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Богацкая И.Г., Елисеев С.М., Зиновьев Г.М. **E2 - 10172**

Кластерная модель адронных взаимодействий и рождение нуклонов средних энергий на ядрах

Исследуется возможность применения кластерной модели адронных взаимодействий к интерпретации данных по рассеянию адронов на ядрах при высоких энергиях. Особое внимание уделено роли вторичных нуклонов средних энергий (g -частиц) в механизме адрон-ядерного взаимодействия. Показано, что не всегда удается одновременно согласовать с экспериментом энергетические и угловые распределения g -частиц.

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Clustering Effect in Hadron Collisions and Production of Intermediate Energy Nucleons from Nuclei

A possibility is investigated to interpret the recent data on hadron-nucleus scattering at high energy ($\geq$ 100 GeV) applying the cluster model of hadronic interactions. Special attention is paid to the role of secondary nucleons with intermediate energies (g-particles). In looking for the mechanism of the hadron-nucleus interaction the importance of simultaneous fitting the data with both energy and angular distributions of g-particles is shown.

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The results of phenomenological description of multiple generation occurring in hadron-nucleus interactions at high energies ($\geq$ 100 GeV) essentially depent on the assumption about interaction of the initial particle with nucleon in nucleus /1,2/. Believing that the first collision results in production of particles (asymptotical states) and that nucleus can be treated as a set of sufficiently independent nucleons one arrives at the model of intranuclear cascade which is in a serious contradiction with the experimental data /3,4/. The most essential disagreement can be seen in the fact that the predicted average multiplicity exceeds essentially the observed one and that the dependence of the multiplicity distribution on initial energy and mass number of a target nucleus deviates strongly from the experimental behaviour. Much more successful in describing the data seem to be the models reducing the treatment of the hadron-nucleus collision to the study of a certain coherent hadron system propagating through the nucleus. These models assume that the first collision in nucleus results in formation of the excited hadron system (cluster, fireball, etc.) which passes through the nucleus and after that serves as a source of secondary particles [2,5,6]. Different manifestations of clusterization in hadron processes can be thought of as a serious argument in favour of such models. The propagation of a cluster through a nucleus naturally gives rise to some specific effects. Studying the latter we can gain an important information on space-time picture of hadron interactions.

Before passing to the detailed exposition of our results we think it useful to remind the reader the main features of hadron-nucleus scattering established in experiments at high energies. Secondary particles produced in hadron-nucleus interaction are usually referred to three classes: i) relativistic or shower particles (s -particles) with $\beta \equiv v/c > 0.7$. This class is mainly composed of pions with momenta $P > 0.14$ GeV/c; ii) particles of intermediate energies (or cascade particles) - g -particles having $0.34 < \beta < 0.7$. The overwhelming majority of these particles makes protons with the momenta 0.3 GeV/c $< P <$ 1 GeV/c; iii) slow particles (b -particles) with $\beta < 0.3$ being the protons, deuterons, and heavier fragments evaporated from the nucleus. This classification is adopted in the experiments using nucleus emulsion technique providing the bulk of data on hadron-nucleus interaction.

Yet in early papers a conjecture was made that this distribution of particles into three groups could reflect the existence of

different modes of their generation [2]. In hadron-nucleus processes shower particles are produced by a fast object traversing the nucleus. The development of the process in nucleus gives rise to the g-particles. Their characteristics reflect the way in which the nucleus participates in the generation of relativistic particles. The peculiar feature of the g-particles is the fact that their mean multiplicity, momentum and angular distributions show the weak dependence on initial energy if the latter exceeds several dozens of GeV [7-10]. The mean number of cascade particles (protons) is $n_g \simeq 3$. It is also worth noting that g-particles are much less collimated in the lab.system than shower particles.

In this paper we want once more accentuate the fact that the investigation of different characteristics of g-particles may turn out to be important for the determination of the mechanism of multiple generation in hadron interactions. At the same time we show that reliable conclusions can be made in the framework of cluster models only in the case of compatible description of angular and momentum spectra of g-particles.

Thus, we assume that the interaction of the incident hadron with the nucleon that belongs to the nucleus results in the formation of cluster. The recoil nucleons appearing because of the multiple scattering of the cluster in the nucleus initiate an intranuclear cascade that in its turn gives rise to g-particles which are observed in experiment. Considering kinematics of this process one obtains

$$M^2 = m^2 - 2[(P_1^2 + m^2)^{1/2} + m_N][(P^2 + m_N^2)^{1/2} - m_N] + 2P_1 P \cos\theta, \qquad (1)$$

where m_N, P, θ are mass, momentum and angle of a scattered nucleon, m, P_1 and M, P_2 are masses and momenta of clusters in the initial and final states, resp. (see Fig.1).

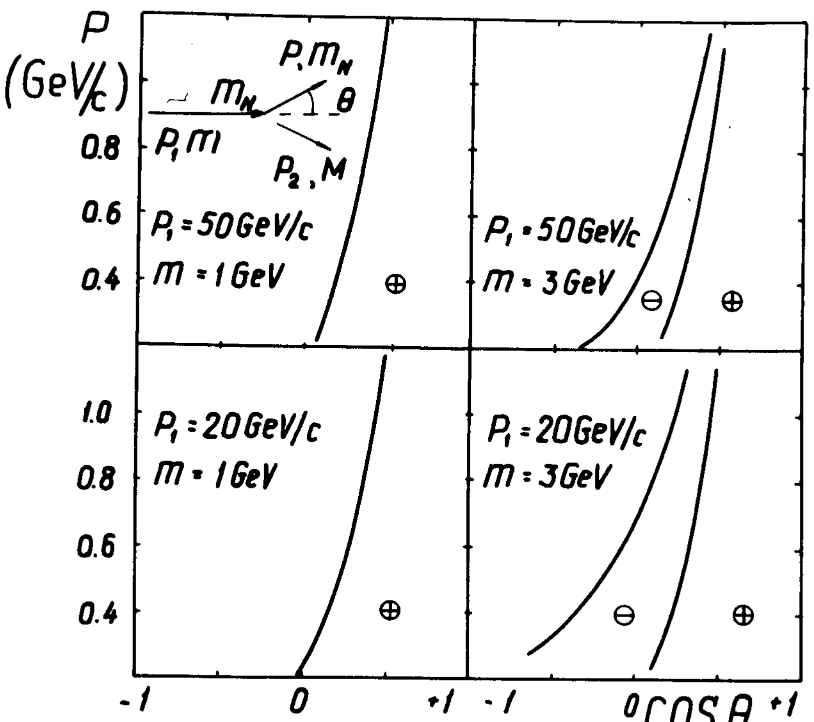

Fig. 1. Kinematically allowed regions of angles of the nucleon escape and of their momenta (in the lab. system) in the cluster-nucleon interaction. Signs ⊖ and ⊕ stand for the regions corresponding to the decrease and increase of the cluster mass in the final state. Notations are given in the left upper part of the figure.

Using relation (1) one can easily prove that the requirement of limited momenta of scattered nucleons at fixed m and P_I implies the existence of kinematically forbidden domains in $(P, \cos\theta)$ plane (see Fig.1) and, hence, a significant asymmetry of $\cos\theta$ distribution. In particular, one can see from Fig.1 that a large number of recoil nucleons should fly forward. However, this asymmetry can, in principle, be essentially smoothed by subsequent rescatterings.

Performing calculations we estimated the probability of cluster formation in the first collision using the model of Jacob and Slansky[11] which provides a good fit to experimental data on hadron-hadron collisions. According to paper [11] a cluster of mass m having transverse momentum k_T is produced with the probability

$$\rho(m, k_T^2) \propto \exp[-\beta/(m - m_p) - Bk_T^2]/(m - m_p)^2 \qquad (2)$$

with $B = 6\ (\mathrm{GeV}/c)^{-2}$, $\beta = 2$ GeV, and m_p is the proton mass, and the momentum distribution of the secondary particles in the cluster rest frame is taken in the form

$$\frac{dD}{dq_L\, dq_T^2} \propto \exp\left(-\frac{q_L^2 + q_T^2}{Q^2}\right), \qquad (3)$$

where q_L and q_T are the longitudinal and transverse momenta of pions, and Q = = 0.35 GeV/c. The longitudinal momentum of a cluster k_L in the c.m.s. of colliding particles is defined from the relation

$$P_L = \frac{11}{m}[k_L(m_\pi^2 + q_L^2 + q_T^2)^{1/2} + q_L(m^2+k_L^2)^{1/2}], \qquad (4)$$

where p_L is the longitudinal momentum of the pion in the c.m.s. Relations (2)-(4) were used for simulating characteristics of clusters in first hadron-nucleon interaction.

The cross section of scattering of the cluster on nucleon has been chosen as $\sigma_c \simeq$ $\simeq$ 25 mb following the well known estimation of paper /12/. Since the momenta of g-particles in the order of magnitude can be compared to the momenta of nucleons due to the internal motion inside the nucleus, our Monte-Carlo calculations have been performed taking account of the same basic factors that are essential at low energies, namely: the Pauli principle, momentum distribution of nucleons in nucleus, etc./3,4/.

At the point of the cluster interaction in nucleus the momenta of the initial nucleon $\vec{P}_3$ and recoil nucleon $\vec{P}$ were simulated. The momentum distribution of recoil nucleons was chosen somewhat harder than the observed distribution of g-particles (see Fig. 2). Then this distribution was varied so that the distribution of nucleons leaving the nucleus coincided with that of g-particles observed experimentally. Further the recoil angle was simulated, and taking into account that

$$M^2 = [E_1 + (P_3^2 + m_N^2)^{1/2} - (P^2 + m_N^2)^{1/2}]^2 - \sum_{i=1}^{3} P_{2i}^2, \; P_{2i} = P_{1i} + P_{3i} - P_i, \qquad (5)$$

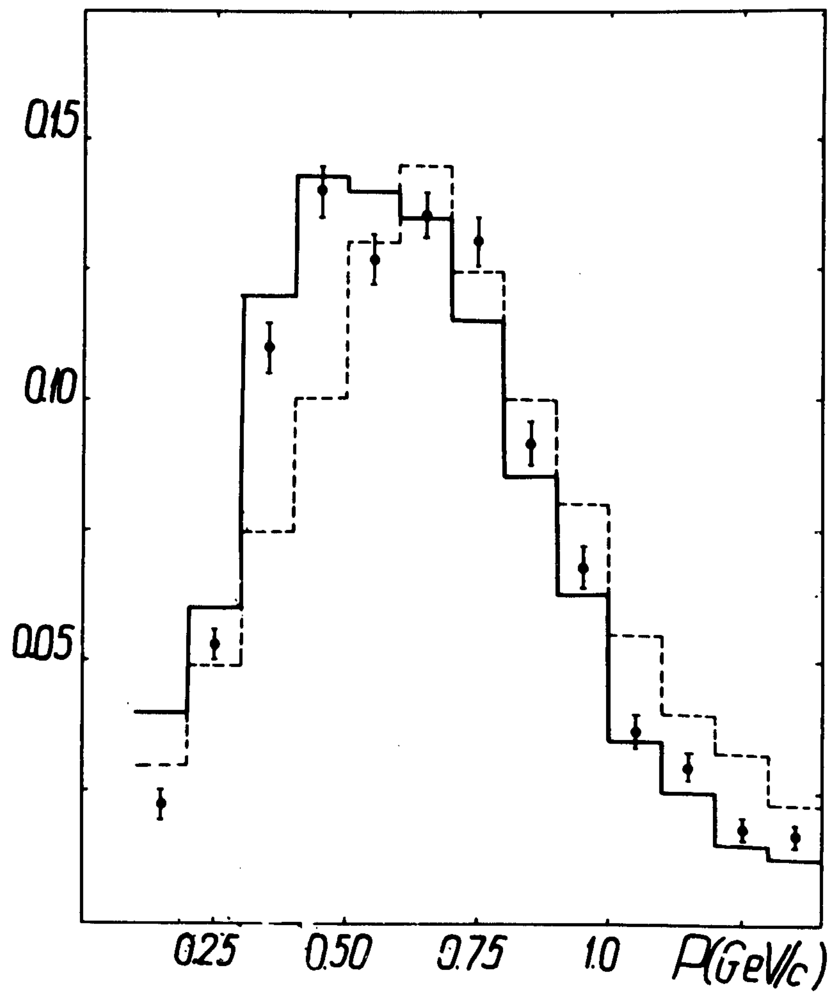

Fig. 2. Momentum distributions of g-particles. The solid line is the results of calculations, the dashed one is the distributions over which the recoil nucleon momenta were simulated in the cluster-nucleon interaction (see the text). Statistical errors are 2-5%. Experimental data are taken from papers /7-10/ .

the mass of cluster M and its momentum $\vec{P}_2$ after scattering on the nucleon were calculated. In relation (5) E_1, P_1 are energy and momentum of cluster before collision, i =1,2,3 denotes x,y,z -components of the momentum in the nucleus frame. In the case when the nucleon momentum and recoil angle belonged to the kinematically forbidden domain, the angle was simulated anew. We followed the particles and clusters taking part in the intranuclear cascade up to their departure from the nucleus.

Our approach allowed us to investigate the angular distributions of g-particles with the momentum distributions being fixed. Different angular distributions of recoil nucleons have been probed: isotopic in the c.m.s., of the form $d\sigma/d|t| \propto \exp(-a^2|t|)$, etc. Also the cross sections of cluster-nucleon interactions and parameters of the cluster model have been varied. We considered the incoming protons of 200 GeV impinging on the nuclear emulsion. The obtained angular distribution of g-particles is plotted in Fig. 3 and the corresponding momentum distributions, in Fig. 2.

One can see that the momentum distribution agrees with experiment whereas the angular distribution does not reveal such an agreement. The asymmetry defined as the ratio of mean numbers of particles flying to the forward and backward hemispheres n_F/n_B is equal to 10 while the observed one does not exceed 2÷3. All the subtleties marked above though influencing slightly the shape of the angular distribution cannot, however, provide agreement of the obtained results with experimental data. We guess

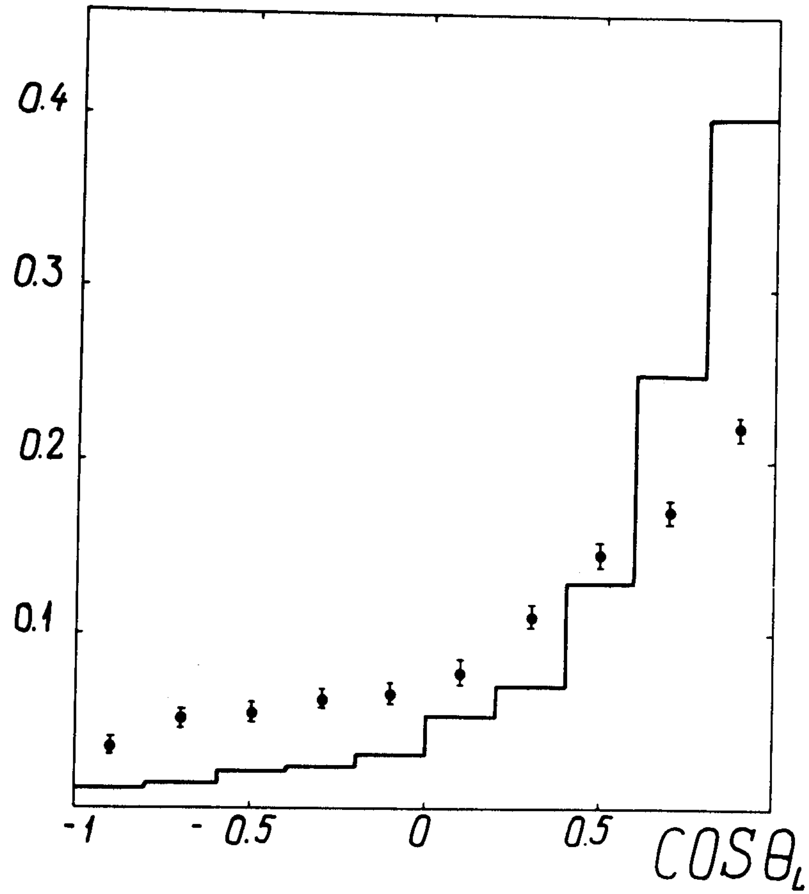

Fig. 3. Angular distributions of g-particles. Notations are the same as in Fig. 2.

that the obtained results evidence that the congruous description of the angular and momentum distributions of g-particles is rather sensitive to the choice of the mechanism of the multiple generation in hadron-nucleus interactions. The study of fine structure effects in the mechanism of hadron-nucleus interactions requires the combined analysis of angular and momentum characteristics of secondary particles.

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