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THE TOPOLOGICAL CHARACTERISTICS IN MULTIPLE PRODUCTION AT HIGH ENERGIES

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Introduction

As is known, about 80% of high energy collisions are accompanied by multiple production of secondaries. Among the characteristics of multipole processes which are most simply measured are the so-called topological cross sections and their correlation moments. Inspite of their integral nature, these values provide rather a detailed information about the process.

The theoretical analysis of the topological characteristics, which is a key problem of multiple production, encounters many difficulties. The main difficulty is to describe uniquely a set of the known properties of different processes.

In recent years a many-component approach to the theory of multiple production has been developing to overcome these problems[1]. It is based on the presence of several production mechanisms of secondaries in each interaction act. This approach is developed in deep relation with the hypothesis about the existence of clusters observed experimentally as correlated groups of particles. Interest in such models stems from the experimental indications to a prevailing number of secondaries produced indirectly (see ref.[2]).

Below, within the proposed phenomenological many-component model of two mechanisms, it is proposed to uniquely describe the topological characteristics and their energy dependences for different types of colliding particles; the physical meaning of different production mechanisms and the properties of hadron associations (clusters) are investigated. Based on the results of the model the predictions are made about the oscillating dependence of an average number of neutral particles on the number of charged particles[9]. Recently, the experimental indications to the existence of this effect have been found[3].

1. The model is constructed under the assumption that there exist two mechanisms of particle production in the hadron-hadron process:

a) dissociations of colliding leading particles with the production of secondaries;

b) independent emission of various neutral hadron associations (clusters) with isospin I = 0.

Based on these assumptions, for the probability of distribution over the number of clusters, we have

$$W^{i,j}_{n_1, n_2, \ldots} = \alpha_i \beta_j P_{n_1}(\langle n_1 \rangle) P_{n_2}(\langle n_2 \rangle) \cdots \qquad (1)$$

where α_i, β_j are the probabilities of the i-th and j-th dissociation channels of an incident and target particle, respectively, n_ℓ, $\langle n_\ell \rangle$ are the multiplicity and average multiplicity of clusters of the type ℓ, $P_n(\langle n \rangle)$ is the Poisson distribution*).

To obtain the observed integral characteristic, topological cross section, one should sum (1) over the number of possible dissociation channels and over the number of clusters taking into account the charge conservation law.

For a concrete phenomenological analysis we may assume that the colliding particles dissociate not more than into three particles and that the probabilities of dissociation into three charged particles are the same both for the incident and target particle[5]. Then we assume for the clusters the following modes of decays: ζ ($\sigma \to \pi^+\pi^-, \pi^0\pi^0$), ω ($\omega \to \pi^+\pi^-\pi^0$), B ($B \to 2\pi^+ 2\pi^-, \pi^+\pi^- 2\pi^0, 4\pi^0$). The scheme does not exclude a possible decay of clusters through the intermediate resonances.

One can easily show that from (1) under the above concrete assumptions, the distribution over multiplicity of charged particles in the processes $ap \to n_{ch} + X_0$ has the form[5]

$$W_{n_c} = \alpha^2 \sum_{n=0}^{\left[\frac{n_c-2}{4}\right]} P_n(b) P_{\frac{n_c-2}{2}-2n}(a) + 2\alpha(1-\alpha) \sum_{n=0}^{\left[\frac{n_c-4}{4}\right]} P_n(b) P_{\frac{n_c-4}{2}-2n}(a) + (1-\alpha)^2 \sum_{n=0}^{\left[\frac{n_c-6}{4}\right]} P_n(b) P_{\frac{n_c-6}{2}-2n}(a), \qquad (2)$$

where a and b are the average numbers of clusters decaying into two and four charged particles, respectively, α is tha probability of dissociating into not more than one charged particle, $[A]$ is the integral part of A.

2. The comparison with the experimental data on the $\bar{p}p$, pp, $K^\pm p$, $\pi^\pm p$ interactions has shown that the proposed scheme describes fairly well the experimental situation at $p_L \gtrsim 100$ GeV.

For comparison we have used the experimental results of ref.[6], which correspond to the following energies: 1) $\bar{p}p$, S= 189 GeV^2, 2) pp, S= 193, 386, 570, 762, 962, 2025, 2810, 3970 Gev^2; 3) K^-p, S= 277 Gev^2; 4) k^+p, S= 189 Gev^2; 5) π^+p, S = 114, 189 Gev^2; 6) π^-p, S = 189, 277, 386 Gev^2. The experimental data included 185 points for the charge distributions and 35 points for the average multiplicity.

*) Formula (1), having an evident physical meaning, is justified within the field-theoretic models in the straight-line-path approximation, which is a theoretical realization of the leading particle hypothesis[4].

For the parameters a and b the following form of the energy dependence*) has been obtained:

$$a = a_1 \left(\ln S/S_0 \right)^{a_2}, \quad b = a_3 \left(\ln S/S_0 \right)^{a_2}, \tag{3}$$

where the parameters a_1, a_2 and a_3 are different for various processes. At that they can be parametrized into a common expression by using mass and charges of colliding hadrons[5].
The experimental points describe satisfactorily $\chi^2 = \frac{295}{185} \simeq 1,6$.
The Table represents the values of the parameters.

Table

	a_1	a_2	a_3	α
$\bar{p}p$	0,101±0,022	1,655±0,085	0,047±0,004	0,774±0,753
pp	0,101±0,022	1,630±0,090	0,047±0,004	0,774-0,753
K^-p	0,059±0,013	1,894±0,076	0,028±0,002	0,694-0,675
K^+p	0,059±0,013	1,868±0,081	0,028±0,002	0,694-0,675
π^-p	0,033±0,007	2,038±0,070	0,016±0,001	0,649-0,630
π^+p	0,033±0,007	2,012±0,075	0,016±0,001	0,649-0,630

3. Based on the model analysis performed, one can make conclusions about certain regularities of multiple distributions and their correlation parameters at high energies and also about certain differences of these characteristics depending on the type of colliding particles.

*) Such a choice stems from the relation of these parameters with the average multiplicity $n_c = 2a+4b+4(1-\alpha)$ (see ref.[5]).

a) The distributions over multiplicity broaden with increasing energy (the distributions are considerably broader than the Poisson distributions with the given average multiplicity). The rate of broadening is different for different processes $V_{pp} \lesssim V_{Kp} \lesssim V_{\pi p}$ at superhigh energies. Such an ordering is ehxibited with increasing energy by the average multiplicity and the rest correlation parametres f_2, f_3, f_4 . Note, that this slight difference in parameters a and b ($a_{2(pp)} < a_{2(Kp)} < a_{2(\pi p)}$) leads to the increasing difference between the correlation parameters of the processes a^+p and a^-p (a=p,K,π), which may turn out to be essential at very high energies.

b) As is seen from formula (3), the ratio of average numbers of clusters decaying into two and four charged particles α and δ is independent of energy. The order of magnitude of this ratio $\frac{\alpha(S)}{\delta(S)} = 2,15$ corresponds to the physical picture in which the four-particle system with isospin I = 0 decays first into two systems with isospins $I_1=I_2=1$, which decay into π-mesons. One can get such a situation by treating, for instance, the four-particle hadron system as a state of two vector ρ-mesons with isospin equal to zero

$$\frac{\omega\left[(\rho\rho)^{I=0} \to \rho^+\rho^- \to \pi^+\pi^0\pi^-\pi^0\right]}{\omega\left[(\rho\rho)^{I=0} \to \rho^0\rho^0 \to \pi^+\pi^-\pi^+\pi^-\right]} = 2 \tag{4}$$

c) The rapidity distribution of clusters decay products in the isotropic decay approximation in the rest frame, neglecting the mass of π-meson, is normalized to unity by the expression

$$D(y,y_c) = \left[2ch^2(y-y_c)\right]^{-1} \simeq \frac{1}{\delta\sqrt{2\pi}} \exp\left[-\frac{(y-y_c)^2}{2\delta^2}\right], \tag{5}$$

where y_c is the rapidity of a decaying cluster, y is the rapidity of a fixed particle from the cluster decay, δ is the approximation parameters*).

Considering the cluster decay in the rest frame ($y_c = 0$), we evaluate the average masses, which have been investigated in the model of two- and four-particle hadron formations. One can easily get[8]

$$\bar{M}_{(2)} \simeq 2\left(m_\pi^2 + \langle P_T^2\rangle\right)^{1/2} \int_{-Y/2}^{Y/2} ch\, y\, D(y;0)\, dy \,, \qquad (6)$$
$$\bar{M}_{(4)} = 2\bar{M}_{(2)} \,,$$

where $Y \sim \ln s/m^2$, $\langle P_T\rangle$ is the mean transverse momentum of secondaries. Substituting into (6) the expression for $D(y, 0)$, we find

$$\bar{M}_{(2)} \simeq \left(m_\pi^2 + \langle P_T^2\rangle\right)^{1/2} e^{\delta^2/2} \qquad (7)$$

At $\langle P_T\rangle \simeq 0{,}4$ GeV/c, $\delta \simeq 0{,}7$ we get, respectively, the values $\bar{M}_{(2)} \simeq 0{,}765$ GeV and $\bar{M}_{(4)} \simeq 1{,}530$ GeV.

It should be mentioned that the mass of two-particle formation turned out to be equal to the mass of ρ-meson.

4. It is clearly seen that the presence of two- and four- (just the number of charged particles is taken into account) particle clusters in the model allows the existence in it of a certain structure in the topological characteristics of processes (see ref.[9]).

a) In the case of topological cross sections it depends on the sum limits in expression (2).

A more attractive characteristic in this sense is the mean multiplicity of neutral particles at fixed number of charged $\langle n_0\rangle_{n_c}$. For simplicity we consider the case when a

*) In the case of π-meson production, the expression is approximated at $\delta \simeq 0{,}72$ (see ref.[7]).

proton dissociates not more than into one charged particle ($\alpha = 1$). We have

$$W_{n_c} = \sum_{n=0}^{\left[\frac{n_c-2}{4}\right]} P_n(\ell)\, P_{\frac{n_c-2}{2}-2n}(a) \,. \qquad (8)$$

Using (8) one can easily get

$$\langle n_0\rangle_{n_c} = C + (a+2\ell)\, W'_{n_c-2} \big/ W'_{n_c} \,. \qquad (9)$$

Substituting into the latter the expression for W_{n_c}, we have (see ref.[9])

$$\langle n_0\rangle_{n_c} = C + \left(a+\frac{a^2}{4\ell}\right)\frac{L_p^{1/2}\left(-\frac{a^2}{4\ell}\right)}{L_p^{-1/2}\left(-\frac{a^2}{4\ell}\right)} - \left(a+\frac{a^2}{2\ell}\right), \quad n_c = 4p+2,\ p=0,1,2,$$

$$\langle n_0\rangle_{n_c} = C + \left(1+\frac{2\ell}{a}\right)(2p+1)\frac{L_p^{-1/2}\left(-\frac{a^2}{4\ell}\right)}{L_p^{1/2}\left(-\frac{a^2}{4\ell}\right)}, \quad n_c = 4p+4,\ p=0,1,2, \qquad (10)$$

where $L_p^s(x)$ are the Laguerre polynomials.

It is seen from (10) that oscillations $\langle n_c\rangle_{n_c}$ can occur along the envelope. Just solving inequalities $\langle n_0\rangle_{n_c} \gtrless \langle n_0\rangle_{n_c+2}$ at different n_c, we get that

$$\langle n_0\rangle_{n_c} < \langle n_0\rangle_{n_c+2} \quad \text{"} \quad n_c = 4p+2 \,,$$
$$\langle n_0\rangle_{n_c} > \langle n_0\rangle_{n_c+2}\,, \quad n_c = 4p+4 \ \text{ for } \ x \equiv \frac{a^2}{4\ell} < x_p^0 \,, \qquad (11)$$

where X_p^o takes the following values:

p	0	1	2	3	4 ...	
X_p^o =	0,5	0,38	0,315	0,272	0,241	(12)

As is seen from (12) at a given $X \equiv \frac{a^2}{4\ell}$ the second inequality in (11) is fulfilled up to a certain P, after which the obtained structure is smoothed (see fig. 1).

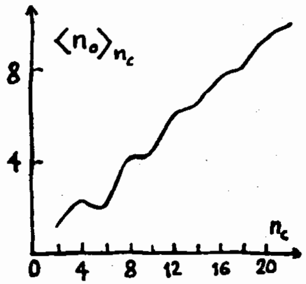

Fig. 1

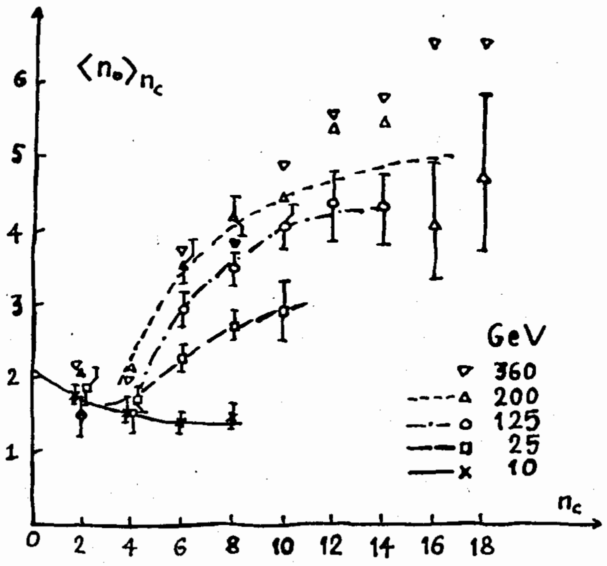

Fig. 2

function $\langle n_o \rangle_{n_c}$ flattening it out at large for this energy values of n_c. At relatively small multiplicities (where the predictions on $\langle n_o \rangle_{n_c}$ can be verified) this quantity behaves differently in experiment. However, it should be mentioned that just at small multiplicities rather a large contribution comes from the diffraction dissociation of incoming particles (see fig.2[3]). The consideration of this fact changes remarkably the picture. The diagram in fig.3 shows relative contributions of the central regions and the diffraction dissociation at various multiplicities of charged particles. The diagram in fig.4 displays the experimental values of $\langle n_o \rangle_{n_c}$ taking into account the contribution from the central region only.

As one can easily see from figs.1 and 4 the experimental situation is well reproduced by the dependence of the average number of neutral particles on the number of charged particles predicted by the model. Unfortunately, owing to large experimental errors, we cannot make a more detailed fitting to determine the model parameters α and δ .

b) Assuming an independent emission of particles from a cluster, one can represent the two-particle distribution function over the rapidities in the form

$$D^{(2)}(y_1, y_2, y_c) = D(y_1, y_c)\, D(y_2, y_c) . \tag{13}$$

Using expressions $D(y, y_c)$ and $D^{(2)}(y_1, y_2, y_c)$, we can represent the two-particle semi-inclusive correlation function $C_{n_c}(y_1, y_2)$ as follows:

$$C_{n_c}(y_1, y_2) = A_{n_c} G(y_1 - y_2) + D_{n_c} , \tag{14}$$

where $G(y_1 - y_2) = \frac{1}{2\sqrt{\pi}\,\delta} \exp\left[-\frac{(y_1-y_2)^2}{4\delta^2}\right]$ is the Gauss distribution, and the coefficients A_{n_c} and D_{n_c} independent of the rapidities are given by different expressions depending on the topology n_c : 1) $n_c = 4p + 2$; 2) $n_c = 4p + 4$ and p= 0, 1, 2,... (see ref.[8]).

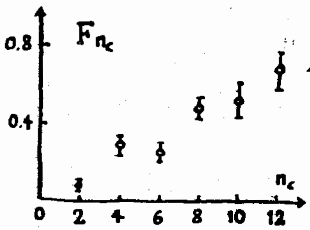

Fig. 3

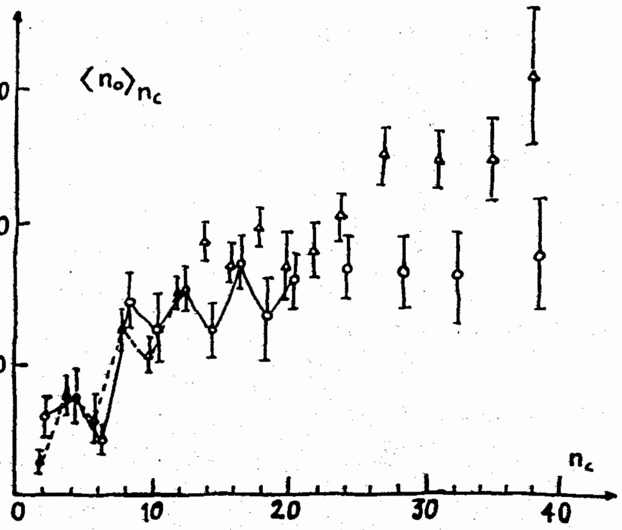

Fig. 4

Analyzing this dependence at extremal values of X : $X \ll 1$ and $X \gg 1$, we get for $n_c \gg 1$

1) $X \ll 1$, $n_c \gg 1$

$$A \sim p, \ D \sim p^2; \ n_c = 4p+2 .$$

$$A \sim p^2, \ D \sim p^4; \ n_c = 4p+4, \quad p = 0, 1, 2, \qquad (15)$$

2) $X \gg 1$, $n_c \gg 1$

$$A \sim p^3, \ D \sim p^4, \ n_c = 4p+2 .$$

$$A \sim p^3, \ D \sim p^6, \ n_c = 4p+4, \quad p = 0, 1, 2, \dots \qquad (16)$$

As is seen from (15), for small $X = \frac{a^2}{4b}$, that corresponds to rather a small portion of clusters decaying into two particles, the coefficients A and D behave differently depending on the event topology n_c . Consequently, the oscillations of the correlation function $C_{n_c}(y_1, y_2)$ as a function of n_c may indicate an increase in the contribution to the multiple process of more many-particle objects*).

5. In conclusion we should like to emphasize that the analysis performed within the phenomenological model indicates an increasing role of many-particle hadron associations (clusters with $n_{cl} \geq 4$) in the processes with large multiplicities, which are not needed for describing the experiments at relatively small energies ($P_L \leq 100$ GeV/c).

A specific property of the obtained expressions for the topological characteristics is their nontrivial dependence on the topology of the process n_c . Conclusion about possible oscil-

*) Note, that such an oscillating behaviour for the topological cross sections has also been obtained in the Regge scheme with multiple vacuum exchange /10/.

lating behaviour of the above-mentioned characteristics comes from different dependence on n_c. The verification of such a dependence testifies to the proposed scheme of production of secondaries through the decay of clusters in the multiple production process. Besides, different behaviour of these characteristics depending on the value of $X = \frac{a^2}{4b}$ provides information on the quantitative ratio of two- and four-particle clusters treated within the model.

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Топологические характеристики в процессах множественного рождения при высоких энергиях

В рамках феноменологической многокомпонентной модели двух механизмов предлагается попытка единого описания топологических характеристик и их энергетической зависимости для различных типов сталкивающихся частиц. Выясняются физический смысл различных механизмов образования и свойства адронных ассоциаций /кластеров/. На основе результатов модели делаются предсказания об осциллирующей зависимости среднего числа нейтральных частиц от числа заряженных $-\langle n_0\rangle_{n_c}$.

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The Topological Characteristics in Multiple Production at High Energies

Within the phenomenological many-component model of two mechanisms, it is proposed to uniquely describe the topological characteristics and their energy dependence for different types of colliding particles. The physical meaning of different production mechanisms and the properties of hadron associations (clusters) are investigated. Based on the results of the model predictions are made about the oscillating dependence of an average number of neutral particles on the number of charged particles $-\langle n_0\rangle_{n_c}$.

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

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Перевод аннотации О.С.Виноградовой.