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A Study of Inelastic Interactions of Deuterons and Alphas in an Emulsion at ~3.6 GeV/Nucleon

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Various experimental characteristics of multiple production in deuteron-nucleus and alpha particle-nucleus interactions in an emulsion at ~ 3.6 GeV/n have been studied in dependence on the atomic number of a target and the number of interacting projectile nucleons. The data obtained do not demonstrate the noticeable collective phenomena and give the strong support to the idea that at energies of about a few GeV per nucleon the cascade mechanism is responsible for global features of heavy ion interactions.

1. Introduction

The recent availability of monoenergetic beams of relativistic heavy ions at the LBL and JINR provides us with the opportunity to investigate nucleus-nucleus interactions at high energies which constitute a new branch of researches – the relativistic nuclear physics. The main process taking place in relativistic heavy ion collisions is, just as in hadron-hadron interactions at high energies, the multiple production of particles. In the present paper we discuss the basic characteristics of this process, such as multiplicity of charged secondaries, one-particle angular distributions and two-particle correlations, as well as their dependence on the number of interacting projectile nucleons and the atomic number of a target in inelastic collisions of deuterons and alpha particles in an emulsion at 9.4 and 16.8 GeV/c, respectively.

2. Experimental Details

Stacks of GOSNIIHIMFOTOPROEKT BR-2 emulsions were exposed to the $p=9.4$ GeV/c (the kinetic energy per nucleon $T=3.8$ GeV/n) deuteron and $p=16.8$ GeV/c ($T=3.4$ GeV/n) alpha particle beams at the JINR Synchrophasotron (Dubna). Inelastic deuteron-nucleus (dA) and alpha particle-nucleus (αA) interactions were recorded as a rule during the double, fast and slow, along the track scanning without any discrimination. The events have been excluded from consideration satisfying the necessary criteria for the selection of elastic dA and αA scatterings. In all the inelastic events charged secondaries were classified in accordance with their ionization and range into following types: a) shower or s-particles with ionization $g/g^0 < 1.4$, g^0 being the plateau grain density for singly charged relativistic particles; b) grey or g-particles with ionization $g/g^0 > 1.4$ and the range in emulsion $l \geqq 3$ mm (the latter corresponds to the kinetic energy of protons $\geqq 25$ MeV);
c) black or b-particles having $g/g^0 > 1.4$ and $l < 3$ mm.
It should be noted that the target recoils observed and relativistic projectile fragments with the charge $Z=2$ (^{3}He and ^{4}He fragments in αA interactions) were not included in the number of b- and g-particles, respectively.
The polar (θ) and azimuthal (φ) angles of all the charged secondaries were measured carefully in inelastic events.
In order to study how characteristics of heavy ion reactions depend on the number of interacting projectile nucleons it is necessary to identify surviving (stripping) fragments of a projectile nucleus. Doubly charged projectile fragments in αA interactions (^{3}He and ^{4}He) could be selected with the confidence at small angles by measuring the ionization on the sufficient track length. As concerns singly charged rel-

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ativistic fragments we have selected them by means of statistical analysis of shower particle angular distributions in the range of very small angles (see below) and we obtained as a result that the background from nonstripping single-charged particles does not exceed, according to our estimate, 10%. Besides, they have been identified on part of the total statistics in accordance with the results of momentum measurements performed on tracks of single-charged secondaries following the method of multiple Coulomb scattering. Hereafter shower particles without noninteracting singly charged projectile fragments will be referred to as s'-particles.

Further we shall consider groups of dA and αA interactions with the different total charge of noninteracting fragments of the incoming nucleus ($Q=0, 1$ in dA and $Q=0, 1, 2$ in αA interactions); when determining Q in individual events we used the charge conservation.

The total statistics of events analyzed in this paper consists of 1439 dA and 1088 αA interactions. Deuteron-nucleus interactions constitute the experimental material of Warsaw-Dubna-Yerevan-Leningrad-Tashkent collaboration [1] purified from the wrong events (it should be noted that angular distributions reported in reference [1] contain therefore the noticeable mistakes). The statistics of αA interactions actually is new and only its small part has been considered earlier in reports of Warsaw-Dubna-Gatchina-Košice-Leningrad-Moscow-Tashkent collaboration [2]. Details of experimental conditions and selection rules were discussed in references [1, 2].

3. Multiplicity of Charged Secondaries

Let us first consider the data on multiplicity of various types of charged secondaries in different Q groups of dA and αA interactions. Figures 1–4 present multiplicity distributions of s', g, b and h particles ($n_h = n_g + n_b$), respectively, obtained for the total ensemble of inelastic dA and αA interactions together with those for the groups of events having different numbers of interacting projectile nucleons (and/or different Q). It is well known that in nuclear collisions the dependence of various characteristics on the atomic number of the target, A, can shed light on the production mechanism. Therefore, we have selected from our samples, according to the necessary criteria of selecting events for emulsion, inelastic interactions of deuterons and alphas on the free emulsion hydrogen. Thereon the remaining events were statistically divided into collisions with light (C, N, O) and heavy (Br, Ag) emulsion nuclei in accordance with the method described in details in references [3]. The multiplicity distributions for these interactions are also plotted in Figures 1–4.

The data obtained on the average multiplicities of charged secondaries are presented in Table 1. Besides, Table 1 gives in parentheses the values of the mean multiplicities calculated in accordance with the cascade-evaporation model for dA [4] and αA [5] interactions. For αA interactions two model predictions are listed: the first belongs to the main version of the model and the second one has been determined according to the simplified version which assumes that

Table 1. Average multiplicities of secondaries in different Q groups (Q being the total charge of noninteracting projectile fragments) of dA and αA interactions in an emulsion

Group of events	Number of events	$\langle n_s \rangle$	$\langle n_{s'} \rangle$	$\langle n_g \rangle$	$\langle n_b \rangle$	$\langle n_h \rangle$	$\langle n_b \rangle / \langle n_g \rangle$
dA	1439	3.08 ± 0.05	2.83 ± 0.05	2.34 ± 0.07	5.78 ± 0.15	8.12 ± 0.20	2.5 ± 0.1
		$(2.9 \pm 0.2)^a$		$(2.6 \pm 0.1)^a$	$(3.0 \pm 0.2)^a$	$(5.5 \pm 0.3)^a$	$(1.2 \pm 0.1)^a$
$dA, Q=0$	1092	3.15 ± 0.06	3.15 ± 0.06	2.67 ± 0.09	6.45 ± 0.18	9.11 ± 0.24	2.4 ± 0.1
$dA, Q=1$	347	2.87 ± 0.08	1.87 ± 0.08	1.34 ± 0.09	3.60 ± 0.21	4.93 ± 0.27	2.7 ± 0.2
αA	1088	3.86 ± 0.08	3.37 ± 0.08	4.64 ± 0.17	4.68 ± 0.15	9.32 ± 0.30	1.0 ± 0.1
		$(5.3 \pm 0.3)^b$		$(3.8 \pm 0.2)^b$	$(4.4 \pm 0.2)^b$	$(8.2 \pm 0.4)^b$	$(1.2 \pm 0.1)^b$
		$(5.3 \pm 0.3)^c$		$(3.6 \pm 0.2)^c$	$(7.8 \pm 0.4)^c$	$(7.8 \pm 0.4)^c$	$(1.2 \pm 0.1)^c$
$\alpha A, Q=0$	517	4.95 ± 0.11	4.95 ± 0.11	7.34 ± 0.27	7.05 ± 0.25	14.39 ± 0.47	1.0 ± 0.1
$\alpha A, Q=1$	365	3.44 ± 0.09	2.44 ± 0.09	2.53 ± 0.16	2.92 ± 0.18	5.45 ± 0.31	1.2 ± 0.1
$\alpha A, Q=2$	206	1.87 ± 0.13	1.06 ± 0.10	1.63 ± 0.25	1.84 ± 0.20	3.46 ± 0.43	1.1 ± 0.2
dCNO	418	2.80 ± 0.06	2.47 ± 0.06	1.03 ± 0.04	2.48 ± 0.06	3.51 ± 0.07	2.4 ± 0.1
dAgBr	935	3.27 ± 0.05	3.06 ± 0.05	3.13 ± 0.08	7.76 ± 0.16	10.88 ± 0.21	2.5 ± 0.1
αCNO	339	2.99 ± 0.08	2.33 ± 0.08	1.41 ± 0.06	1.46 ± 0.06	2.88 ± 0.09	1.0 ± 0.1
αAgBr	667	4.49 ± 0.08	4.12 ± 0.08	6.82 ± 0.18	6.87 ± 0.16	13.69 ± 0.31	1.0 ± 0.1

[a] Predictions of the cascade model [4] for dA interactions
[b] Predictions of the cascade model [5] for αA interactions
[c] Predictions of the cascade model with some simplifying assumptions [5]

cascades caused in the target by nucleons of incoming alphas are independent of each other; it is seen, of course, that these two values are very close.

The analysis of these data results in the following main conclusions.

1. Multiplicities (the average values and distributions) of all types of charged secondaries in relativistic heavy ion collisions essentially depend on the number of interacting projectile nucleons and on the atomic number of a target nucleus. They increase as Q falls and A increases.

2. In the group of dA interactions with $Q=1$, which contains neutron-nucleus (nA) collisions together with small contribution of inelastic reactions $d+A\rightarrow d+$anything, and in the group of αA interactions with $Q=2$ (it is composed mostly of nA collisions with admixture of reactions $\alpha+A\rightarrow\alpha+$anything and $(2n)+A\rightarrow$anything) multiplicities of secondary particles, especially $\langle n_b\rangle$ and $\langle n_g\rangle$, are smaller than those in free nucleon-nucleus interactions at the same energy per incident nucleon. In fact, according to the compilation of experimental data presented in Reference 6, the average multiplicities in proton-nucleus interactions at $T\simeq 3.6$ GeV are as follows: $\langle n_g\rangle_{pA}=3.0$, $\langle n_b\rangle_{pA}=5.0$ and $\langle n_h\rangle_{pA}=8.0$. Moreover, one can infer that even in the group of αA events with $Q=1$, where the average number of interacting projectile nucleons is equal to 2, the multiplicity of heavy prongs characterizing the degree of intranuclear cascade development and excitation of a target is smaller considerably than in pA interactions, although, of course, $\langle n_{s'}\rangle_{\alpha A}>\langle n_s\rangle_{pA}$.

These observations clearly show that inelastic events with the stripping fragments actually are the peripheral interactions of colliding nuclei and the number of heavily ionizing particles is the quantitative, though statistical, measure of the impact parameter in inelastic collisions of heavy ions.

3. A rise of multiplicity of all types of charged secondaries with the growth of the atomic number of a target becomes stronger when the atomic number of a projectile increase (see the last four lines in Table 1). This means that in heavy ion collisions, when the target is fixed and the number of nucleons in the projectile changes, a redistribution takes place for probabilities of different impact parameters. Otherwise, for the fixed target nucleus the impact parameter distribution depends on the number of interacting projectile nucleons and/or the atomic number of the projectile (see also below).

4. The interrelation between the numbers of grey (mainly knock-out protons) and black (mostly the evaporation products) particles essentially depends on the atomic number of the projectile nucleus, A'. In dA interactions, just as in pA collisions (see Ref. 6), $\langle n_g\rangle$ is smaller considerably than $\langle n_b\rangle$ – see the last column in Table 1, whereas in αA interactions one has $\langle n_g\rangle\simeq\langle n_b\rangle$. It is interesting to notice that for the fixed projectile the ratio $\langle n_b\rangle/\langle n_g\rangle$ practically depends neither on the number of interacting projectile nucleons nor on the atomic number of the target.

Thus, with a rise of the incoming nucleus mass the number of target nucleons knocked out in direct processes increases, whereas the degree of excitation of the residual nucleus remains unchanged or even slightly decreases when we pass from deuteron to alpha induced collisions. The first observation is evidently related to the increase in the number of interacting projectile nucleons, the second one is a possible consequence of the fact that in heavy ion interactions the impact parameter is redistributed in such a way that its large values give larger contribution. Another factor leading to a suppression of heavy particle multiplicity in interactions of nuclei with the composite target (such as an emulsion) is the change of relative probabilities (cross sections) of collisions with separate components of a mixture (with light and heavy emulsion nuclei, for instance); However this factor hardly can explain the difference observed for dA and αA interactions.

5. In general, the agreement between the experimental data on multiplicities and predictions of the cascade-evaporation model [4, 5] is not satisfactory – for dA interactions the model describes the data on $\langle n_s\rangle$ and $\langle n_g\rangle$ and cannot explain $\langle n_b\rangle$ and there is the reverse situation for αA interactions (see Table 1). The reasons of this are unclear; of course, it is necessary to check model in many points, not only in multiplicity, in order to draw the reliable conclusions about its applicability.

It should be noted that the extreme peripherality of reactions $A'+A\rightarrow A'+$ anything ($A'=d, \alpha$) fixed above casts doubt on the procedure used in Reference 7 for determining of cross sections of deuterons and alpha particles inside the target nucleus after the intranuclear collisions. In fact, the hidden assumption about the similarity of impact parameter distributions in inelastic reactions $A'+A\rightarrow A'+$ anything and $A'+A\rightarrow$ anything positively contradicts the experimental results: the former ones correspond to the extremely large impact parameters, i.e. in inelastic reactions with the surviving projectile nucleus in the final state the participation of more than one target nucleons is unlikely. So, for instance, for selected inelastic events from the group αA, $Q=2$ having the surviving α-particle the mean multiplicities are smaller several times than those for the total group of αA interactions with $Q=2$ presented in Table 1 and $\langle n_{s'}\rangle$ in this sub-

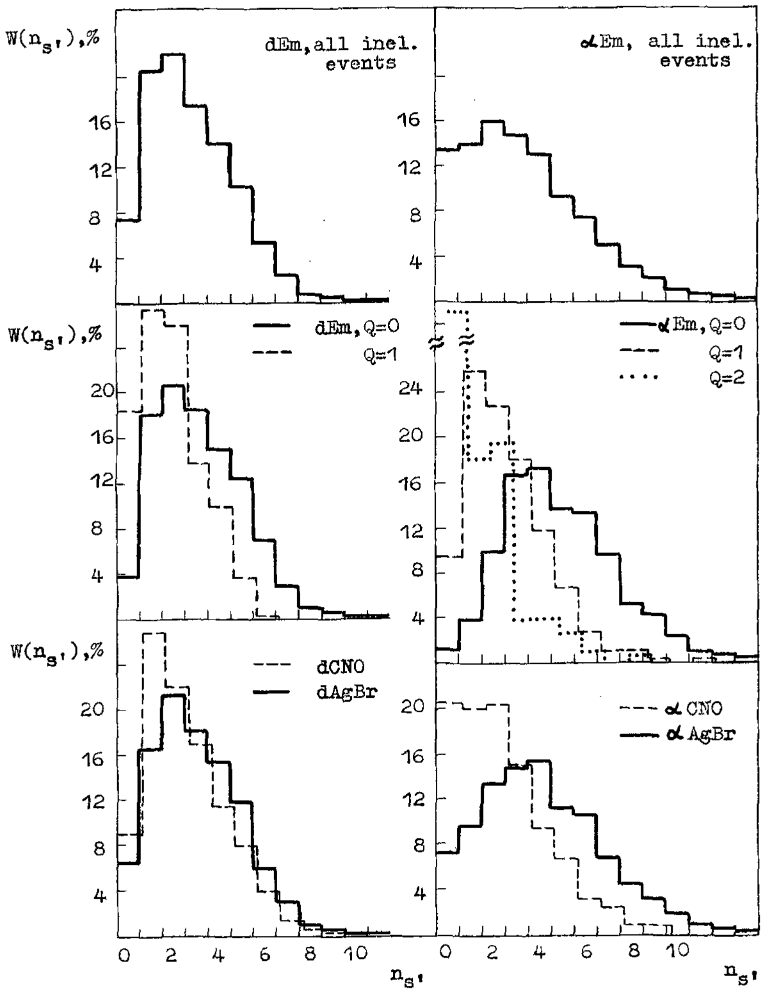


Fig. 1. Multiplicity distributions of s'-particles in different groups of dA (the left half of the figure) and αA (the right half) interactions

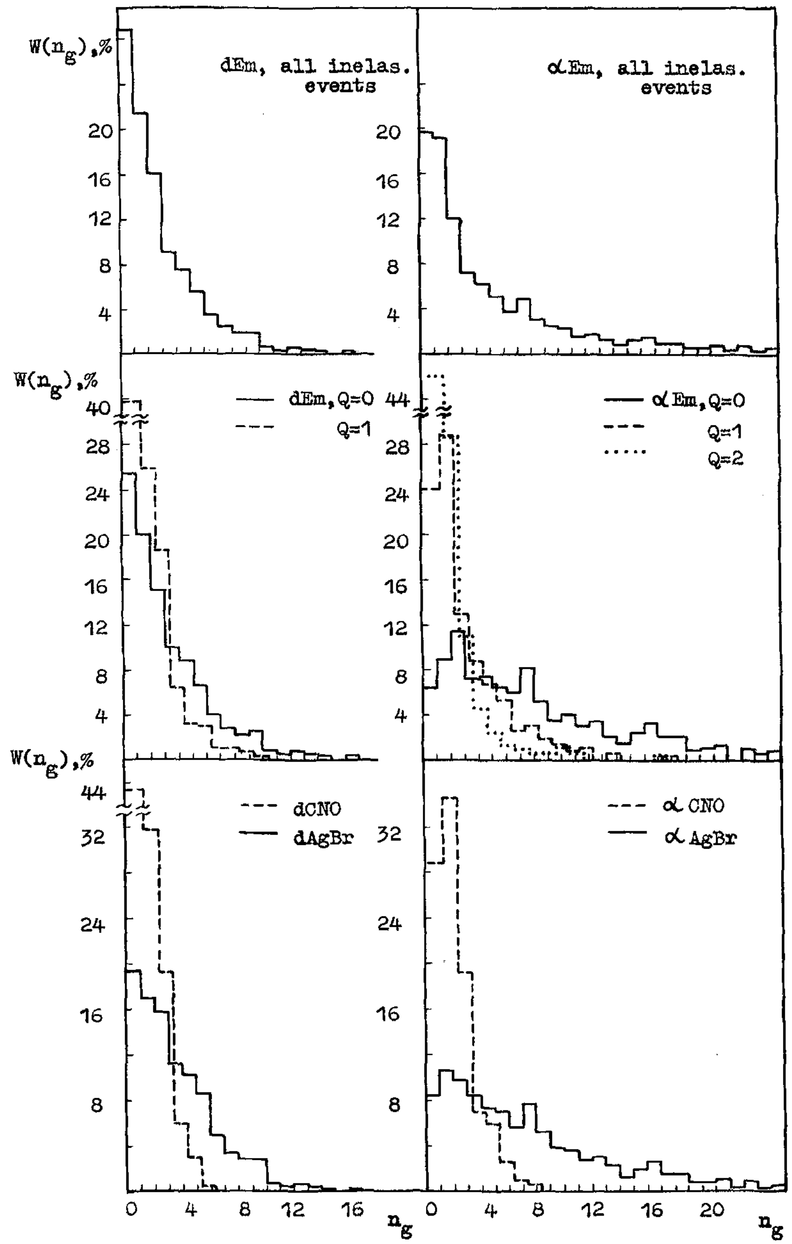


Fig. 2. Multiplicity distributions of g-particles. The designations are the same as in Figure 1

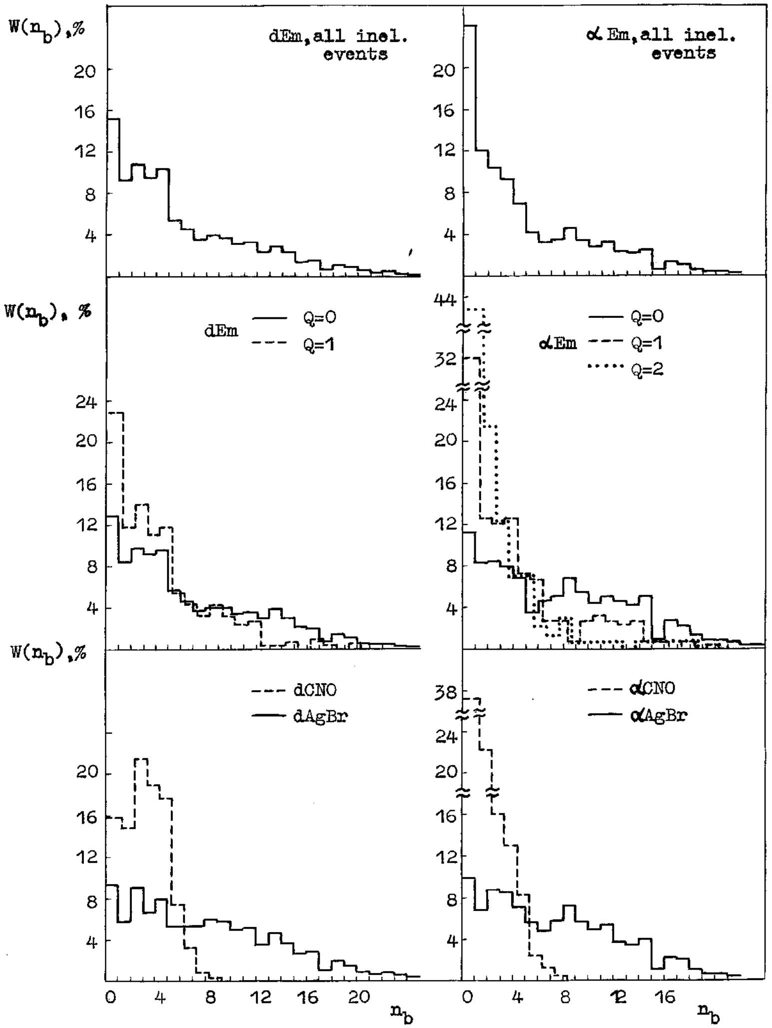


Fig. 3. Multiplicity distributions of *b*-particles. The designations are the same as in Figure 1

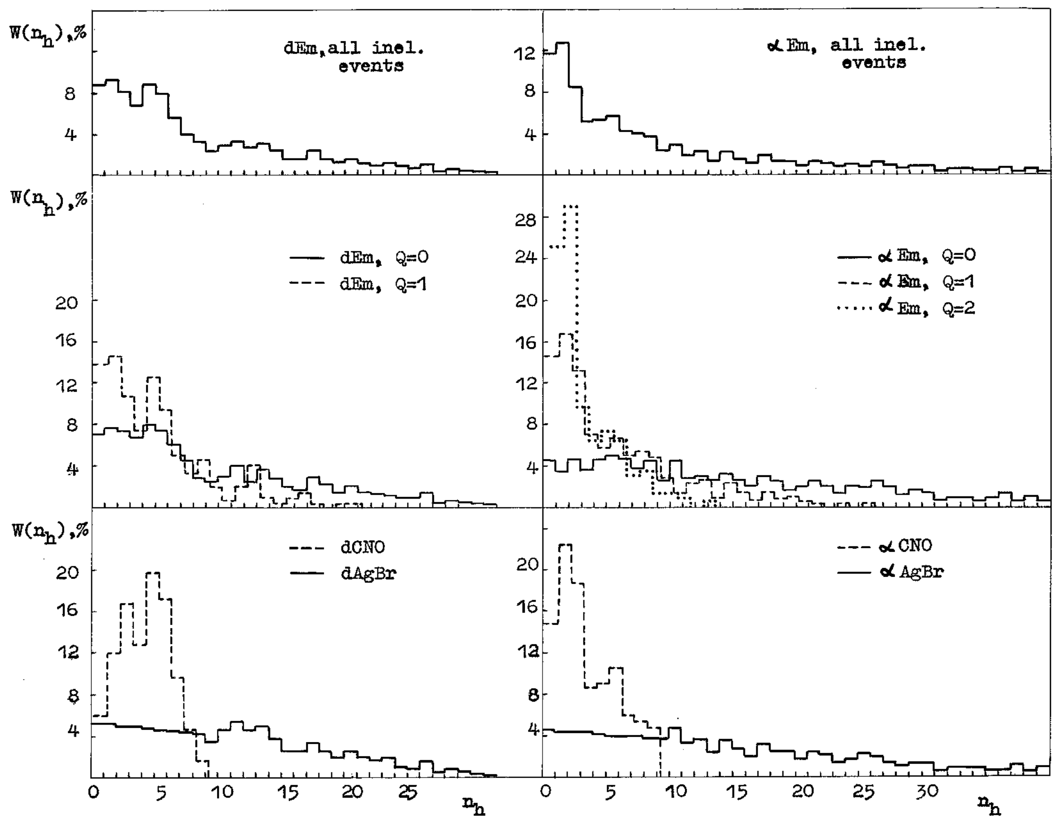


Fig. 4. Multiplicity distributions of *h*-particles. The designations are the same as in Figure 1

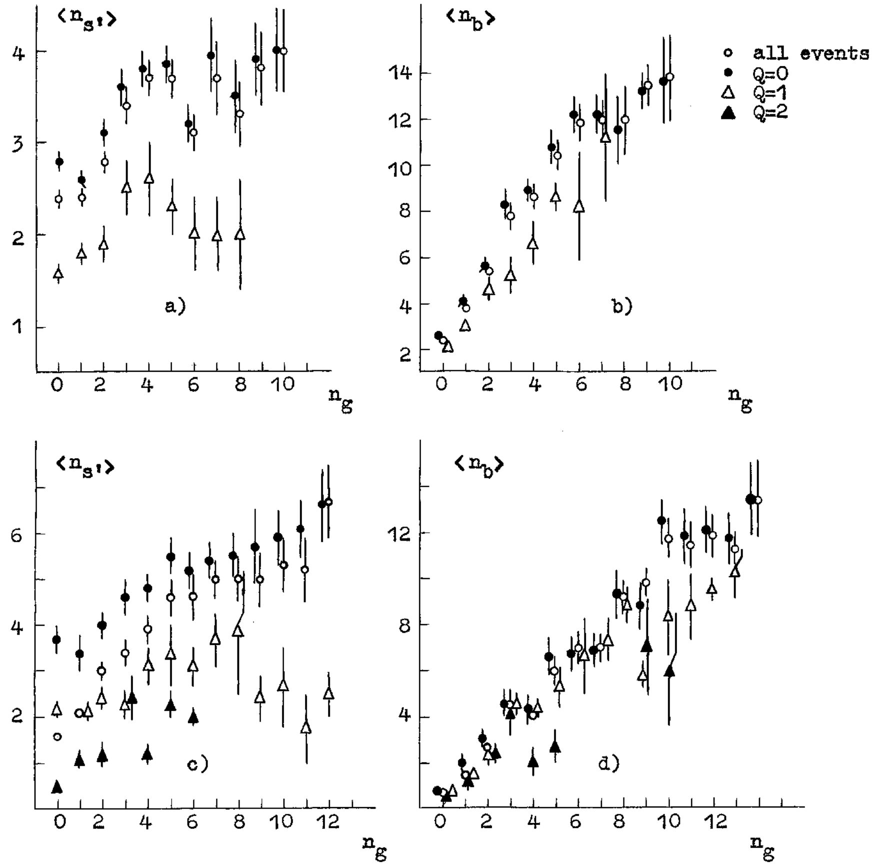


Fig. 5. Multiplicity correlations $\langle n_{s'}(n_g)\rangle$ (*a, c*) and $\langle n_b(n_g)\rangle$ (*b, d*) in different groups of dA (*a, b*) and αA (*c, d*) interactions

ensemble being equal to 0.98 ± 0.13 is smaller considerably than in interactions of alphas with the free emulsion hydrogen (in the last case we have $\langle n_{s'}\rangle_{\alpha H} = 1.6 \pm 0.1$). In general, when considering the inclusive spectra of secondaries in the limited kinematical regions available from electronic experiments, one should remember the danger of the assumption that in the particular reaction considered the impact parameter distribution is the same as in the full ensemble of inelastic collisions.

We are now going to consider multiplicity correlations of the type $\langle n_i(n_j)\rangle$ ($n_i, n_j = n_{s'}, n_b, n_g, n_h$) in dA and αA interactions. Some examples of such correlations ($\langle n_{s'}(n_g)\rangle$ and $\langle n_b(n_g)\rangle$) are plotted in Figure 5. The following can be concluded from the data.

i) In the quantitative respect there is the difference between n_g dependences of $n_{s'}$ in different Q groups of dA and αA events: for the fixed n_g the smaller Q, the larger $\langle n_{s'}\rangle$ becomes. So, for $Q=0$ the average multiplicity of s'-particles is larger, even at minimal n_g, than for $Q=1$ (dA interactions) and/or $Q=2$ (αA interactions) and extremely large n_g. Thus, at our energy multiplicity of particles produced (s') depends on the number of interacting projectile nucleons stronger than on the target size. At fixed Q the value of $\langle n_{s'}\rangle$ increases with n_g monotonically and achieves a plateau at the value n_g(plat) which depends on Q and A' in such a way that the larger Q, the smaller n_g(plat) becomes. This is consistent with the statement above that the degree of peripherality of heavy ion reactions is related to Q. Similar features were also observed for $\langle n_{s'}(n_b)\rangle$ and $\langle n_{s'}(n_h)\rangle$ dependences (not shown here).

ii) Correlations between heavy particle multiplicities $\langle n_b(n_g)\rangle$ and $\langle n_g(n_b)\rangle$ also depend on Q, though more weakly. On the other hand they are different for different incoming nuclei. It is probable that this is a consequence of the decrease of nuclear density during the cascade development inside the target (the so-called trailing effect) and of the A-dependence of impact parameter distributions discussed above. It should be emphasized that qualitatively correlations between heavy prongs multiplicities in heavy ion collisions are similar to those observed in hadron-nucleus interactions.

Thus, we see that the totality of experimental data on multiplicity and multiplicity correlations in heavy ion interactions provides one with the plentiful material useful to understand the production mechanism and to test different theoretical approaches suggested.

4. Angular Distributions of Secondary Particles

Shower particle angular distributions demonstrate the prominent peaks in the range of very small angles θ

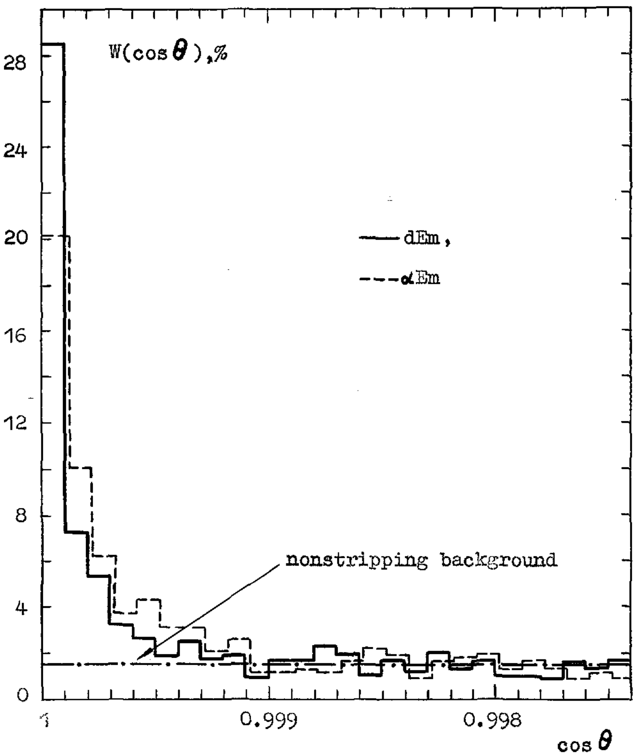


Fig. 6. Angular distributions of s'-particles in the very forward range for dA and αA interactions. The dotted-dashed line shows the nonstripping background taken from pA interactions

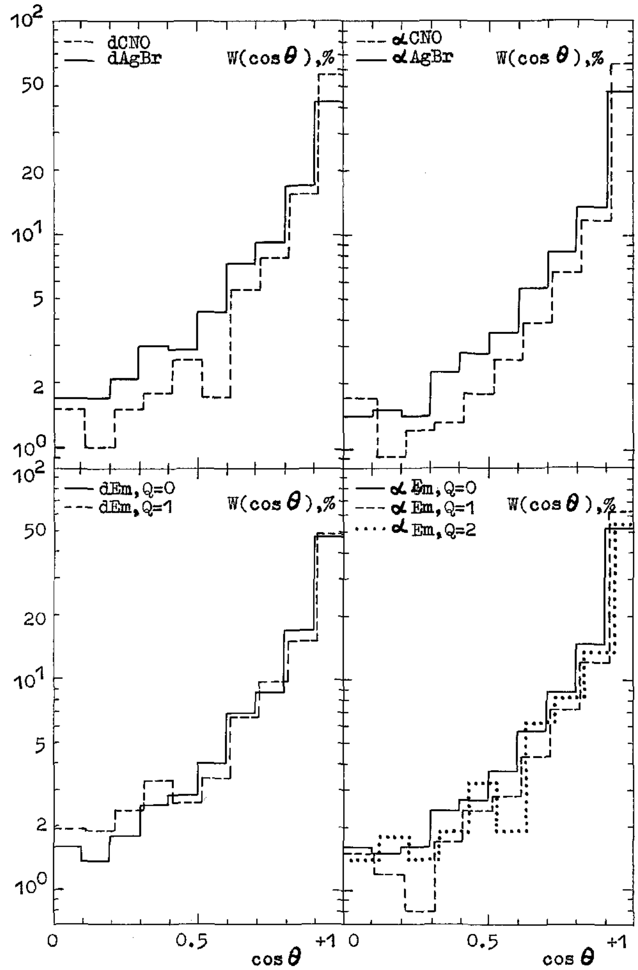


Fig. 7. Angular distributions of s'-particles in different groups of dA (the left half of the figure) and αA (the right half) interactions

caused by the well-known phenomenon of proton stripping (Fig. 6). In pA collisions at nearby energies angular distribution $(d\sigma/d\Omega)$ is close to the uniform one at these angles [9, 10, 11] that allows one to separate statistically singly charged fragments from s-particles. Comparing this subtractive method with the results of more precise identification based on momentum measurements [11] we made sure that the background from nonstripping protons did not exceed 10% and the average multiplicities of such fragments determined following these two methods coincided within experimental errors. The data on fragmentation cross sections and related topics have been discussed in References 11, 2.

Angular distributions of s', g and b particles in different Q groups of dA and αA collisions are plotted in Figures 7, 8 and 9, respectively, and Table 2 presents the values of the forward-backward asymmetry coefficient for g and b particle θ distributions defined as $A = \langle n^{(f)}/n^{(b)} \rangle$, $n^{(f)}(n^{(b)})$ being the number of particles having $\theta < 90°(\theta > 90°)$.

The most important conclusion following from the data presented is the weak dependence of angular distributions of all types of secondary particles on Q and A. More exactly, angular spectra within experimental errors do not depend on Q for all types of secondaries. As concerns the target size dependence, angular distributions of s' and g particles exhibit a weak dependence on A. In fact, one can see from Figures 7, 8 that they shift slightly towards larger angles with increasing A. It is interesting to note by the way that just the same dependence has been observed for particles produced in high-energy hadron-nucleus interactions.

We have also found that the dispersion of inclusive distribution on pseudorapidity $\eta = \ln\text{ctg}(\theta/2)$ for s' particles within errors is independent of A and Q. It has been shown in Reference 12 that in the coherent tube (CTM, see [13]) and related models which assume that a collision with a tube of nuclear matter is responsible for nuclear production and the mechanism of such an interaction is similar to that realized in hadron-nucleon collisions at some higher center of mass energy, the dispersions of η distributions should increase with the A and the number of interacting projectile nucleons. So, we see, our experimental data do not confirm this prediction. This means that at energies under consideration heavy ion interactions

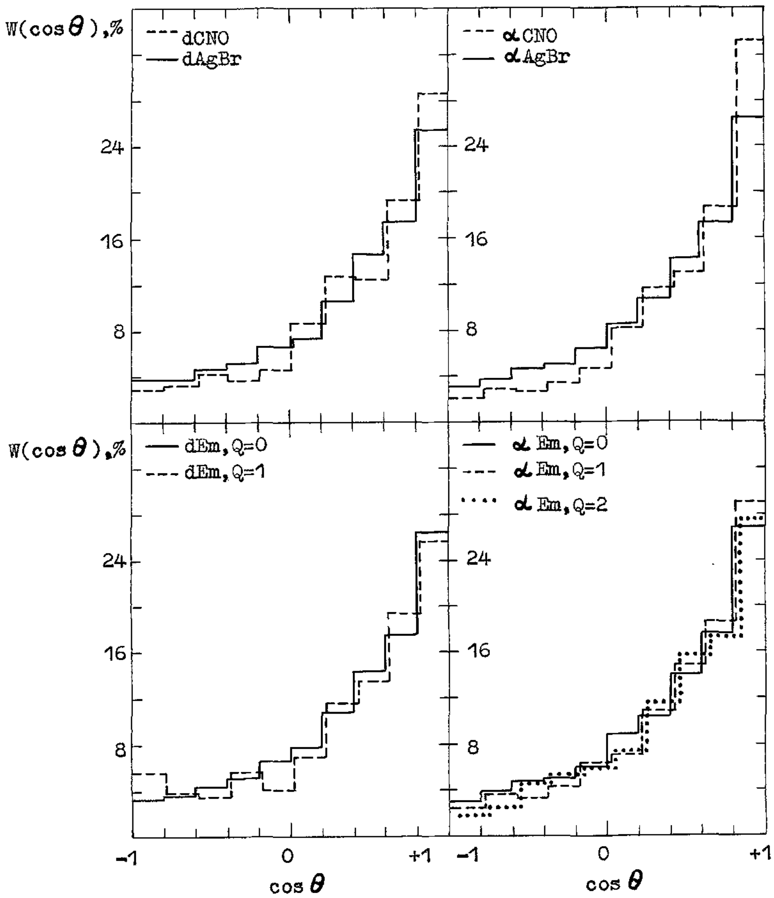


Fig. 8. Angular distributions of *g*-particles. The designations are the same as in Figure 7

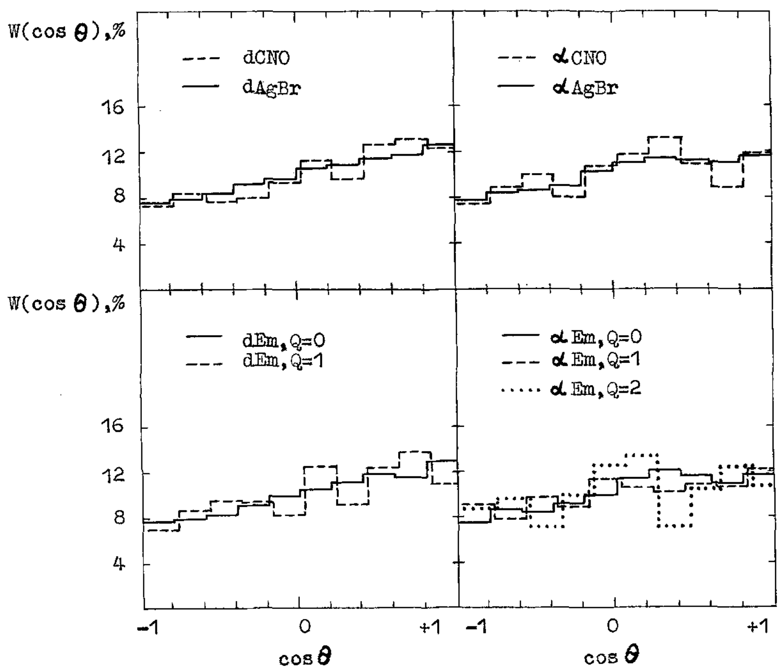


Fig. 9. Angular distributions of *b*-particles. The designations are the same as in Figure 7

Table 2. Asymmetry coefficients of polar angle distributions of grey and black particles in different groups of dA and αA interactions

Group of events	$\langle n_g^{(f)}/n_g^{(b)}\rangle$	$\langle n_b^{(f)}/n_b^{(b)}\rangle$
dA	3.3 ± 0.1	1.36 ± 0.03
$dA, Q=0$	3.3 ± 0.1	1.35 ± 0.03
$dA, Q=1$	3.4 ± 0.4	1.39 ± 0.08
dCNO	4.4 ± 0.5	1.43 ± 0.09
dAgBr	3.1 ± 0.1	1.34 ± 0.03
αA	3.6 ± 0.1	1.28 ± 0.04
$\alpha A, Q=0$	3.5 ± 0.1	1.33 ± 0.04
$\alpha A, Q=1$	4.0 ± 0.3	1.16 ± 0.07
$\alpha A, Q=2$	3.9 ± 0.5	1.12 ± 0.12
αCNO	5.6 ± 0.7	1.31 ± 0.12
αAgBr	3.4 ± 0.1	1.28 ± 0.04

should most likely be considered as the totality of more elementary collisions (the cascade process?). In any case, the collective phenomena in nucleus-nucleus (and hadron-nucleus) collisions are not expressed so strongly as the CTM suggests.

Angular distributions of b particles were found to be the most stable to the change of A and Q demonstrating the universality of the evaporation mechanism in interactions of nuclei.

Finally, we would like to emphasize that one-particle angular spectra of heavy particles do not show any noticeable anomalies which can be related to collective phenomena such as the nuclear shock waves. This question will be considered in some details in the next section.

5. Angular Correlations

Although there has been an increasing interest in the study of correlation phenomena among secondaries in multiple production in recent years, there exist only a few works concerning the problem in hadron-nucleus and heavy ion interactions. An investigation of correlations in nuclear production is of importance not only for particles produced, but also for the target (and/or projectile) fragments. Correlation effects among such fragments would arise as a manifestation of collective processes, in particular due to realization of nuclear shock waves. We have shown in References 14, 15 that this mechanism can be detected with high efficiency, if one uses the method of correlation functions which is sensitive enough to the short-range angular correlations arizing when fragments of nuclear matter are emitted preferentially in the direction perpendicular to the Mach shock front.

Let us consider two-particle inclusive correlations in the reactions

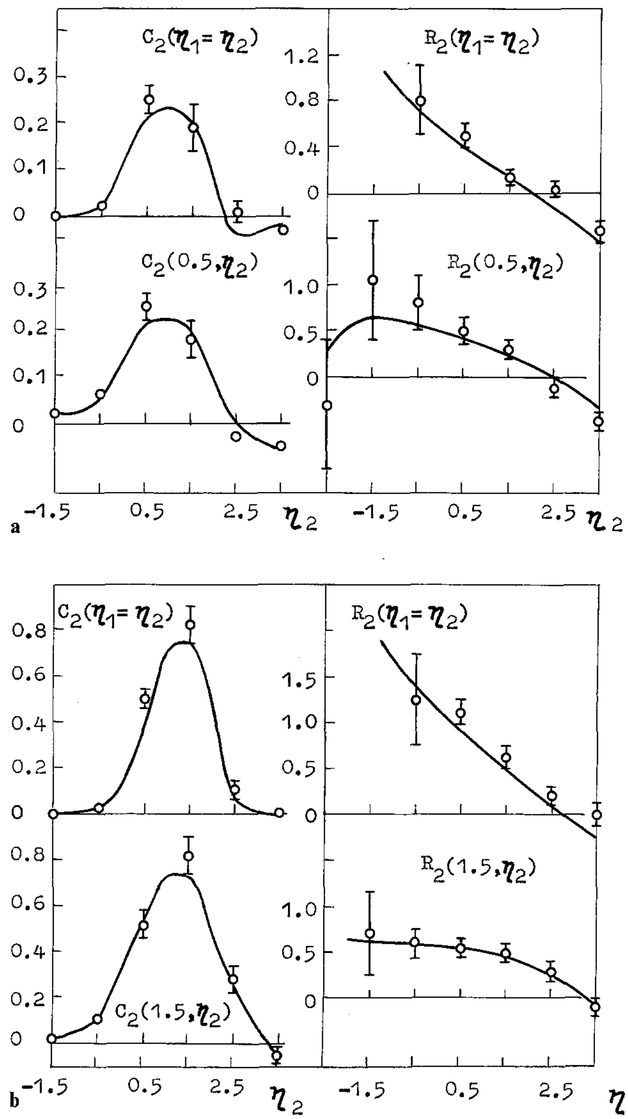


Fig. 10. **a** correlation functions C_2 and R_2 in dA interactions for s'-particles. The solid curves represent predictions of the IEM (see the text); **b** the same as in Figure 10a but for αA interactions

$$d + A \to 1 + 2 + \text{anything}, \tag{1}$$

$$\alpha + A \to 1 + 2 + \text{anything}, \tag{2}$$

where 1 and 2 denote s', g and b particles, employing the wellknown correlation functions

$$C_2(z_1, z_2) = \frac{1}{\sigma}\frac{d^2\sigma}{dz_1\,dz_2} - \frac{1}{\sigma^2}\frac{d\sigma}{dz_1}\frac{d\sigma}{dz_2} \tag{3}$$

$$R_2(z_1, z_2) = \sigma\frac{d^2\sigma}{dz_1\,dz_2} \Big/ \frac{d\sigma}{dz_1}\frac{d\sigma}{dz_2} - 1 \tag{4}$$

where as arguments z_1, z_2 we take $z = \cos\theta$ for grey and black particles and $z = \eta = \ln\text{ctg}(\theta/2)$ for shower particles.

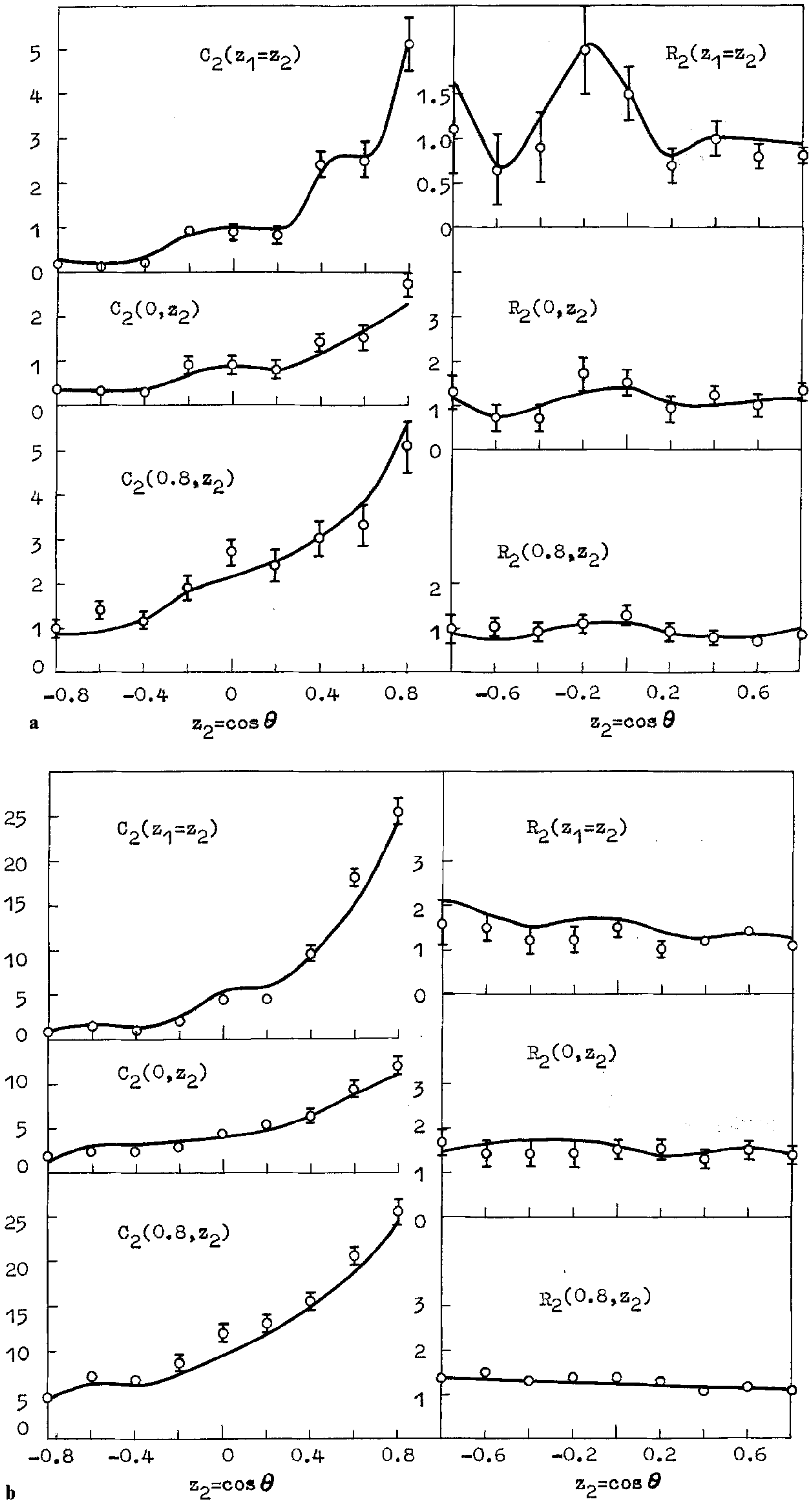
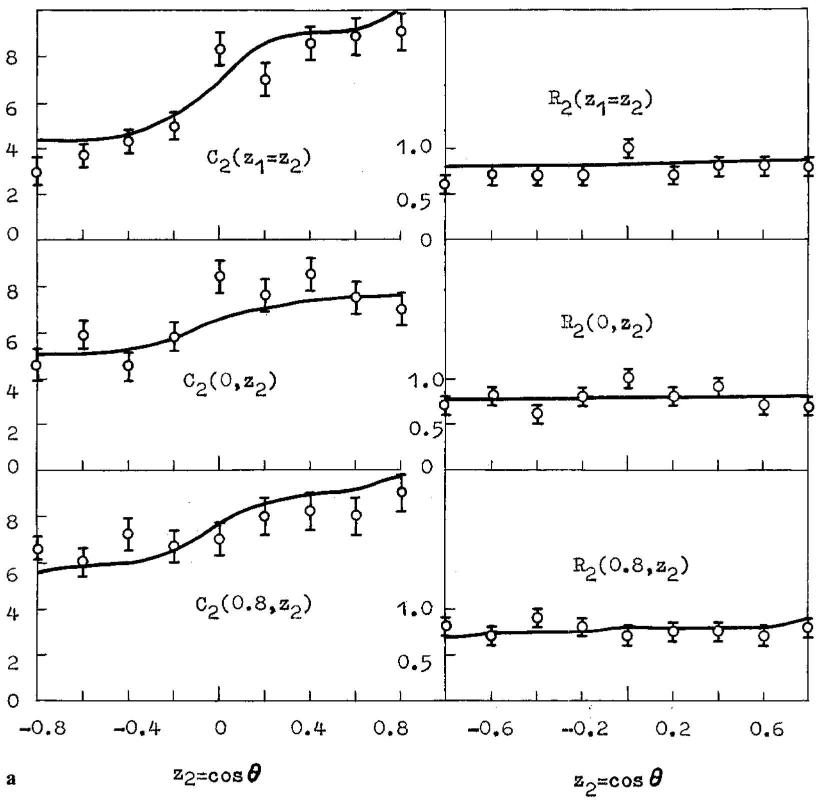


Fig. 11. a correlators C_2 and R_2 for g-particles in dA interactions. The curves belong to the IEM; **b** the same for αA interactions

It is known that the broad multiplicity distributions of secondary particles and the dependence of one-particle distribution on multiplicity (for s particles) lead to strong pseudocorrelations, i.e. to $C_2, R_2 \neq 0$ even in the absence of any dynamical correlations. In view of this, we have calculated correlation functions (3, 4) in events simulated by the Monte Carlo method for all experimental groups of interactions considered according to the simple independent emission model (IEM). We assumed in this model, that:



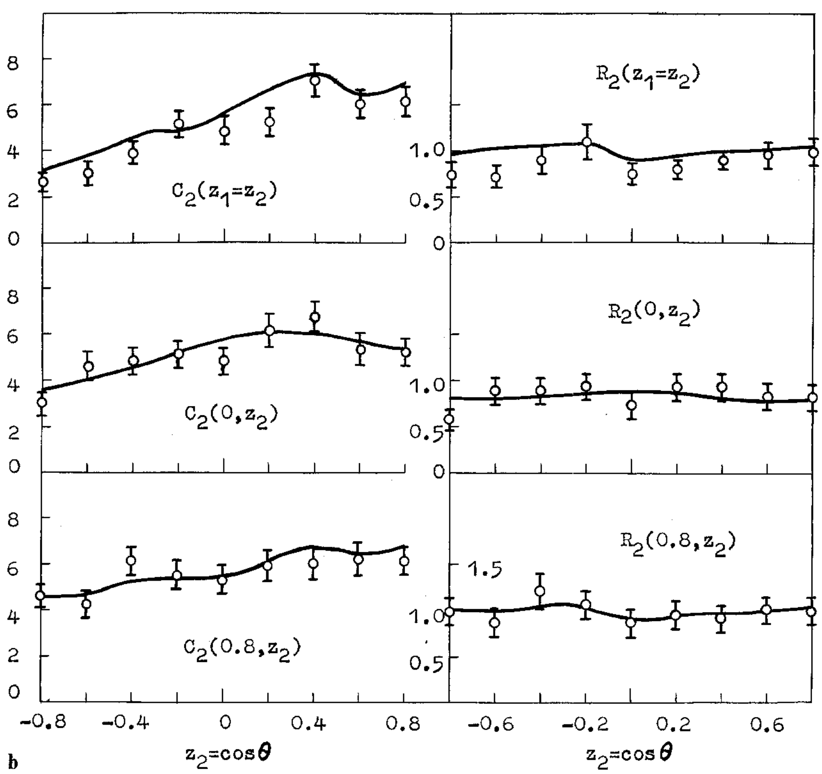


Fig. 12. **a** correlators C_2 and R_2 for b-particles in dA interactions. The curves belong to the IEM; **b** the same for αA interactions

(i) particles of all types are emitted independently of each other;
(ii) angular distributions of all types of particles coincide exactly with the empirical semi-inclusive (i.e. at fixed n_s, n_g and n_b) one-particle spectra;
(iii) multiplicity distributions coincide with the empirical spectra for all groups studied.

It was shown earlier [16] that every enhancement of experimental values of correlators C_2 and R_2 over the C_2(IEM) and R_2(IEM) calculated in framework

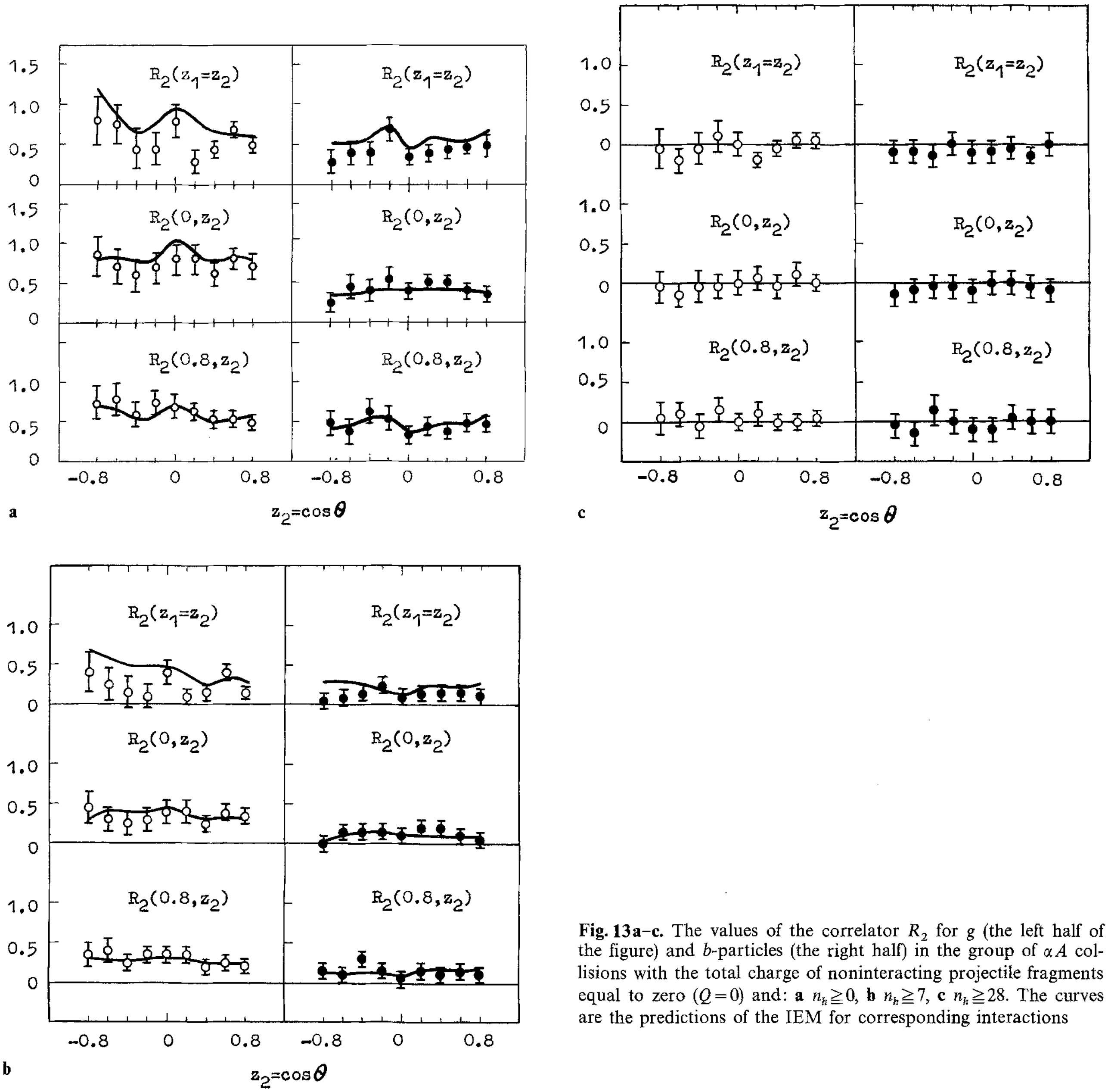


Fig. 13a–c. The values of the correlator R_2 for g (the left half of the figure) and b-particles (the right half) in the group of αA collisions with the total charge of noninteracting projectile fragments equal to zero ($Q=0$) and: **a** $n_h \geqq 0$, **b** $n_h \geqq 7$, **c** $n_h \geqq 28$. The curves are the predictions of the IEM for corresponding interactions

of the IEM may be considered as a manifestation of short-range correlations of dynamical origin since the action of conservation laws in multiple production does not increase C_2(IEM) and R_2(IEM) at small enough $\Delta z = |z_1 - z_2|$.

The experimental and theoretical values of the correlators (3, 4) for the total ensemble of dA and αA interactions are plotted in Figures 10, 11 and 12 for s, g and b particles, respectively. One can see that the experimental values of C_2 and R_2 are in a good agreement with predictions of the IEM at all values of arguments z_1, z_2, i.e. the data do not demonstrate dynamical effects. The absence of any short-ranged correlations between the target fragments (see the values of correlators at $z_1 = z_2$) contradicts the hypothesis that the nuclear shock waves are formed in interactions of deuterons and alpha particles with emulsion nuclei at energies considered. The same conclusion has been drawn for collisions of nitrogen ions in emulsion at 2.1 GeV/n [15].

Since the nuclear shock waves affect characteristics of interactions most strongly in central collisions of nuclei we have additionally considered correlations in different Q groups of dA and αA interactions. Furthermore, selecting events in accordance with both the total charge of noninteracting projectile fragments and the number of heavily ionizing fragments of the target we were able to study interactions which could be considered as central for both the colliding nuclei. For instance, heavy ion collisions in emulsion characterizing by $Q=0$ and $n_h \geqq 28$ should be treated as very central interactions of the projectile with heavy emulsion nuclei.

Figure 13 examplifies the values of the normalized correlator R_2 at some selected z_1, z_2 for g and b particles from αA interactions having $Q=0$ and with the following cut-offs imposed on the number of heavy prongs: $n_h \geqq 0$, $n_h \geqq 7$, $n_h \geqq 28$. It is seen that the data presented do not exhibit any features contradicting the assumption that secondary particles are emitted independently. Moreover, one can infer from Figure 13 that the experimental values of R_2 decrease with the number of heavy particles and IEM quite satisfactorily reproduces such behaviour of the normalized correlator. It is interesting to note that just the same dependence of R_2 on n_h has been earlier observed for hadron-nucleus interactions at very high energies (see, e.g. [12]).

A good agreement of the experimental data on two-particle correlations with predictions of the independent emission model probably indicates the prominent role of the cascade mechanism in multiple production in heavy ion collisions at energies considered.

6. Conclusions

We have discussed here a large amount of experimental data on dA and αA interactions at energy of about 3.6 GeV/n. The main results of the present investigation can be briefly summarized as follows.

1. Multiplicity of all types of secondary particles depends on the atomic number of target and the number of interacting projectile nucleons. Inelastic events with a large number (and/or the large total charge) of projectile fragments belong to extremely peripheral collisions of interacting nuclei.
2. Angular distributions of all types of secondaries demonstrate the remarkable stability to the change of A and the number of interacting projectile nucleons.
3. The data do not demonstrate the short-range angular correlations which are required by models of nuclear shock waves.

Thus, heavy ion interactions at energies of about a few GeV per nucleon do not show the strong collective phenomena and it is likely that they can be described in general by models of the cascade-evaporation type, although the agreement between the existing quantitative predictions of this model and the experimental data are not yet so good.

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