CORRELATIONS OF SECONDARY PARTICLES IN INTERACTIONS OF ^{16}O NUCLEI IN PHOTOEMULSION AT ENERGY 3.7 GeV PER NUCLEON

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SUMMARY

This work presents the multiplicity correlations of secondary charged particles produced in interactions of ^{16}O nuclei with photoemulsion nuclei at energy 3.7 GeV per nucleon. The dependence of the correlations on the centrality of interaction and also on the energy and on the mass number of primary nuclei has been studied. Obtained results have been compared with calculations from cascade – evaporation model.

At first the correlation dependences between every two kinds of secondary particles were studied. These dependences can be approximated by a linear function in the statistical limited range of experimental values. The best fits are summarized in a table. The experimental dependence of $\langle N_s \rangle$ on N_h has the characteristic behaviour with plateau at $4 \leq N_h \leq 8$, which consists mainly the collisions of oxygen nuclei ^{16}O with a light nuclei of photoemulsion (^{12}C, ^{14}N, ^{16}O), especially with carbon nuclei. The average multiplicity values of slow target fragments $\langle N_b \rangle$ depend strongly on the number of recoil protons up to the values $N_g \cong 13$ with the following saturation at higher N_g. In the experimental dependences of average multiplicities $\langle N_g \rangle$ and $\langle N_b \rangle$ on N_h it was observed that in a region $N_h \leq 20$ the values of $\langle N_g \rangle$ are like the values of $\langle N_b \rangle$, i. e. the fast and the slow target fragments contribute to the production of h – particles by equivalent rate, but the contribution of fast target fragments (g – particles) predominates at upper numbers of N_h. Also the correlation between the average multiplicity values $\langle N_i \rangle$ and the summary charge Q of the noninteracting fragments of primary nucleus has been investigated. Used model describes the studied characteristics of secondary particles qualitatively.

Keywords: *average multiplicity, correlations, target fragments, nuclear interactions, photoemulsion*

1. INTRODUCTION

The aim of presented work is to study the multiplicity correlations among different types of the secondary charged particles produced in interactions of ^{16}O nuclei with photoemulsion nuclei at energy 3.7 GeV per nucleon. More information about the nucleus – nucleus interaction than multiplicities yield the multiplicity correlations between secondary particles. Thus the correlations can contribute to the better understanding of production mechanism in nuclear collisions. Characteristics of secondary charged particles differ each other according to the energy and the mass of primary nucleus. Our experimental results are compared with the modiefied cascade – evaporation model (CEM) developed by G. J. Musulmanbekov [6].

2. EXPERIMENTAL METHODS

The presented data were obtained with help of conventional emulsion stacks. The emulsion detector was irradiated horizontally in the Laboratory of High Energies of JINR at Dubna by oxygen beam with an energy of 3.7 GeV per nucleon. For the analysis 2823 events of interactions ^{16}O+emulsion measured along the tracks of primary nuclei were used within the EMU01 collaboration [7]. For all charged particles the polar θ and azimutal Ψ emission angles were determined. The charged secondary particles were divided into the following types in accordance with ordinary photoemulsion methodical criteria:

s – particles (shower): Singly charged relativistic particles with a velocity $\beta \geq 0.7$. These are predominantly pions and protons produced over the whole region of phase space.

h – particles (heavily ionizing particles): Target fragments which include *g – particles* (grey) – fast target fragments with a range in emulsion ≥ 3 mm and having a velocity $\beta < 0.7$; and *b – particles* (black) – charged particles with the range < 3 mm, slow target fragments mainly evaporation products from the remnant of the target nucleus.

3. CORRELATIONS

Fig. 1a shows the dependence of the average multiplicity of relativistic charged particles $\langle N_s \rangle$ on the heavily ionizing particles N_h for interactions of oxygen nuclei with photoemulsion at energy 3.7 GeV per nucleon in comparison with the theoretical calculations according to CEM. The cascade – evaporation model describes the experimental data very well at small values of N_h, ($N_h \leq 8$). Some disagreement is observed at higher values of N_h, which represent the interactions of oxygen nuclei with the heavy targets of photoemulsion, i. e. bromine ^{80}Br and silver ^{108}Ag. As the model overestimates the values of average multiplicity of N_s in this region, it predicts higher production of relativistic particles.

The experimental dependence $\langle N_s \rangle = f(N_h)$ has the characteristic behaviour with plateau in a region of small values N_h, which consists mainly of the collisions of ^{16}O nuclei with light nuclei of photoemulsion: ^{12}C, ^{14}N and ^{16}O. The similar flow of experimental dependence with plateau was observed in ^{22}Ne experiment at the same energy [3]. Fig. 1b describes this correlation only for the theoretical values. There are separated the interactions of oxygen nuclei with the light (C, N, O) and the heavy (Br, Ag) nuclei of photoemulsion. It is evident, that the mentioned plateau at $4 \le N_h \le 8$ rises in consequence of the interactions of ^{16}O nuclei with the light nuclei of photoemulsion, especially with carbon nuclei (not presented here).

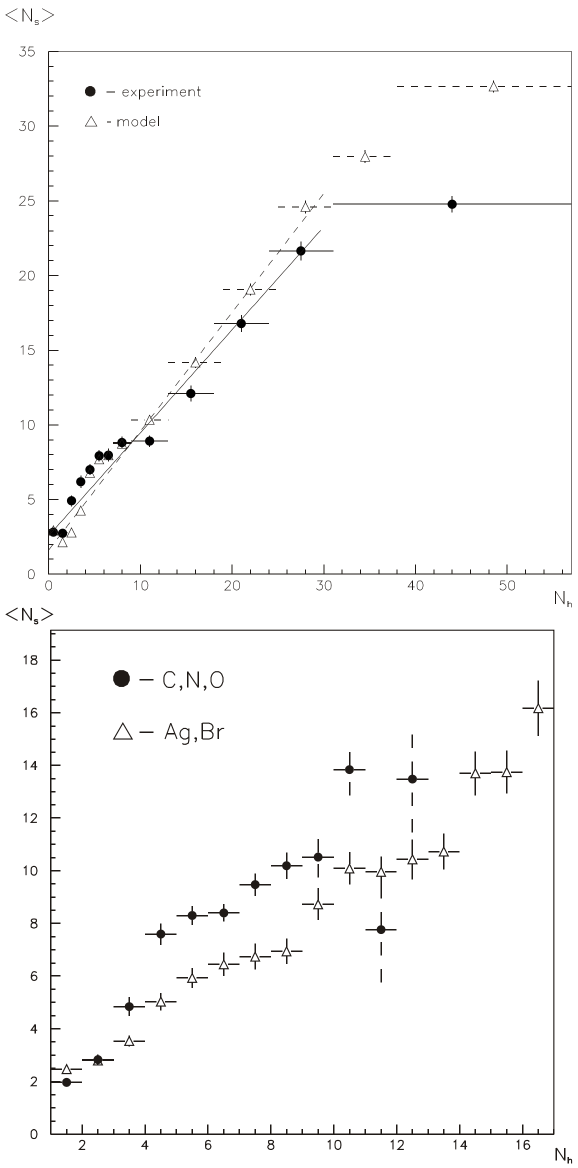

Fig. 1a) The correlation of $<N_s>$ on N_h for ^{16}O experiment at energy 3.7 GeV per nucleon compared with CEM, **b)** The theoretical calculations given by CEM for interactions with different nuclei of photoemulsion.

We can note (Fig. 1a), that the average multiplicity values of relativistic particles $<N_s>$ increase rapidly with the increasing number of target fragments N_h. This reflects that the number of nucleons of incident nucleus which interacted with the target as well as the number of collisions inside the target nucleus and the degree of excitation of this target nucleus, increase with the decrease of the impact parameter, i. e. with the increase of the value of N_h.

The correlation of $<N_s>$ on N_h can be approximated by a linear dependence with positive slope up to the values of $N_h \cong 30$. The best fit for this linear relation is: $\langle N_s \rangle = 0.69 N_h + 2.58$, where $\chi^2 / ndf = 88.71/10$.

From the comparison of the slopes for interactions of oxygen nuclei at 3.7 GeV per nucleon with ^{16}O experiment at energy 200 GeV per nucleon $\left(\langle N_s \rangle = 4.4 N_h + 14.0\right)$ [5] and with ^{1}H collisions at 3.7 GeV per nucleon $\left(\langle N_s \rangle = -0.02 N_h + 1.8\right)$ [4] we can conclude, that the production of relativistic particles increases with increasing of the mass number and energy of primary nuclei.

The correlation of average multiplicity values of slow target nucleus fragments $<N_b>$ on number of fast target fragments N_g for interactions of oxygen nuclei with emulsion at energy 3.7 GeV per nucleon shown in Fig. 2 is compared with the theoretical calculations of CEM. The multiplicity of slow target fragments depends strongly on the number of recoil protons up to the values $N_g \cong 13$ with the following saturation at higher N_g.

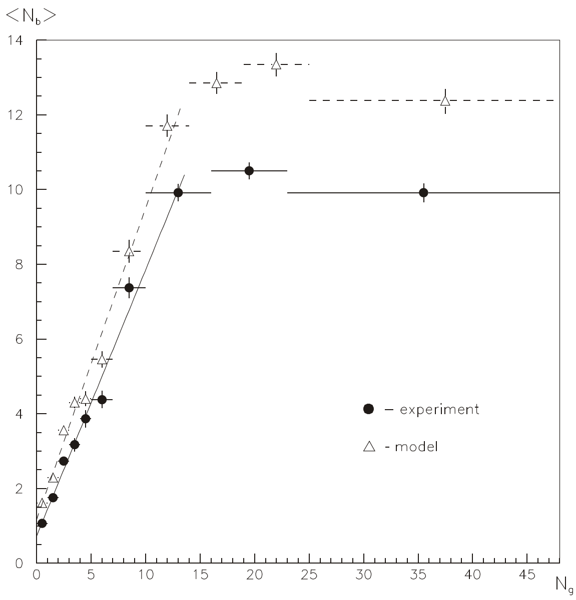

Fig. 2 The correlation of $<N_b>$ on N_g for ^{16}O experiment at energy 3.7 GeV per nucleon compared with CEM.

The rising part of this correlation is well reproduced by the CEM calculation and the best linear fit is: $\langle N_b \rangle = 0.71 N_g + 0.72$, where $\chi^2 / ndf = 15.91/6$. The inclination coefficient is lower than in the case of ^{1}H+emulsion collisions at the same energy, where the mentioned coefficient has value 1.09 ± 0.02 [4]. The plateau observed at the values $N_g \geq 13$ is badly described by used model.

Tab. 1 summarizes all multiplicity correlations of various types of secondary particles in the interactions of ^{16}O nuclei with photoemulsion at energy 3.7 GeV per nucleon. We can see that there is a linear correlation between the multiplicities of every two kinds of secondary particles of the type: $\langle N_i \rangle = a_{ij} \cdot N_j + b_{ij}$ where $i \neq j$. In parentheses are given the results of theoretical calculations obtained by the cascade – evaporation model.

Tab. 1 Multiplicity correlations for ^{16}O experiment at 3.7 GeV per nucleon compared with theoretical calculations given by CEM.

	N_h	N_g	N_b
$\langle N_h \rangle$	—	$1.57N_g+0.44$ 1) ($1.67N_g+0.93$)	$2.12N_b-0.21$ 2) ($1.98N_b+0.04$)
$\langle N_g \rangle$	$0.52N_h-0.23$ 3) ($0.46N_h-0.21$)	—	$1.13N_b+0.27$ 4) ($0.99N_b+0.53$)
$\langle N_b \rangle$	$0.50N_h-0.23$ 5) ($0.54N_h-0.26$)	$0.71N_g+0.72$ 6) ($0.83N_g+1.16$)	—
$\langle N_s \rangle$	$0.69N_h+2.58$ 7) ($0.79N_h+1.62$)	$1.27N_g+2.61$ 8) ($1.46N_g+2.18$)	—

The fitting is done up to $N_g \leq 19$ 1), $N_b \leq 10$ 2), $N_h \leq 30$ 3), $N_b \leq 10$ 4), $N_h \leq 19$ 5), $N_g \leq 13$ 6), $N_h \leq 30$ 7) and $N_g \leq 13$ 8) for statistical reason.

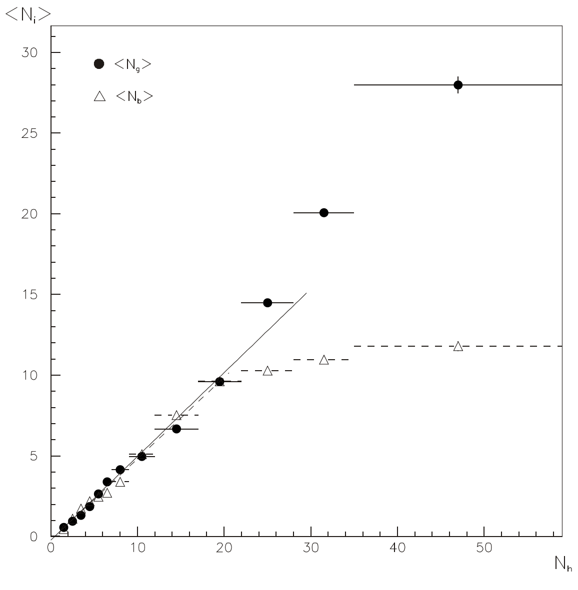

Fig. 3 The correlations of $\langle N_g \rangle$ and $\langle N_b \rangle$ on N_h for ^{16}O experiment at energy 3.7 GeV per nucleon.

Fig. 3 shows the presented experimental average multiplicities $\langle N_g \rangle$ and $\langle N_b \rangle$ as a function of N_h. We can see that in a region $N_h \leq 20$ the values of $\langle N_g \rangle$ and $\langle N_b \rangle$ are equal, i. e. the fast and the slow target fragments contribute to the production of h – particles by equivalent rate. At upper values of N_h (the central interactions of ^{16}O nuclei with heavy nuclei of photoemulsion ^{80}Br and ^{108}Ag) predominates the contribution of g – particles.

The same behaviour of experimental dependence $\langle N_g \rangle$ and $\langle N_b \rangle$ on N_h was observed in ^{22}Ne experiment at the same energy [3]. But it differs from the behaviour of mentioned correlations at higher energy (200 GeV per nucleon [5]), where the values of $\langle N_b \rangle$ are higher than the values of $\langle N_g \rangle$ in whole range of N_h.

Fig. 4 presents the dependence of the mean multiplicities of secondary charged particles on the centrality of interaction given by the summary charge Q of spectator projectile fragments. We can see that the average multiplicity values for each types of secondary particles increase with decreasing Q (with increasing of the centrality degree).

The dynamic range of $\langle N_b \rangle$ is smaller than the ranges of values for the other types of secondary particles. This indicates that slow target fragments have the weakest correlation on the centrality. Furthermore the dependence of $\langle N_b \rangle$ on Q shows an indication of saturation with increasing of the centrality degree (at smallest values of Q). There is stronger dependence of the mean multiplicity $\langle N_i \rangle$ on Q in the case of fast target fragments and relativistic particles.

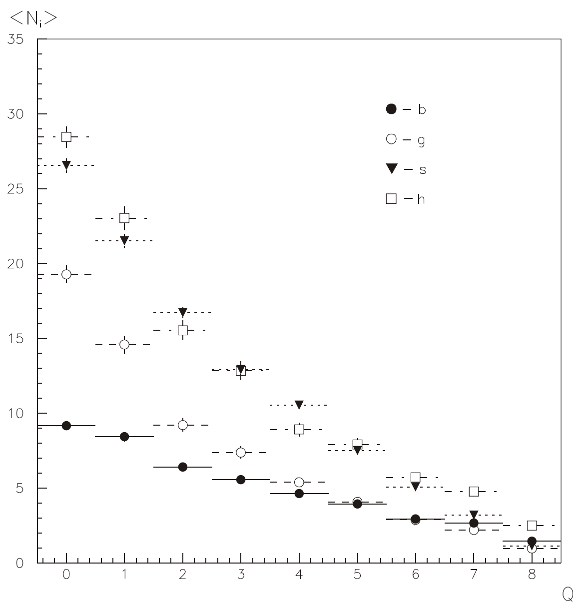

Fig. 4 The correlations of average multiplicity values $\langle N_i \rangle$ on summary charge Q for different types of secondary charged particles.

The formation of slow target nucleus fragments is the result of the evaporating process in nuclear interaction and the b – particles represent the remnant of the target nucleus, whereas the fast target fragments (g – particles) are mainly protons knocked out in the direct process [1]. Already at larger impact parameters the target remnant is rather excited and a further excitement (emission of g – particles) will only have a limited influence on the number of evaporated b – particles.

Our experimental correlations of the average multiplicity values $<N_i>$ on summary charge Q were compared with the ^{16}O experiments at higher energies [1] and different (^{12}C, ^{16}O, ^{22}Ne) primary nuclei at the same energy [2, 8]. The distributions of mean values $<N_i>$ on Q indicate the same behaviour with increasing primary energy and these trends are saved for each types of secondary particles. With the increasing mass number of primary nucleus increase the average multiplicity values $<N_i>$ and the flow of correlations is similar as in our experiment.

4. CONCLUSION

The multiplicity correlations between every two kinds of secondary particles in inelastic interactions of oxygen nuclei with photoemulsion at energy 3.7 GeV per nucleon were studied, leading to the following conclusions:

- The multiplicity correlations between every types of secondary charged particles can be approximated with a linear function in the statistical limited range of experimental values: $\langle N_i \rangle = a_{ij} \cdot N_j + b_{ij}$ where $i \neq j$.
- The dependence of $<N_b>$ on Q indicates some saturation with increasing of the centrality degree (at smallest values of Q).
- The average multiplicity values of relativistic particles and target fragments increase rapidly with decreasing of summary charge Q.
- The cascade – evaporation model describes the studied characteristics of secondary particles well.

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