Correlations in multiple production on nuclei

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It is shown that secondary interactions of the produced particles inside the nucleus lead to negative contributions to the short-range correlations in rapidity. A reversal of the sign of the correlation between the fast particles and the fragments of the target nucleus is predicted on going from the central part of the spectrum to fragmentation of the incident particle. An experimental study of the correlations in production on nuclei would make possible a sufficiently reliable choice between different multiple-production models.

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1. The purpose of the present study was call attention to a number of specific possibilities of investigating the nature of two-particle correlations which are produced in the investigation of multiple production on nuclei. Our main statement is that the correlations in production on nuclei should be less than in production on nucleons. The correlator $R_2(y_1,y_2)$ given by

$$R_2(y_1,y_2)=\sigma_{in}\left(\frac{d^2\sigma}{dy_1dy_2}\Big/\frac{d\sigma}{dy_1}\frac{d\sigma}{dy_2}\right)-1$$

can become even negative for a sufficiently heavy target nucleus (in production on protons, $R_2(y_1,y_2)$ is positive in the central region). We note that at first glance a growth of the correlator with increasing atomic number of the nucleus would seem more natural, since the more particles in the first generation of the cascade, the more of them are produced in the succeeding interactions, the number of which increases with increasing atomic number of the nucleus. The predicted decrease of $R_2(y_1,y_2)$ with increasing nuclear dimensions is due to the finite energy of the particles that take part in the interactions within the nucleus. If we neglect the finite-energy effects, then according to the estimates of[1] the correlator, to the contrary, would increase logarithmically with increasing number of the nucleus.

We start below from the multiperipheral model of hadron-nuclear interactions, proposed by Kancheli[2] and developed subsequently in[3,4] (see also the review[5]). The model explains well the available data on interactions with nuclei. The observation of the predicted effects in correlations would be an additional weighty argument favoring this model.

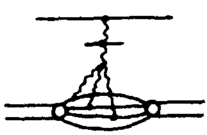

FIG. 1.

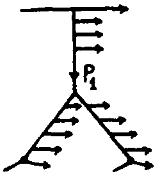

FIG. 2.

2. As shown by Kancheli,[2] in the multiperipheral model the main contribution to the inclusive spectra on the nuclei is made by the reggeon diagrams of the "fan" type (Fig. 1). If the reggeons on this diagram were to have sufficiently high energies, then large positive long-range correlations would arise in the part of the spectrum $y < y^c$ where the particle production is of the many-ladder type. Indeed, in the case of many-ladder production we have

$$R_2(y_1,y_2) = \langle j^2\rangle / \langle j\rangle^2 - 1 + R_2^0(y_1,y_2)/\langle j\rangle, \quad (1)$$

where $\langle j\rangle$ is the average number of ladders and $R_2^0(y_1,y_2)$ is the correlator within one ladder.[1,6,7] However, an analysis carried out in[3-5] shows that actually the reggeons below the fission point have a rather small energy, $\lesssim$3—10 GeV. Consequently, an important role is played by effects connected with energy conservation, and formula (1) cannot be used in practice.

We consider the structure of the final state in the case of interaction with two nucleons, see Fig. 2. Let the momentum p_1 be fixed. Then the production of particles with momenta $k < p_1$ is two-ladder particle production at an initial momentum p_1 and at a "rapidity" $y^* = \ln(p_1/\mu)$[1]. In this process, the production of a pair of particles with $e^{y_1} + e^{y_2} \geq e^{y^*}$ is impossible by virtue of the energy conservation. At these rapidities we have $R_2(y_1,y_2) = -1$. The correlator remains negative in a rather wide range of rapidities $y^* - y_1, y^* - y_2 \lesssim 1$. If we move far enough from the edge of the spectrum, then the analog of the term $\langle j^2\rangle/\langle j\rangle^2 - 1$ in formula (1) leads to positive correlation. However, several additional rescatterings can lead to cancellation of this positive contribution to the correlation.

In a real situation it is necessary to average over the rapidities y^*. Numerical estimates show that the correlator at the nucleus is smaller than the correlator at a nucleon almost everywhere, with the exception of a small rapidity

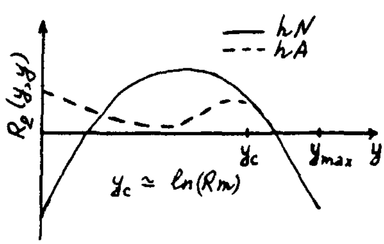

FIG. 3.

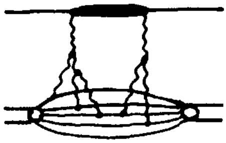

FIG. 4.

region $y \lesssim 1$, where the correlator at the nucleus should be larger than at the nucleon. The expected dependence of $R_2(y,y)$ on the atomic number of the nucleus is shown in Fig. 3. An analogous decrease of the correlator can be observed also at a fixed nucleus, by separating the interactions with large numbers of rescatterings. To this end it is necessary to select events with different numbers of recoil nucleons (protons) n_p. The dependence of the correlator on n_p should be similar to the dependence on $A^{1/3}$. This possibility of monitoring the structure of the final state by means of the number of recoil protons makes the study of correlations in the production on nuclei much more interesting than in the production on nucleons.

3. We did not take into account above the possible multipomeron diagrams of the eikonal type (Fig. 4). The relative contribution of such diagrams increases with increasing $A^{1/3}$ [8] and they make a positive contribution to the correlator (the term $\langle j^2\rangle/\langle j\rangle^2 - 1$ in formula (1)). At sufficiently high energy, $E \gtrsim (50 - 100)A^{1/3}$ GeV, the eikonal diagrams would lead to a dependence of the correlator $R_2(y,y)$ on y in the form shown in Fig. 5. At lower energies, the eikonal diagrams lead to $R_2^A(y,y) < R_2^N(y,y)$ also in the particle fragmentation region.

The eikonal diagrams are important in correlations between fast particles and the products of fragmentation of the nucleus. In the absence of eikonal diagrams, the correlator of the number of fast particles and of the number of fragments of the nucleus would be equal to zero. [9] With increasing number of ladders of the eikonal type, the density of the particles in the particle fragmentation region decreases by virtue of the energy conservation. On the other hand, the number of products of the disintegration of the nucleus increases with increasing number of ladders. In interactions with emulsion nuclei, the excitation of the nucleus is characterized by the so-called number N_h of "gray" and "black" tracks in the star. In the parametrization $d\sigma/dy = a(y) + b(y)N_h$ the slope $b(y)$ is positive in the central region $y_{max} - y \gtrsim 1$ and negative in the region of fragmentation of the incident particle $y_{max} - y \lesssim 1$.

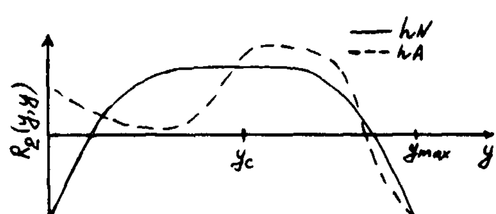

FIG. 5.

The contribution of the eikonal diagrams can be decreased by selecting events in which there is a sufficiently rapid leading particle with momentum $k \gtrsim p/2$. In such events, all the changes of the correlations with increasing number of recoil nucleons or with increasing dimensions of the nucleus are due completely to effects of secondary interactions within the nucleus.

4. The experimental information on the correlations in multiple production on nuclei is extremely skimpy. In[10], indications were obtained that the sign of $b(y)$ changes as $y \to y_{max}$, and the effect is due to fragmentation of the incident particle. In[11] there was observed a decrease of the short-range correlations with increasing N_h in interaction in emulsions. However, the accuracies are low, since the possibility of acquiring statistics are sharply limited in emulsion experiments.

5. We note in conclusion that a study of the correlations would make it possible to reject models such as the hydrodynamic model or the tube model. In these models, the transition to the nucleus leads only to an increase of the effective initial energy $E \to EA^{1/3}$ (see, e.g., [12]). Therefore the correlators at the nuclei and nucleons should be similar to each other.

The eikonal model in which it is assumed that only the leading particle experiences secondary interactions within the nucleus, and all the newly produced particles inside a nucleus do not interact, is discussed in a number of papers. In the eikonal model the correlations at the nucleus should also be smaller than at the nucleon, but only in the region of fragmentation of the incident particle. In the central region, on the other hand, the correlator on the nucleus should be larger than on the nuclei.

This possibility of choosing between different models of multiple production makes the study of correlations in production on nuclei an interesting and important problem.

More detailed calculations of the dependences of the correlations on the atomic number and on the number of recoil protons will be published in a subsequent article.

[1)]The discussed effects should manifest themselves most clearly in the distributions precisely in the laboratory momentum of the energy, and not in the distribution in the rapidity $Y + \ln(\epsilon + p_z/\epsilon - p_z)$.

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