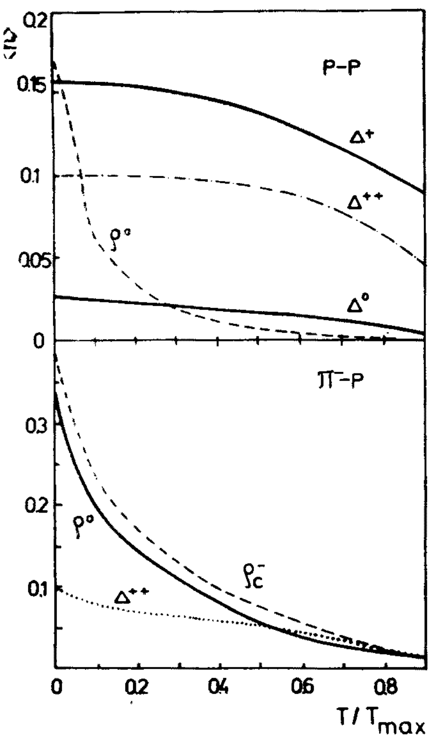

Fig. 2

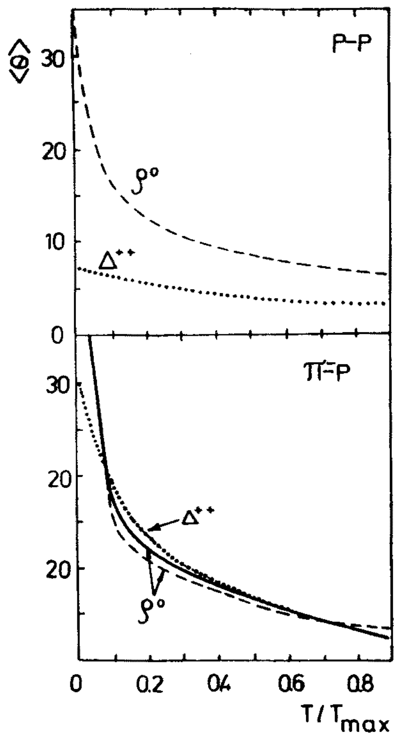

Fig. 3

Fig. 2. The average number of Δ- and ρ-resonances ⟨n⟩, with kinetic energies higher than $\mathcal{T}$. $\mathcal{T}_{max}$ is the highest possible energy of resonance particle [4]. Inelastic p-p and π^--p interactions at $T = 100$ GeV

Fig. 3. Average emission angle ⟨θ⟩ (in degrees) of Δ^{++} and ρ^0-mesons with kinetic energy higher than $\mathcal{T}$. Centre-of-mass system. Inelastic p-p and π^--p collisions at 100 GeV. In the case of π-p interactions the values of ⟨θ⟩ for the forward and backward hemisphere are plotted by solid and dashed curves, respectively

direction of the primary particles[4]. Distributions for Δ^+ and Δ^0 particles are similar. This allows us to make a conclusion that the majority of the Δ resonances appear to be the leading particles. At the same time the number of the leading particles among the meson resonances is considerably smaller.

In Fig. 4 the distributions of the radius of the space region connected with the produc-

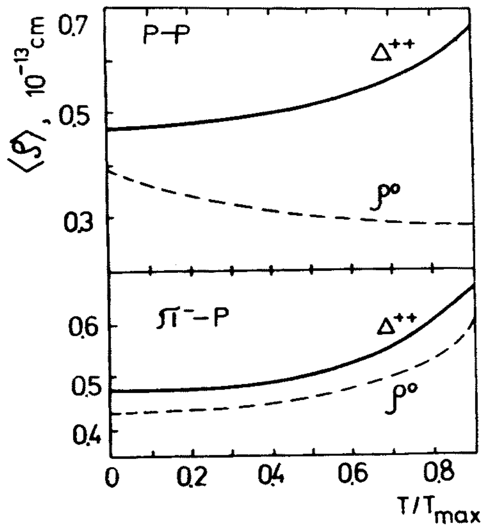

Fig. 4

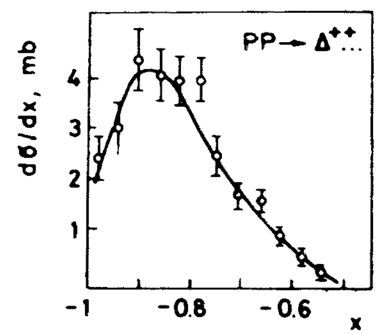

Fig. 5

Fig. 4. The distribution of the average distances at which the resonance particles with kinetic energies higher than $\mathcal{T}$ are produced. Inelastic p-p and π^--p interactions at 100 GeV

Fig. 5. Inclusive distribution of $d\sigma/dx$ for Δ^{++} resonances in p-p collisions at $T = 68$ GeV in the region $|t| \leq 0.8$ (GeV/c)^2 [7]

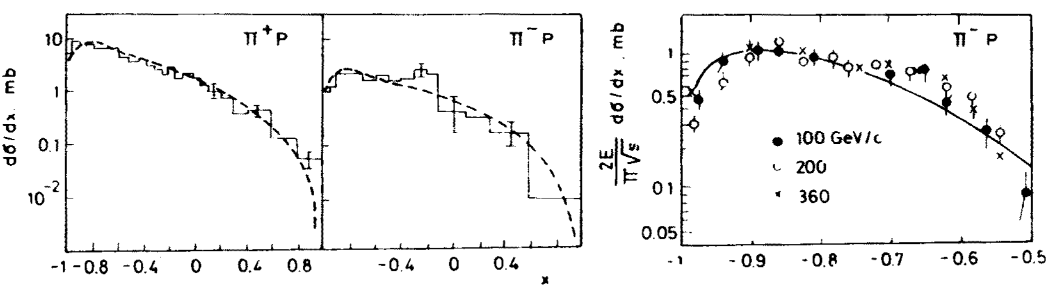

Fig. 6. Distribution of $d\sigma/dx$ for Δ^{++} resonances in π^--p collisions at $T = 15$ and 100 GeV. The curves are the results of calculations; The histograms and experimental points in the region $|t| < 1$ (GeV/c)^2 are taken from [8, 41]

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[4] In the case of p-p interaction the data for the forward hemisphere ($\theta \leq \pi/2$) are presented. Because of the symmetry of the initial system they coincide with the data for the backward hemisphere. In the case of π-p interaction the Δ-resonance angles are presented with respect to the direction of the proton motion (i.e., in fact π-θ). For the ρ^0-mesons in the π^--p interaction the distributions for the forward and the backward hemispheres are separately shown in Fig. 3 [4]. Within the accuracy of the approximation they are not distinguishable.

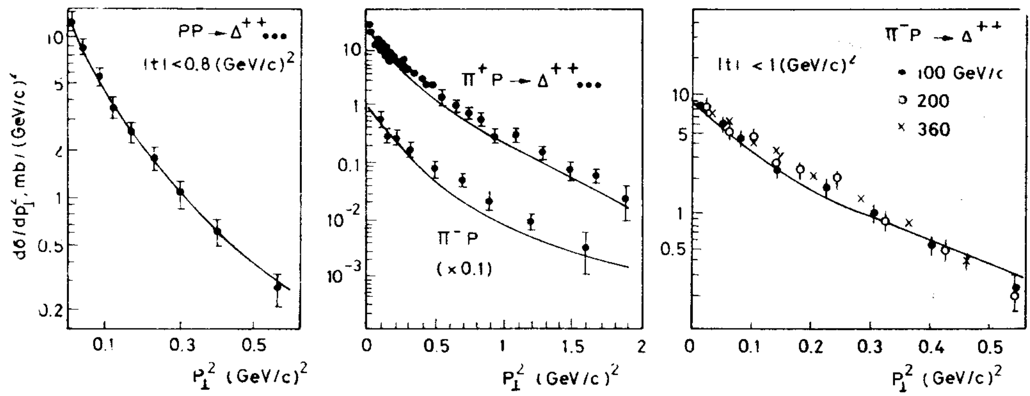

Fig. 7. Distribution of $d\sigma/dp_\perp^2$ for Δ^{++} resonances in p-p collisions at $T = 68$ GeV and π^--p collisions at $T = 15$ and 100 GeV. Experimental points are taken from [7, 8, 41]

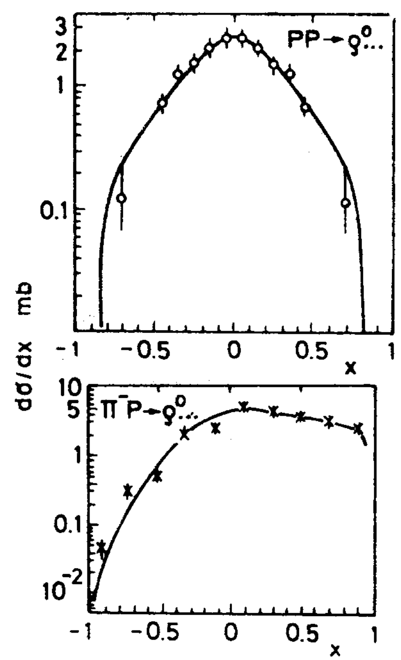

Fig. 8

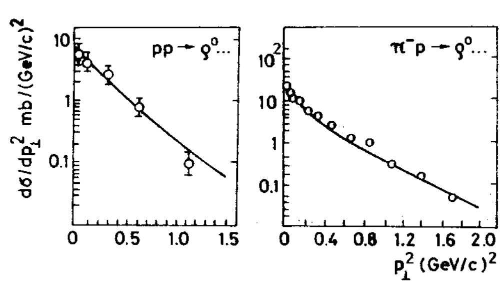

Fig. 9

Fig. 8. Distribution of $d\sigma/dx$ for ρ^0-mesons in p-p collisions at $T = 11$ GeV and π^- p collisions at 15 GeV. Experimental points are taken from [9–11]

Fig. 9. Distribution of $d\sigma/dp_\perp^2$ for ρ^0-mesons in p-p collisions at $T = 11$ GeV and π^--p collisions at 15 GeV. The points correspond to experimental data [9–11]

tion of resonance $\langle \varrho(\mathcal{T}) \rangle = \hbar / \langle p_\perp(\mathcal{T}) \rangle$ are shown, where $\langle p_\perp(\mathcal{T}) \rangle$ is average transverse momentum of the particle of energy $\mathcal{T}$. Comparing these results with the data for nucleons and π mesons obtained from paper [4] one can conclude, that high energy baryons are produced mainly at big radii. High energy mesons in N-N interaction are produced mainly in a region of smaller radii. In π-N interaction, where the share of the leading mesons is considerably higher, their production is connected with periphery as a rule.

The range of differential distribution approximations of Δ^{++}-resonance is illustrated by Figs. 5–7. As in the case of integral characteristics, approximations are in good agreement

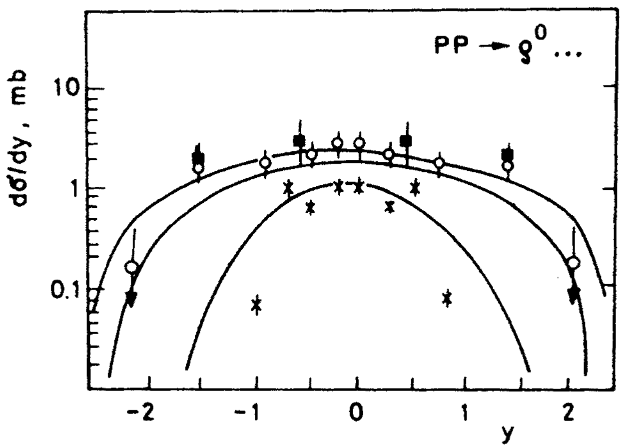

Fig. 10. The c.m. rapidity distribution $d\sigma/dy$ $\left(y = \frac{1}{2} \ln \frac{E+p_\parallel}{E-p_\parallel}\right)$ for ρ^0-mesons in p-p collisions at $T = 11$(×), 68 (○) and 200 (■) GeV. Experimental points are taken from [9]

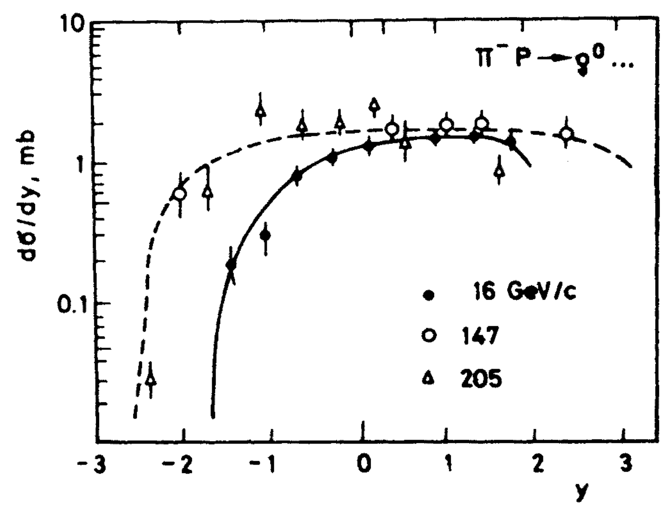

Fig. 11. The same as in Fig. 10. The inelastic π^--p interaction. The curves are the result of calculations at $T = 15$ and 200 GeV. The points correspond to experimental data from [9]

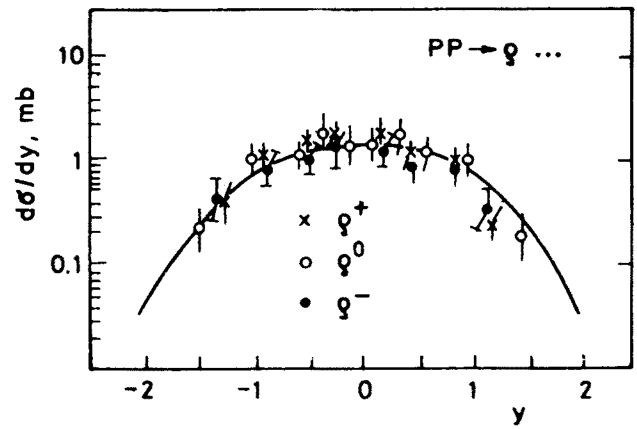

Fig. 12. The same as in Fig. 10 for ρ^+, ρ^- and ρ^0-mesons in p-p collisions at $T = 23$ GeV [6, 23]. The curve is calculated by the expression (2)

with the experimental data. In Figs. 8–12 we compare with the experiment the various differential characteristics of ρ^0-mesons, calculated by expressions (1) and (2). The calculations appear to be in good agreement with the experimental data. As for the other charge sign, only fragmentary experimental data are known (see, for example, Fig. 12). On the whole, because of the absense of precise fit of the coefficients agreement of theoretical calculations with the experiment is not so good.

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