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THE MANY COMPONENT MODEL OF INDEPENDENT EMISSION OF CLUSTERS AND THE DESCRIPTION OF DATA ON CHARGED PARTICLE DISTRIBUTIONS. CHARGE-NEUTRAL AND "FORWARD-BACKWARD" CORRELATIONS AT HIGH ENERGIES

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Многокомпонентная модель независимого испускания кластеров и описание данных по зарядовым распределениям, зарядово-нейтральным и "вперед-назад"-корреляциям при высоких энергиях

Приводится описание зарядовых распределений и зарядово-нейтральных корреляций на основе многокомпонентной модели, включающей в себя статистически независимое рождение нейтральных кластеров в центральной области при наличии определенных каналов диссоциации сталкивающихся частиц.

Показано, что при энергиях $E_L \geq 100$ ГэВ основной вклад в распределения по числу заряженных частиц дают тяжелые кластеры (Cl. → 4π). Производится оценка массы такого кластера. Показывается, что "загиб" вниз функций $f(n_{ch}) = \langle n_{\pi^0} \rangle_{n_{ch}}$, где n_{π^0} – число π^0 – мезонов, а n_{ch} – число заряженных частиц, вполне объясняется кинематическими ограничениями.

На основе простых предположений о распределении продуктов распада кластера в пространстве быстрот дано объяснение недавно появившимся данным о корреляциях типа "вперед-назад".

Работа выполнена в Лаборатории теоретической физики ОИЯИ.

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The Many Component Model of Independent Emission of Clusters and the Description of Data on Charged Particle Distributions, Charge-Neutral and "Forward-Backward" Correlations at High Energies

The charged particle distributions and charge-neutral correlations are described within the many component model involving statistically independent production of neutral clusters in the central region in the presence of certain dissociation channels of colliding particles.

It is shown that at energies $E_L \geq 100$ GeV the main contribution to the distributions over a number of charged particles is given by heavy clusters (Cl.→4π). The mass of such a cluster is evaluated. It is also shown that the bending of the function $\langle N_{\pi^0} \rangle_{N_{ch}}$, where N_{π^0} is the number of π^0 -mesons and N_{ch} is the number of charged particles, is interpreted within the kinematic constraints.

Based on simple assumptions about the distribution of the decay products of clusters in the rapidity space the recent data on the "backward-forward"-type correlations are explained.

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1. Introduction

The present paper is devoted to the description of some regularities of multiple production within the many component phenomenological model of two mechanisms [1].

The many component nature of charged particle distributions at high energies is sufficiently justified at present. However, the number of components and their relation is still to be discussed (for the discussion of this problem see, for instance, the review papers [2]). The origin of different components in the multiplicity distributions of charged particles can be explained, as is known, under the assumption about the existence of two mechanisms of secondary particle production: diffraction excitation (DF) of colliding hadrons and the mechanism of independent emission (MIE) in the central region.

Without specifying the dynamics of interaction resulting in different mechanisms of particle production, we shall use the phenomenological assumptions about the nature of secondary particle production affected by each of these two mechanisms.

In recent years of wide use is the hypothesis on clustering of secondaries in the central region (CR) (see, for instance, ref. [2,3]). It should be noted that there are different viewpoints concerning the characteristics of clusters such as their charge, average multiplicity of the decay, mass and so on*).

*) For various models describing the production and decay of different clusters, see, for instance, the papers [4-6].

Unfortunately, it is very difficult to measure the clusters. Therefore, the assumptions about the properties of clusters and the regularities of their production and decay can be verified by comparing the dependence obtained on the basis of these assumptions with the experimental data.

In this paper § 2 contains short formulation of the basic statements of the model of two mechanisms which is then used for the description of charge particle distributions and charge-neutral correlations in pp -collisions (§ 3) and for the explanation of recent data on "forward-backward" correlations (§ 4).

2. Formulation of the Cluster Phenomenological Model of Two Mechanisms

The model of two mechanisms is based on the assumption about statistically independent (neglecting the kinematic restrictions) production of neutral clusters in the central region when certain dissociation channels of leading particles are open. The cluster multiplicity distribution in the central region is of the Poisson nature. An analogous dependence can be obtained in the field-theoretical models with bremsstrahlung[7], sources[8], and within the straightline path approximation[9] in quantum field theory.

The cluster rapidity

$$y = \frac{1}{2} \ln \frac{E_p + p_{\parallel}}{E_p - p_{\parallel}}$$

is in the interval $[-Y, Y]$, where $Y \sim \ln S$,and S is the square of the total energy in the center of mass system. If the clusters are produced with equal probability in this interval of rapidities, then in the absence of the kinematic restrictions

the distribution over a number of clusters is

$$W_n = P_n(\langle n \rangle) = e^{-\langle n \rangle} \cdot \frac{\langle n \rangle^n}{n!}$$

and $\langle n \rangle \sim Y$. Let us classify the clusters according to their decay modes. The production of clusters disintegrating into

two pions: $\sigma \to \pi^+\pi^-, \ \pi^0\pi^0$

three pions: $\omega \to \pi^0\pi^+\pi^-$

four pions: $\beta \to 2\pi^+2\pi^-, \ \pi^+\pi^-2\pi^0, \ 4\pi^0$

and so on.

A specific feature of the multiple production processes is the "broadening" with increasing energy of charged particle distributions. Thus, one may assume that with increasing energy large contribution is given by much heavier clusters (not σ- and ω- ,but β -clusters and so on).

This fact has already been pointed out in ref.[3]. The increasing slope of the dependence $f(n_{ch}) = \langle n_{\pi^0} \rangle_{n_{ch}}$ in πp-interactions with increasing energy also accounts for the above fact (see, for instance, ref.[10]). The results of our description of the multiplicity distributions and charge-neutral correlations in pp-collisions confirm this conclusion (see § 3).

Hereafter we shall change the masses of clusters M by their mean values $\bar{M}$.

The diffraction excitation mechanism gives the contribution mainly to the channels with small multiplicity of secondaries. In what follows we shall need some concrete schemes of the proton dissociation. Let us write them out

1. $p \to p$ (DE is absent).

2. $p \to \pi^0 p$.

3. $p \to n \pi^+$.

4. $p \to p \pi^0 \pi^0$.

5. $p \to n \pi^+ \pi^0$.

6. $p \to p \pi^+ \pi^-$.

Note, that at high energies, one should take into account the contribution of other dissociation channels (for instance, $p \to N 3\pi$ and so on).

The leading clusters carry away the finite part of the energy, and the sum energy of clusters in the central region is then equal to

$$E' \simeq \sqrt{S} \cdot (1-x_1)(1-x_2) ,$$

where

$$x_{1,2} = \frac{2\,|q'_{1,2\parallel}|}{\sqrt{S}} ,$$

$q'_{1,2\parallel}$ are the longitudinal momenta of leading clusters, and $\sqrt{S}$ is the total energy of incident particles in the c.m. system. Under the assumption of small momenta of clusters, the conservation law of momenta influences slightly the multiplicity distribution,etc. However, since the masses of clusters cannot be already considered to be small, at large multiplicities one should take into account the restrictions imposed by the conservation of energy law. We take into account the conservation of energy law in the following way: Let us assume that the masses of all produced clusters do not exceed E' , i.e.,let us add to the multiplicity distribution the multiplier

$$\theta[E' - \Sigma \bar{M}] .$$

Thus, the total multiplicity distribution of clusters in the central region is

$$W_{n_\sigma n_\omega n_B \ldots} = \frac{1}{W(E')} \cdot \prod_i P_{n_i}(\langle n_i \rangle)\, \theta[E' - \Sigma M] , \qquad (2.2)$$

where $i = \sigma, \omega, B$ and so on.

The distribution (2.2) is normalized, and $W(E')$ is the normalization factor.

The differential cross section of the production of n_σ σ-clusters, n_ω ω-clusters and so on under the assumption that the leading particles are excited in the i-th and j-th channels, respectively, is

$$\frac{1}{\sigma_{inel.}} \cdot \frac{d\sigma^{ij}_{n_\sigma n_\omega \ldots}}{dx_1\, dx_2} = F_{ij}(x_1 x_2 | S)\; W_{n_\sigma n_\omega \ldots}(E') . \qquad (2.3)$$

The basic relation in the considered model is (2.3), which is used as the initial one for constructing the distributions, etc. Integrating it over dx_1 and dx_2 , we obtain

$$\frac{\sigma^{ij}_{n_\sigma n_\omega \ldots}}{\sigma_{inel.}} = \int dx_1 dx_2\; F_{ij}(x_1 x_2 | S)\; W_{n_\sigma n_\omega \ldots}(E') .$$

This expression can be simplified by changing in the integral $E' \simeq \sqrt{S}(1-x_1)(1-x_2)$ by some mean value $\bar{E}'$. Then we have

$$\frac{\sigma^{ij}_{n_\sigma n_\omega \ldots}}{\sigma_{inel.}} = F_{ij}(S) \cdot W_{n_\sigma n_\omega \ldots}(\bar{E}') . \qquad (2.4)$$

We use the logarithmic parametrization for the dependence of average numbers of clusters on the energy in the energy interval under consideration, i.e.,

$$\langle n_i \rangle = A_i + B_i \ln \frac{S}{S_0} ,$$

$$S_0 = 1\ GeV^2 .$$

Using (2.4) one can easily obtain the distributions over the number of combinations $\pi^+\pi^-$, $\pi^+\pi^-\pi^0$, $2\pi^+2\pi^-$, ... produced in the decay of ρ-, ω-, B- and other clusters, respectively

$$W^{ij}_{n_{\pi^+\pi^-},\, n_{\pi^+\pi^-\pi^0},\dots} = F_{ij} \prod_{\ell} P_{n_\ell}(\langle \tilde{n}_\ell \rangle)\, \theta[\bar{E}' - \sum n_{\ell'} \bar{M}_{\ell'}], \qquad (2.5)$$

where $\langle \tilde{n}_\ell \rangle = \langle n_{\pi^+\pi^-} \rangle, \langle n_{\pi^+\pi^-\pi^0} \rangle, \dots$ and $\bar{M}_{\ell'}$ are the corresponding average masses.

Obviously, the number of charged particles n_{ch} and the number of π^0-mesons n_{π^0} are connected with $n_{\pi^0\pi^0}, n_{\pi^+\pi^-}, \dots$ by the relations

$$\begin{aligned} n_{ch} &= 2n_{\pi^+\pi^-} + 2n_{\pi^+\pi^-\pi^0} + 2n_{\pi^+\pi^-2\pi^0} + 4n_{2\pi^+2\pi^-} + \ell^{(1)i}_{ch} + \ell^{(2)j}_{ch} \\ n_{\pi^0} &= 2n_{\pi^0\pi^0} + n_{\pi^+\pi^-\pi^0} + 2n_{\pi^+\pi^-2\pi^0} + 4n_{4\pi^0} + \ell^{(1)i}_{\pi^0} + \ell^{(2)j}_{\pi^0}, \end{aligned} \qquad (2.6)$$

where $\ell^{(1,2)i}_{ch\,(\pi^0)}$ are the numbers of charged particles (π^0-mesons) in the i-th dissociation channel of the first (second) leading hadron.

The distribution over the number of charged particles acquires the form

$$W_{n_{ch}} = \sum_{ij} F_{ij} \cdot \sum_{n_K} \prod_K P_{n_K}(\langle \tilde{n}_K \rangle) \times \theta[\bar{E}' - \sum n_\ell \bar{M}_\ell] \cdot \delta_{n_{ch};\, 2n_{\pi^+\pi^-} + \dots + \ell^{(2)j}_{ch}}. \qquad (2.7)$$

Analogously, for the function $\langle n_{\pi^0} \rangle_{n_{ch}}$ we have

$$\langle n_{\pi^0} \rangle_{n_{ch}} = \frac{1}{W_{n_{ch}}} \cdot \sum_{ij} F_{ij} \sum_{n_\ell} (2n_{\pi^0\pi^0} + \dots + \ell^{(2)j}_{\pi^0}) \times \prod_{\ell'} P_{n_{\ell'}}(\langle \tilde{n}_{\ell'} \rangle) \cdot \theta[\bar{E}' - \sum n_K \bar{M}_K] \times \delta_{n_{ch};\, 2n_{\pi^+\pi^-} + \dots + \ell^{(2)j}_{ch}}. \qquad (2.8)$$

Hereafter, we use the assumption about the factorization of the factor F_{ij}, i.e.,

$$F_{ij} = F_i F_j .$$

The quantities F_i play the role of probabilities of the corresponding dissociation channels. The normalization condition

$$\sum F_i = 1$$

is fulfilled.

Due to the local conservation of an isospin, we obtain

$$F_3 = 2F_2 .$$

3. The Description of Charged Particle Distributions and Charge-Neutral Correlations in pp-Interactions at $E_L \gtrsim 102$ Ge

Using relations (2.7), (2.8) and the factorization condition, we obtain

$$\begin{aligned} W_{n_{ch}} = \sum \prod_K P_{n_K}(\langle \tilde{n}_K \rangle) \cdot \theta[\bar{E}' - \sum_\ell n_\ell \bar{M}_\ell] \times \\ \times \{ V_1^2 \cdot \delta_{n_{ch};\, 4n_1+2n_2+2} + 2V_1(1-V_1) \cdot \delta_{n_{ch};\, 4n_1+2n_2+4} + \\ + (1-V_1)^2 \cdot \delta_{n_{ch};\, 4n_1+2n_2+6} \} \end{aligned} \qquad (3.1$$

$$\begin{aligned} \langle n_{\pi^0} \rangle_{n_{ch}} = \frac{1}{W_{n_{ch}}} \cdot \sum \prod_K P_{n_K}(\langle \tilde{n}_K \rangle) \cdot \theta[\bar{E}' - \sum_\ell n_\ell \bar{M}_\ell] \times \\ \times \{ [V_1^2 \cdot (2n_2+4n_3) + 2V_1 V_2] \cdot \delta_{n_{ch};\, 4n_1+2n_2+2} + \\ + [2V_1(1-V_1) \cdot (2n_2+4n_3) + 2(1-V_1)V_2] \; \delta_{n_{ch};\, 4n_1+2n_2+4} + \\ + (1-V_1)^2 \cdot (2n_2+4n_3) \cdot \delta_{n_{ch};\, 4n_1+2n_2+6} \}. \end{aligned} \qquad (3.2$$

$$n_1 = n_{2\pi^+2\pi^-}; \quad n_2 = n_{\pi^+\pi^-2\pi^0}, \quad n_3 = n_{4\pi^0}$$

for the multiplicity distributions $W_{n_{ch}}$ and charge-neutral correlations. The quantities V_1 and V_2 are simple combinations of the parameters F_i :

$$V_1 = \sum_1^5 F_i \ ,$$
$$V_2 = F_5 + 2F_6 \ .$$

Note, that with increasing energy (and increasing number of channels), the quantities V_1 and V_2 will comprise a larger number of constituents. Accordingly, a larger number of components will appear in the multiplicity distributions. The increase in the number of components in the distributions with increasing energy is a specific feature of the given model. Thus, the model predicts the "broadening" of distributions $W_{n_{ch}}$ with increasing energy and the bending of the curve $\langle n_{\pi^0} \rangle_{n_{ch}}$ at large n_{ch} , which is due to the kinematic restrictions.

Formulae (3.1) and (3.2) have been used for the description of multiplicity distributions $W_{n_{ch}}$ at energies E_L=102, 205, 303, 1480 and 2100 GeV (the data are taken from/11/) and of $\langle n_{\pi^0} \rangle_{n_{ch}}$ at E_L=205 GeV/12/. As a result, a statistically good description of these data is obtained (see Figs. 3.1 ÷ 3.6).

The experimental material used comprises 81 points. Two points (the values of $W_{n_{ch}}$ at n_{ch} =10 at E_L=1480 GeV and 2100 GeV are not on the smooth curve). The description of the remaining 79 points gave χ^2=74.

The best description is achieved when the cluster mass is

$$\overline{M}_B \simeq 2{,}1 \ \mathrm{GeV/c^2}$$

what is in agreement with the accepted values of this quantity (see, for instance,/3/).

The inelasticity coefficient is equal to

$$\xi = \frac{\bar{E}'}{\sqrt{s}} \simeq 0{,}61 \ .$$

From the comparison with the experimental data, for the quantities V_1 and V_2 ,we obtain

$$V_1 = V_{11} + V_{12} \ln \frac{s}{s_0} \ ,$$
$$V_{11} = 0{,}6 \pm 0{,}04 \ ,$$
$$V_{12} = 0{,}1 \pm 0{,}05 \ .$$
$$V_2 = 0{,}32 \pm 0{,}08 \ .$$

For $\langle n_B \rangle = A + B \ln \frac{s}{s_0}$,we obtain

$$A = 1{,}25 \pm 0{,}07 \ ,$$
$$B = 0{,}8 \pm 0{,}08 \ .$$

The "bending" of the curve $f_{n_{ch}} = \langle n_{\pi^0} \rangle_{n_{ch}}$,as it was already mentioned, is due to the kinematic restrictions only .

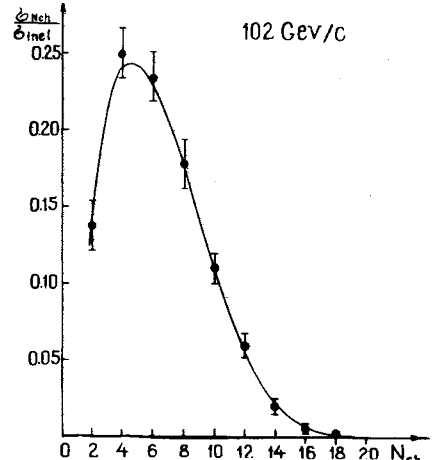

Fig. 3.1. The multiplicity distribution at E_L=102 GeV.

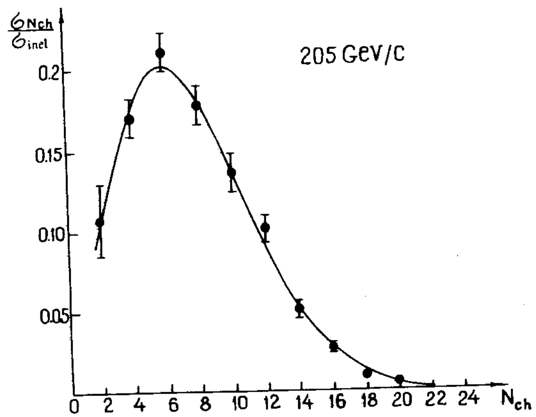

Fig. 3.2. The multiplicity distribution at E_L=205 GeV.

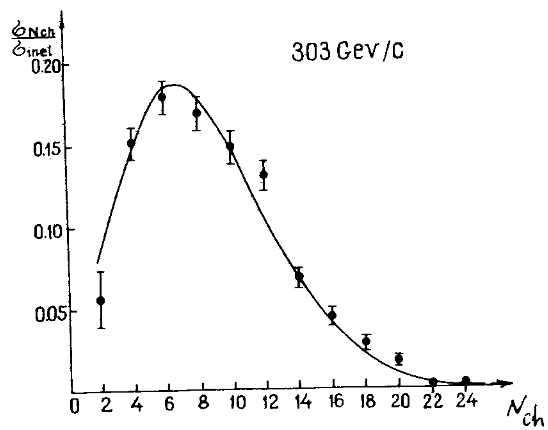

Fig. 3.3. The multiplicity distribution at E_L=303 GeV.

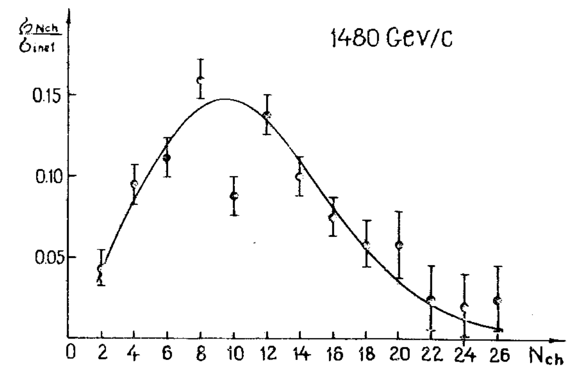

Fig. 3.4. The multiplicity distribution at E_L=1480 GeV.

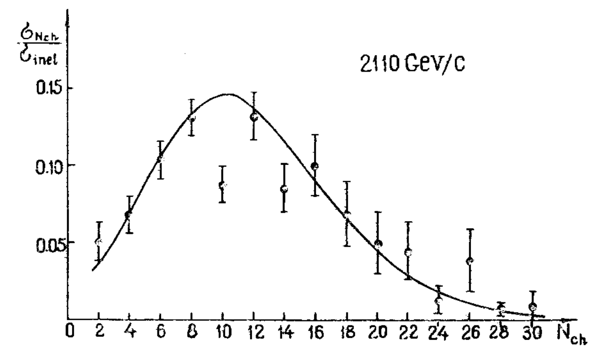

Fig. 3.5. The multiplicity distribution at E_L=2100 GeV .

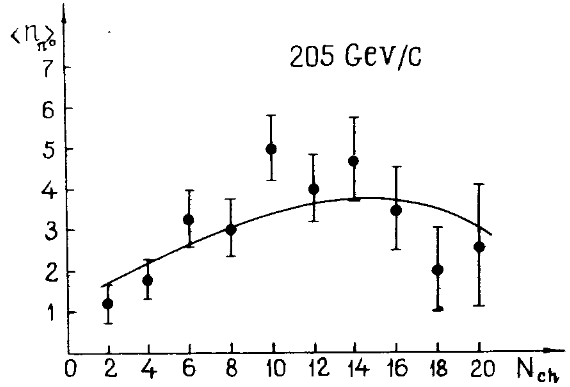

Fig. 3.6. Charge-Neutral Correlations at E_L=205 GeV.

4. The "Forward-Backward"-Type Correlations in the Model of Two Mechanisms

Now let us describe the "forward-backward"-type correlations between charged particles. The data obtained recently by the ACHM-collaboration/13/ have shown that the average number of particles in the "forward" hemisphere (in the center of mass system) $\langle n^{(F)} \rangle_{n(B)}$ increases linearly with increasing number of particles in the "backward" hemisphere $n^{(B)}$, the slope being of an order of 1/3.

This testifies to the strong short-range correlations. Now we shall show how this dependence can be explained within the model with uncorrelated production of neutral clusters. (The contribution of the dissociation products and the kinematic restrictions are neglected).

We use the assumption that the rapidities of σ-clusters, which are produced in the decay of B-cluster, are close to the rapidity of B-cluster, i.e.,

$$y_\sigma \approx y_B$$

and the rapidities of pions, which are produced in the decay of σ-clusters, have the rapidities

$$y_\pi = y_\sigma \pm \Delta ,$$

where $y_{\sigma(B)}$ is the rapidity of σ(B)-cluster, and Δ is a certain parameter. Generally, the result depends weakly on the form of the distribution over the pion rapidity.

B-cluster disintegrates into the combinations $2\pi^+2\pi^-$, $\pi^+\pi^-2\pi^0$ and $4\pi^0$. The combination of four π^0-mesons does not contribute to the correlation dependences of charged particles. The distribution over $n_{2\pi^+2\pi^-}$, $n_{\pi^+\pi^-2\pi^0}$ has the form

$$W'_{n_{2\pi^+2\pi^-},\, n_{\pi^+\pi^-2\pi^0}} = P_{n_{2\pi^+2\pi^-}}(D)\, P_{n_{\pi^+\pi^-2\pi^0}}(D) ,$$

where

$$D = \langle n_{2\pi^+2\pi^-} \rangle = \langle n_{\pi^+\pi^-2\pi^0} \rangle .$$

The whole rapidity interval can be devided into three regions $[-Y,-\Delta]$, $[-\Delta,\Delta]$ and $[\Delta, Y]$. If the rapidity of B-cluster disintegrated into the combination $2\pi^+2\pi^-$ is in the interval $[-Y,-\Delta]$, then, obviously, all four charged pions fly "backward", and if, in the interval $[-\Delta, \Delta]$, then two charged pions fly "forward" and two "backward", etc...

The probability of a cluster to get into the regions $[\Delta, Y]$, $[-\Delta,\Delta]$ and $[-Y,-\Delta]$ is equal to

$$\omega_1 = \frac{Y-\omega}{2Y} = \frac{1}{2} - \frac{1}{2}\omega$$
$$\omega_2 = \omega$$
$$\omega_3 = \frac{1}{2} - \frac{1}{2}\omega$$

respectively, where

$$\omega = \frac{\Delta}{Y} .$$

The probability of the rapidities of n_1 combinations $2\pi^+2\pi^-$ to get into the first interval, n_2, to the second, and n_3, to the third, and of the rapidities of the numbers of combinations $K_{1;2;3}$ $\pi^+\pi^-2\pi^0$ to get to the first, second and third intervals, respectively, is

$$W_{n_1,\dots K_3} = \Pi\, P_{n_i}(D_i)\, P_{K_i}(D_i) \;; \qquad D_i = D\,\omega_i .$$

The numbers of "forward" and "backward" particles are related to $n_1,\dots K_3$ by

$$n^{(F)} = 4n_1 + 2n_2 + 2K_1 + K_2 + 1 \,,$$

$$n^{(B)} = 2n_2 + 4n_3 + K_2 + 2K_3 + 1 \,.$$

The distribution over the number of particles flying "backward" has the form

$$W_{n^{(B)}} = \sum_{n_1,\dots K_3} \prod_{i=1}^{3} P_{n_i}(D_i)\, P_{K_i}(D_i)\cdot \delta_{n^{(B)};\,2n_2+4n_3+K_2+2K_3+1} =$$

$$= \sum_{n_2 n_3} P_{n_3}(D_3)\, P_{n_2}(D_2)\cdot P_{n^{(B)}-1-4n_3-2n_2}(D_2)$$

and the function $\langle n^{(F)}\rangle_{n^{(B)}}$ is represented as

$$\langle n^{(F)}\rangle_{n_B} = \frac{1}{W_{n^{(B)}}}\cdot \sum \prod_{i=1}^{3} P_{n_i}(D_i)\, P_{K_i}(D_i)\,\times$$

$$\times\,(2n_2+4n_1+2K_1+K_2+1)\cdot\delta_{n^{(B)};\,2n_2+4n_3+K_2+2K_3+1} =$$

$$= n^{(B)} + 6D_1 - \frac{2}{W_{n^{(B)}}}\cdot\sum_{n_2 n_3 K_3}(2n_3+K_3)\,\times$$

$$\times\, P_{n_2}(D_2)\, P_{n_3}(D_3)\cdot P_{K_3}(D_3)\cdot P_{n^{(B)}-1-4n_3-2n_2-2K_3}(D_2)$$

The last two formulae predict the linear increase at $n^{(B)} \gtrsim 5$ (see, fig. 3.7).

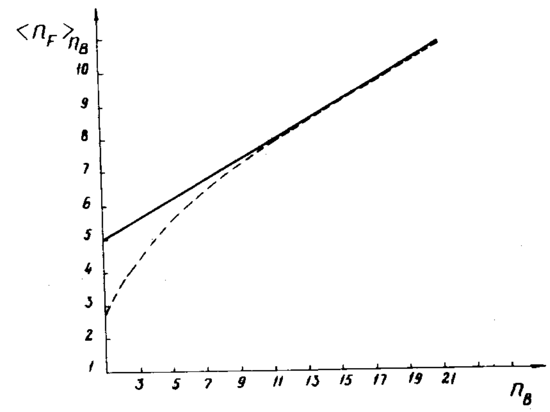

Fig. 3.7. The dependence of the average number of particles emitted in the "forward", direction as a function of the number of particles emitted in the "backward" direction

The deviation of the theoretical curve from the experimental one (at $\sqrt{s} = 5$ GeV) at small values $n^{(B)}$ is due to the fact that we have not taken into account the contribution of the diffraction component.

The parameter Δ is sufficiently large and equals

$$\Delta \approx 0{,}6\; Y$$

what accounts for a rather large slope of the curve.

At $Y \sim 1{,}5 \div 3$, $\Delta \sim 1$, what is in agreement with other estimates of this quantity.

The agreement of theoretical results with the experimental ones testifies to the assumption that the neutral clusters dominate, and allows one to find the probabilities of various dissociation channels within the model under consideration.

So, the idea to unify two mechanisms of secondary particle production, namely, a) the mechanism of independent production (neutral clusters) in the central region; b) the mechanism of dissociation of leading particles with local conservation of charge and other quantum numbers appeares to be rather fruitful and makes it possible to explain a wide spectrum of experimental regularities. Besides, the comparison of the theoretical dependences with the experimental ones allows one to obtain within our model the numerical estimates for physical quantities such as average mass of clusters, inelasticity coefficient and others.

Of much interest is the theoretical and experimental investigation of possible separation of contributions from various mechanisms. Besides, it would be desirable to check experimentally the effect of "clusterization", and particularly, the assumption about the dominance of clusters in the central region with zero charge.

In conclusion we are grateful to Professors A,N.Tavkhelidze and V.A.Matveev for interest in this work and stimulating comments. Thanks are also to I.V.Andreev, Yu.A.Budagov, I.M.Dremin, N.P.Zotov, S.P.Kuleshov, V.I.Savrin and L.A.Slepchenko for useful discussions.

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