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DESCRIPTION OF MULTIHADRON PRODUCTION AT SUPERHIGH ENERGIES IN THE MULTICOMPONENT APPROACH

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The necessity of constructing phenomenological schemes based on the idea of interaction stems from the absence of a strong interaction theory. Such phenomenological models allow one to describe and classify a great amount of experimental data, and to make predictions for the behaviour of quantitites measured experimentally. The high-energy experiments enable one to select the most realistic models, thus providing a deeper inside into the phenomena.

At present there are models for the description of high energy hadron interactions. Conventionally, they can be divided into three groups: i) the so-called H-models (hydrodynamic, statistical, thermodynamic, etc) based on the assumption of one excited system, ii) F-models (the models of fragmentation, bremsstrahlung, inelastic diffraction, etc ...) assuming two excited systems, iii) M-models (multiperipheral model, Regge model, parton model, model of independent cluster production, model of uncorrelated jets, etc.) with many excited centers.

All these models in the range of their applicability describe satisfactorily the experimental situation on multiple hadron production up to the ISR energies. Moreover, one cannot choose unambiguously one of these models, since the basic characteristics of the multiple production change slowly as a function of energy. Thus, the new data of the $\bar{p}p$ scattering at $\sqrt{S}$ =540 GeV at the CERN SPS Collider are highly important. Under such a sharp increase in energy ($\sqrt{S_{max}}$ =63 GeV at the ISR), even an average multiplicity of charged secondaries, which is the most general characteristic, becomes sensitive to various models. In particular, the data on multiplicity show that the models predicting the $S^{1/4}$ growing law of an average multiplicity (H-model) are invalid. They also reject a weak $\sim \ln S$ dependence of this quantity (F-model, M-model). It is evident that the study of the multiple production is more profitable in the framework of the synthetic-multicomponent approach assuming two or more acting mechanisms of a simultaneous particle generation, which only in combination provide the observed multiplicity [1,2].

In what follows the multiple characteristics of the $\bar{p}p$ process at $\sqrt{S}$ =540 GeV are considered within the multicomponent approach.

In this report we review the papers [3] in which the results obtained at the CERN have in fact been predicted.

In the first section we investigate the pseudorapidity distributions in the central region of the production of secondaries in the framework of the automodel approach. We also describe the narrowing and increase in the peak of this distribution with increasing which have been observed in the UA5 experiment [4].

In the second section we compare some predictions made within the multicomponent cluster model with the data obtained

in the UA5 at the SPS Collider. An extrapolation of this model describing well the data at the ISR energy is shown to be in a satisfactory agreement with the data at $\sqrt{S}$ =540 GeV.

1. As is known, various models of multiple production predict a plateau in the central region for the single-particle rapidity distributions. However, the experiments at still higher energies detect the deviation of distributions from the plateau. Such a behaviour is explained within some models.[5]. From the UA5 experiment at the pp Collider at $\sqrt{S}$ =540 GeV the pseudorapidity distributions at a fixed multiplicity become narrower and the distribution peak grows with increasing n_c.

We consider an inclusive collision of two high-energy hadrons with the production of ν types of secondaries $a+b \to c(\bar{p})+(n_1-1)+n_2+\dots n_\nu$. Based on the renormalization group analysis for this reaction cross section, when momentum of a c-type particle is fixed, we get [6]

$$\frac{d}{d\tau} E_c \frac{d\sigma^{n_1,n_2,\dots n_\nu}}{d\vec{p}_c} = -\left[\gamma_1 n_1 + \dots + \gamma_\nu n_\nu\right] E_c \frac{d\sigma^{n_1,\dots,n_\nu}}{d\vec{p}_c}, \qquad (1)$$

where $\tau = \ln \frac{p_c p_a}{p_a^2}$ is the "time" evolution component[6,7], $\gamma_1, \dots, \gamma_\nu$ are "anomalous dimensions" of the $i=1,\dots,\nu$ -types of fields of the relevant particles. The given total "anomalous dimension" is $\mathcal{X}_{n_1,\dots,n_\nu} = \gamma_1 n_1 + \dots + \gamma_\nu n_\nu$.
Averaging over multiplicities of all particle types apart from the first type, we get for the corresponding total anomalous dimension

$$\mathcal{X}_{n_1} = \gamma_1 n_1 + \sum_{i=2}^{\nu} \gamma_i \langle n_i(n_1) \rangle, \qquad (2)$$

where $\langle n_i(n_1)\rangle$ is the average multiplicity of the i-th particle type, which is associated with the production of n_1 particles of the type C. Averaging (2) over n_1 once more, we get the total average anomalous dimension $\mathscr{X}\langle n\rangle$ for the reaction $a+b\to c(\vec{p})+X$:

$$\mathscr{X}\langle n\rangle=\sum_{i=1}^{3}\gamma_i\langle n_i\rangle. \tag{3}$$

Consequently, for the reaction $a+b\to c(\vec{p})+(n_1-1)+X$ cross section we have

$$E\,\frac{d\sigma_{n_c}}{d\vec{p}}=C_{n_c}\cdot e^{-\mathscr{X}_{n_c}\cdot\tau}, \tag{4}$$

where C_{n_c} is the normalization coefficient.

Using an appropriate representation

$$\frac{P_a P_c}{P_b^2}=\frac{P_1}{|\vec{P}_b|}\,ch\,(\eta-\beta)$$

in the system of cylindrical coordinates in the zero mass limit ($m\to0$), one can easily obtain from (4) the following expression for the normalization cross section over pseudorapidity η :

$$\frac{1}{\sigma_n}\frac{d\sigma_n}{d\eta}=A\,\frac{[ch(\eta-\beta)]^{-\mathscr{X}_{n_c}}}{B\left(\frac{1}{2},\frac{\mathscr{X}_{n_c}}{2}\right)}, \tag{5}$$

where $A\sim n_c$, and β is pseudorapidity corresponding to the initial vector P_b.

Figure 1 shows the results of comparison of expression (5) with the experimental semi-inclusive spectra for five intervals of multiplicity n_c for $\bar{p}p$ collisions at $\sqrt{S}$=540 GeV. As it is seen from the figure a satisfactory description is obtained for the effect of narrowing and increase in the distribution peak with increasing n_c observed experimentally (χ^2=0,8÷1,0 for each individual curve). The parameters A and $\mathscr{X}_{n_c}$ increase

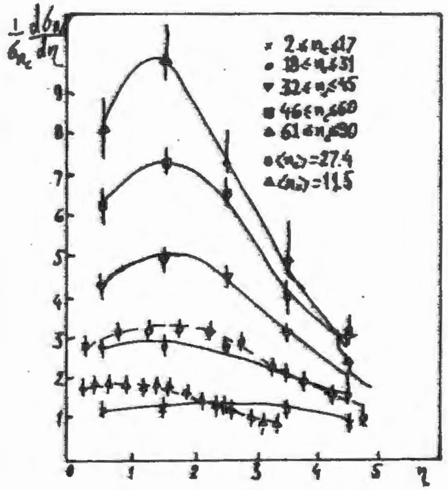

Fig.1

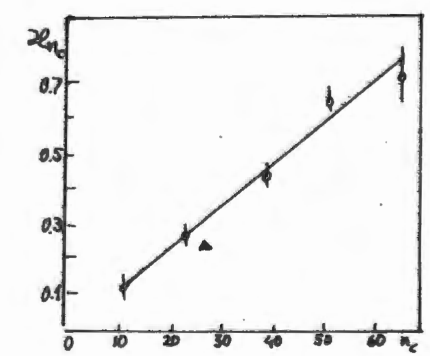

Fig.2

linearly with n_c. Fig.2 shows the values of $\mathcal{L}_{n_c}$ and $\mathcal{L}_{\langle n_c \rangle}$ as functions of n_c and $\langle n_c \rangle$, respectively. The solid curve corresponds to the linear approximation $\mathcal{L}_{n_c} = (0{,}006 \pm 0{,}002) n_c + (0{,}129 \pm 0{,}094)$, that can also be justified within the above approach.

It is easily seen that under an uncorrelated production of particles of different types $\langle n_i (n_j) \rangle = \langle n_i \rangle$, $i \neq j$, and the ratio

$$L(z_c, \nu) = \frac{\mathcal{L}_{n_c}}{\mathcal{L}_{\langle n_c \rangle}}$$

depends linearly on n_c. Under the correlated production of particles of several types the ratio $\frac{\langle n_i (n_j) \rangle}{\langle n_i \rangle}$, as it has been shown in ref. [8], can be represented in the following unified automodel form:

$$\Phi^i(z_c, \nu) \equiv \frac{\langle n_i (n_j) \rangle}{\langle n_i \rangle} = z_c \frac{\Psi(\nu, a+1, \frac{a}{\nu} z_c)}{\Psi(\nu-1, a, \frac{a}{\nu} z_c)}, \qquad (6)$$

where $\Psi(\alpha, \beta, x)$ is the degenerate hypergeometric function, $z_c = \frac{n_c}{\langle n_c \rangle}$, and the parameter a is given by the condition

$$\sum_{i=1}^{\nu} \frac{\langle n_i^2 \rangle}{\langle n_i \rangle^2} + 2 \sum_{i \neq j = 1}^{\nu} \frac{\langle n_i n_j \rangle}{\langle n_i \rangle \langle n_j \rangle} = \nu^2 \left(\frac{1}{a} + 1 \right). \qquad (7)$$

As it is seen from (7), the parameter a has the meaning analogous to the Wroblewsky parameter: $\sqrt{a} = \frac{\langle n \rangle}{D}$ at $\nu = 1$.

Then, using the identities (see ref. [7])

$$\gamma_i \langle n_i \rangle = \gamma_j \langle n_j \rangle, \quad i, j = 1, \dots, \nu$$

we get

$$L(z_c, \nu) = \frac{z_c}{\nu} + \frac{\nu - 1}{\nu} \Phi(z_c, \nu). \qquad (8)$$

The analysis of expression (8) shows that at $\nu \gg 1$ one can make a substitution

$$L(z_c, \nu \gg 1) \equiv L(z_c) = \Phi(z_c, \nu). \qquad (9)$$

Fig.3 shows the dependence of $L(z_c)$ on z_c. From it we get the following value for the parameter a: $\sqrt{a} \simeq 1{,}79 \pm 0.78$, that is in good agreement with the relevant experimental value[4]

$$\frac{\langle n \rangle}{D} \simeq 1.8.$$

Thus, in the framework of the automodel analysis we have considered the pseudorapidity distributions in the central region of secondary production. For the corresponding "anomalous dimension" of the solution of the renormalization group equation, a linear increase with multiplicity is found. A good description is achieved of the experimental data on pseudorapidity semi-inclusive distributions in pp collisions at $\sqrt{S}$ =540 GeV obtained at the SPS Collider.

2. Hence, within the multicomponent cluster model [3] one can obtain a good agreement with the experimental data on the characteristics of multiple production at high energies. Let us describe briefly the basic assumptions of the model. The model is constructed within the multicomponent approach (see refs.[1,2]) by assuming two particle-production mechanisms in the hadron--hadron collisions:

i) dissociation of colliding particles with the production of secondaries;

ii) independent emission of different types of neutral hadron associations (clusters) in the central region.

For the probability of distribution over the number of clusters, decaying into $n_1, n_2, \ldots$ charged particles, we get

$$W^{i,j}_{n_1,n_2,\ldots} = \alpha_i \beta_j P_{n_1}(\langle n_1\rangle) P_{n_2}(\langle n_2\rangle) \ldots \tag{10}$$

where α_i and β_i are the probabilities of the i-th and j-th dissociation channels of colliding hadrons; $n_\ell, \langle n_\ell\rangle$ are the multiplicity and average multiplicity of clusters of the type ℓ; $P_n(\langle n\rangle)$ is the Poisson distribution. Note, that this formula for the probability is justified in the framework of field theory in the straight-line path approximation [9]. Then, using the experimental indications that the colliding particles dissociate not more than into three charged particles and that the clusters decay through hadron associations of the type $\sigma \to 2\pi$, $\omega \to 3\pi$ and $B \to 4\pi$, we get for the distribution over charged particle multiplicity

$$W_n = \alpha^2 \sum_{i=0}^{[\frac{n-2}{4}]} P_i(b) P_{\frac{n-2-4i}{2}}(a) + 2\alpha\beta \sum_{i=0}^{[\frac{n-4}{4}]} P_i(b) P_{\frac{n-4-4i}{2}}(a) + \beta^2 \sum_{i=0}^{[\frac{n-6}{4}]} P_i(b) P_{\frac{n-6-4i}{2}}(a), \tag{11}$$

where a and b are the average numbers of clusters decaying into 2 and 4 charged particles, respectively; α is the probability of dissociation into not more than one charged particle, $\beta = 1-\alpha$, and $[A]$ is the integer of A. With W_n, one can easily calculate the average multiplicity and other correlation moments

$$\langle n\rangle = 2a + 4b + 2 + 2\beta,$$
$$f_2 = \langle n\rangle + 4b - 8\beta^2 - 4, \tag{12}$$

etc.

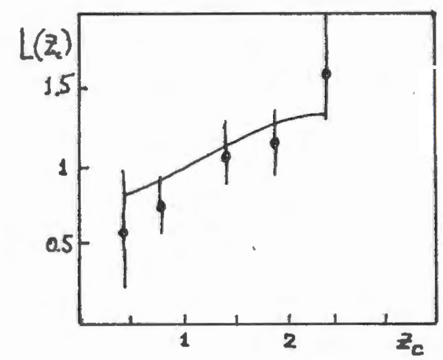

Fig.3

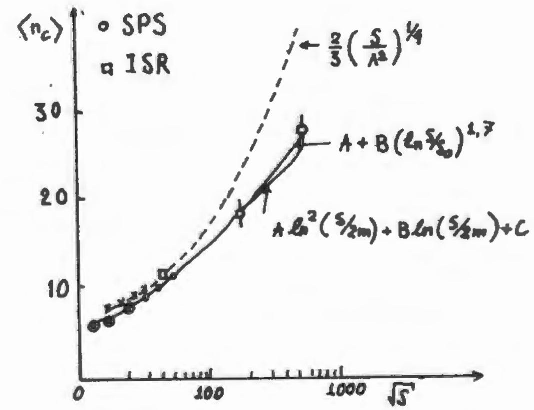

Fig.4

The energy dependence of the parameters α , a and b is found from the comparison of the formulae obtained with the experimental data on charge distributions and average multiplicity for the $\bar{p}p$, pp, $K^{\pm}p$ and $\pi^{\pm}p$ interactions in the ISR energy region 100 $\div$ 4000 GeV^2 [10]

$$a = a_1 (\ln s/s_0)^{a_2}, \quad b = a_3 (\ln s/s_0)^{a_2}, \quad \alpha = \frac{1 + a_4 \ln s/s_0}{1 + \ln s/s_0} . \tag{13}$$

The constants a_1, a_2, ... a_4 turn out to be related with the quantum numbers (mass and charge of colliding particles) as follows:

$$\begin{aligned} a_1 &= A_1 (m_a + m_b)^2 \\ a_2 &= A_2 + A_3 (m_a + m_b)^2 + A_4 (\ell a + \ell b)^2 \\ a_3 &= A_5 (m_a + m_b)^2 \\ a_4 &= A_6 + A_7 (m_a + m_b)^2 , \end{aligned} \tag{14}$$

where the values of A_1, ... are determined from the aforementioned joint description of the experimental data (see the table), the experiment being described quite satisfactorily

$$\chi = \frac{295}{185} = 1,6 . \tag{15}$$

Table

i	$A_i \pm \Delta A_i$	i	$A_i \pm \Delta A_i$
1	0.513 $\pm$ 0.041	6	2.226 $\pm$0.072
2	0.058 $\pm$ 0.020	7	−0.162 $\pm$0.070
3	0.029 $\pm$ 0.008	8	−0.006 $\pm$0.001
4	0.013 $\pm$ 0.002		

Fig.4 illustrates the diagram of the dependence of average charged multiplicity on energy. Note, that the corridor of errors for $\langle n \rangle$ is about 10% and increases with energy. As one

can easily see from the table and above formulae, the model described predicts a more rapid than logarithmic increase with energy for the average multiplicity $\langle n \rangle \sim (\ln s/s_0)^{1,7}$ in $\bar{p}p$ collisions.

This prediction is in agreement with the recent results on the average multiplicity $\langle n \rangle$ in $\bar{p}p$ collisions at $\sqrt{s}$ =540 GeV [3] : $\langle n \rangle^{expt}$ =27.4 $\pm$ 2.0 $\langle n \rangle^{th} \simeq$ 27.7$\pm$3 It is worth mentioning that the obtained in ref. [4] increase in pseudorapidity particle density in the central region 3.0 $\pm$ 0.1 confirms the increase in the contribution of multiparticle heavy clusters to the production of secondaries, which has been indicated in the model under consideration.

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Описание характеристик множественного рождения адронов при сверхвысоких энергиях в многокомпонентном подходе

В рамках автомодельного анализа исследовано распределение по псевдобыстроте в центральной области рождения вторичных частиц. Дано описание поведения пика этого распределения с ростом n_c , наблюдаемого в UA5 эксперименте. Некоторые предсказания в рамках многокомпонентной кластерной модели сравниваются с данными, полученными в UA5 эксперименте. Показано удовлетворительное согласие экстраполяции этой модели и данных при $\sqrt{s}$ = 540 ГэВ.

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Description of Multihadron Production at Superhigh Energies in the Multicomponent Approach

The pseudorapidity distribution in the central region of the production of secondarics is investigated in the framework of the automodel approach. The narrowing and increase in the peak of this distribution with increasing of n_c , which have been observed in the UA5 experiment, are described. Some predictions made within the multicomponent cluster model are compared with the data obtained in the UA5 at the SPS collider. An extrapolation of this model describing well the data at ISR energy is shown to be in a satisfactory agreement with the data at $\sqrt{s}$ = 540 GeV.

The investigation has been performed at the Laboratory of Theoretical Physics, JINR.

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