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COLLECTIVE FORMATION OF SECONDARY PARTICLES IN INTERACTIONS OF ASYMMETRIC NUCLEI*

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A study of characteristics of the events of complete destruction of the projectile nucleus in the interactions between asymmetric nuclei for different initial states of the collision is performed. In the interactions of the sulfur nuclei with heavy emulsion nuclei at energy of 200 AGeV, an anomalous high number of events of complete destruction of the projectile nuclei is observed. The high probability of such events depends on the energy of interaction (it is not detected in the interactions of the sulfur nuclei with emulsion nuclei at the energy of 3.7 AGeV) on the degree of asymmetry of the interacting nuclei (it is not detected in interactions of the sulfur nuclei with light emulsion nuclei) and on the initial state of interaction (it is not detected in peripheral collisions). These events are characterized by high multiplicity of secondary particles and a narrow peak in the region of small values of average pseudorapidity.

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1. Introduction

Quark–gluon plasma (QGP) is a special state of nuclear matter, in which quarks become quasi-free. The expansion of secondary particles, formed from a fireball of nuclear matter, leads to the collective nature of the formation of secondary particles. The search and investigation of the QGP manifestations led to a purposeful concentration of both theoretical and experimental studies in nucleus–nucleus interactions [1, 2].

First of all, the interaction with extreme characteristics is investigated: large transverse momenta of secondary particles [3], high particle density per

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unit interval of pseudorapidity distribution [4], large multiplicities [5], *etc.* For the research and for analysis of non-statistical fluctuations in distributions of secondary particles, different approaches and methods are used [6, 7].

In the relativistic heavy-ion collisions, nucleons can be divided into two distinct categories: those that experience an inelastic collision with at least one nucleon from the opposing nucleus (participants) and those that do not (spectators). The participant nucleons ultimately create the bulk of secondary particles observed in the detectors. The spectators include one-charge, two-charge, and multi-charge fragments of colliding nuclei [8].

The greater the overlap of the interacting nuclei, the lower the aggregated charge of the spectator fragments should be. Therefore, fragmentation analysis should significantly improve the accuracy of estimating the parameters of the initial state of the interaction.

In the colliding beam experiments, information on the projectile fragmentation is usually not available. Therefore, to evaluate the geometry of the collision, the accelerator experiment with the fixed target has more advantages [9, 10].

Moreover, the fixed target mode allows for the intensive study of rare processes, the measurements of the parameters needed to analyze the data of cosmic rays [11–14].

In this paper, the analysis of the events of complete destruction of the projectile nucleus is presented. Such events are considered as events in which the most favorable conditions for the formation of the QGP have been created. It is assumed that the events of complete destruction are central interactions, in which the maximum energy of the projectile nucleus is transferred into the interaction area.

2. Dependence of probability of complete destruction of projectile nucleus on interaction energy

For the analysis, we used the experimental data on inelastic interactions of sulfur nuclei with emulsion nuclei ^{32}S+Em at energies of 3.7 and 200 AGeV [15, 16].

To estimate the number of interacting protons (participants) of the projectile nucleus, we used an auxiliary value $n_{g'} = Q - \Sigma Z_{\mathrm{f}}$, where Q is charge of the projectile nucleus and ΣZ_{f} is the sum of the charges of all fragments of the projectile nucleus.

Figure 1 shows the distribution by the number of interacting protons of the projectile nucleus $n_{g'}$.

As it can be seen from Fig. 1 (a), a trough-like distribution with an increased number of events in the area of both small and large values of $n_{g'}$ is observed. In the area of small values of $n_{g'}$ the increase of the probability

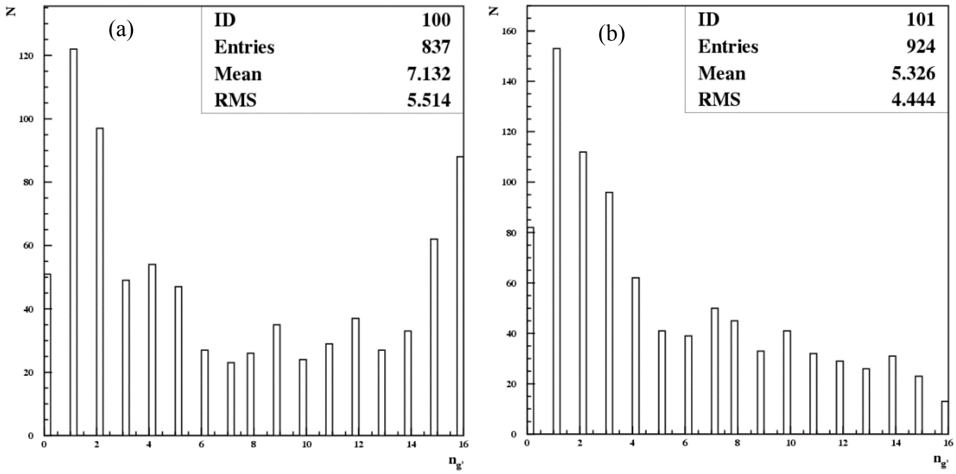

Fig. 1. Distribution by the number of interacting protons of the projectile nucleus $n_{g'}$ for interactions of sulfur nuclei ^{32}S with emulsion nuclei at 200 AGeV (a) and at 3.7 AGeV (b).

of events is explained by the increase of peripheral interactions. The peak at large $n_{g'}$ requires special consideration. The events with $n_{g'} = 16$ correspond to complete destruction of the projectile nucleus. In the events with $n_{g'} = 15$, one single-charge fragment is detected. The probability of such events (with $n_{g'} = 16$ or $n_{g'} = 15$) is $\sim 15\%$ from the presented ones in Fig. 1 (a).

At the first stage, we analyzed the dependence of the probability of the events of complete destruction on the energy of the projectile nucleus. Figure 1 (b) shows the distribution by the number of interacting protons of the projectile nucleus for interactions of ^{32}S+Em at 3.7 AGeV.

As can be seen from Fig. 1 (b), anomalous number of the events of complete destruction of the projectile nucleus is not detected. Thus, the probability of such events depends critically on the energy of the primary nucleus.

3. The interaction of nuclei of different degrees of asymmetry

The nuclear photoemulsion is a convenient detector for estimation of the influence of asymmetric parameters (relative size) of the interacting system on the probability of occurrence of the events of complete destruction of the projectile nucleus. It includes light, medium, and heavy nuclei. This allows us to analyze various types of nuclear interactions obtained under exactly the same experimental conditions.

In the analyzed experiments, a standard nuclear emulsion of the BR-2-type was used. It includes hydrogen (39.2%), nuclei of the CNO group (35.3%), and the AgBr nucleus (25.5%). To separate the interaction with light (CNO) and heavy (AgBr) nuclei, we considered events with the number of target-nucleus fragments $N_h \leq 8$ and with $N_h > 8$. The criterion $N_h = 8$ corresponds to the charge of the largest of the light nuclei of the photoemulsion — the oxygen nucleus.

The distribution by the number of interacting proton of the projectile nucleus $n_{g'}$ for ^{32}S+Em interactions with a different number of fragments of the target nucleus N_h is shown in Fig. 2. For comparison, the interactions of ^{32}S+Em at 200 AGeV and 3.7 AGeV are presented.

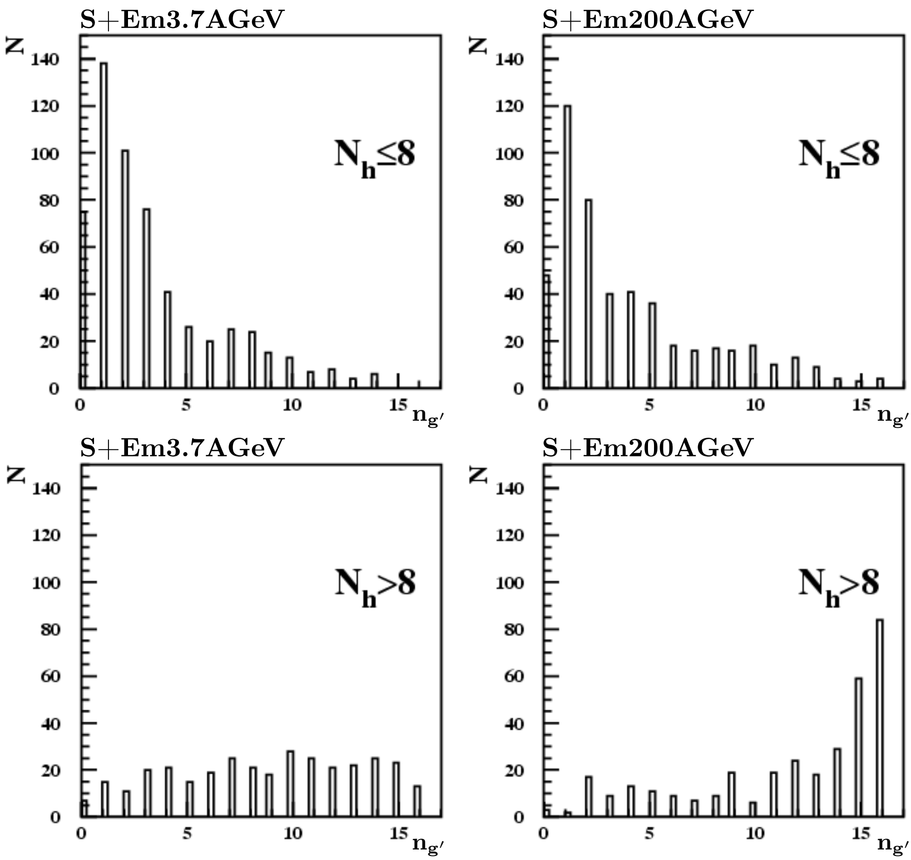

Fig. 2. The distribution of the number of interacting proton of the projectile nucleus $n_{g'}$ for ^{32}S+Em interactions at 3.7 and 200 AGeV with different numbers of fragments of the target nucleus N_h.

As it can be seen from Fig. 2, in the events with $N_h \leq 8$, the distributions of $n_{g'}$ are similar regardless of energy. A significant difference is found in the events of the interaction of sulfur with heavy nuclei of the photoemulsion. At lower energies, an almost flat-like distribution is observed and at 200 AGeV, the significant peak in the region of large values of $n_{g'}$ is observed.

4. Initial state of collision

One of the most optimal approaches for separating peripheral and central events is an analysis of the dependence of the number of fragments of the target nucleus on the multiplicity of secondary particles. This dependence is shown in Fig. 3.

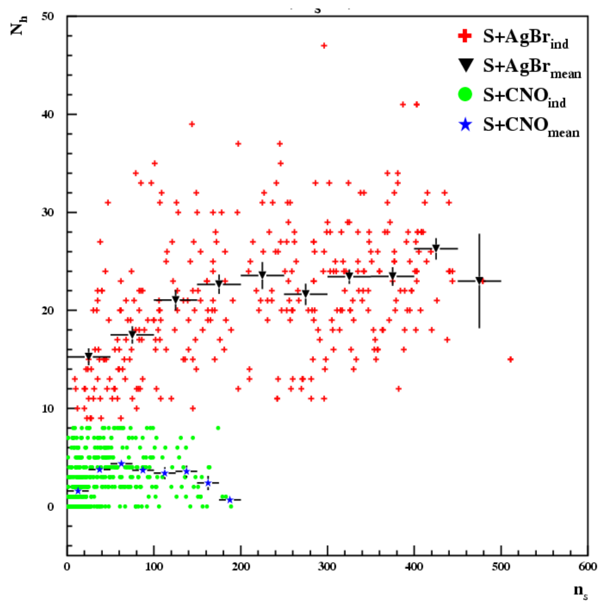

Fig. 3. The dependence of the number of fragments of the target nucleus N_h on the multiplicity of n_s particles for the interactions of ^{32}S+Em at 200 AGeV.

As it can be seen from Fig. 3, in ^{32}S+AgBr interactions, the average dependence shows the steady growth before $n_s \cong 200$. Then it goes on the plateau. A similar growth is discovered and for ^{32}S+CNO dependence, but before $n_s \cong 75$. These criteria allow us to separate peripheral and central collision.

To understand the distinctive features of the events of complete destruction, we performed a comparative analysis of the distributions of secondary particles in events with $n_{g'} \leq 14$ and $n_{g'} \geq 15$. The results of the comparison for the multiplicity of the secondary particles n_s, the number of the fragments of the target nucleus N_h, and the mean pseudorapidity distributions of secondary particles are shown in Fig. 4.

As it can be seen from Fig. 4, all the graphs presented are critically different from each other. The multiplicity distribution of the secondary particles for the events $n_{g'} \leq 14$ is concentrated in the region of small values with the mean value of $n_s = 66.83$. The multiplicity of events with $n_{g'} \geq 15$

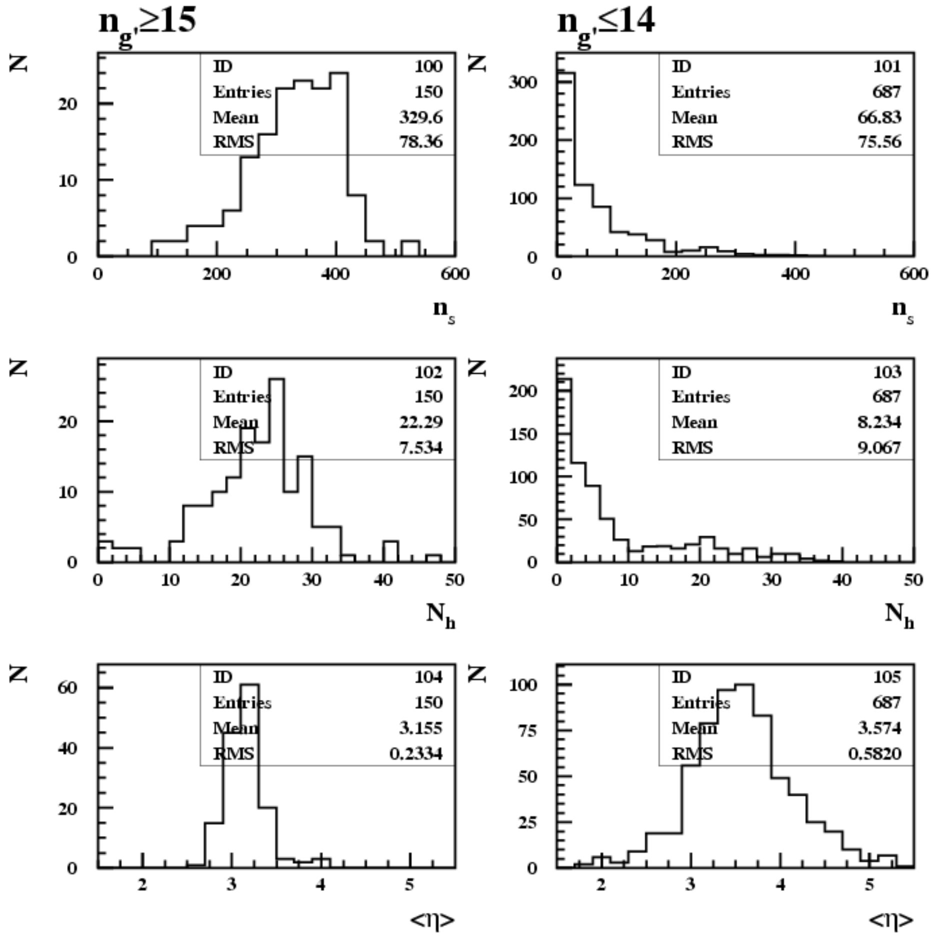

Fig. 4. The multiplicity distribution of secondary particles n_s, the number of the target nucleus fragments N_h, and the mean pseudorapidity distributions $\langle\eta\rangle$ of secondary particles for the ^{32}S+Em at 200 AGeV interactions with a different number of interacting protons of the projectile nucleus $n_{g'}$.

is 5 times higher. The number of fragments of the target nucleus in most events with $n_{g'} \geq 15$ is bigger than eight. Thus, basically, such events appear in the interactions of sulfur with heavy nuclei of the emulsion, which is confirmed by the results presented in Fig. 2.

The mean pseudorapidity distribution of secondary particles in events with $n_{g'} \geq 15$ is characterized by a narrow peak in the region of small values $\langle\eta\rangle$ (of large values of the transverse momentum). The dispersion of the distribution, in this case, is 2.5 times less than for events with $n_{g'} \leq 14$.

An increase in the number of events with large transverse momentum, in accordance with modern concepts, is interpreted as a signal of quark–gluon plasma [17].

5. Conclusion

In interactions of sulfur nuclei at 200 AGeV with heavy nuclei of photoemulsion, an anomalously high probability of the events of complete destruction of the projectile nucleus is found. In 15% of events, the projectile nucleus is destructed completely, or one single-charge fragment remains. The high probability of such events depends on the energy of interaction (it is not detected in the interactions of the sulfur nuclei with emulsion nuclei at the energy of 3.7 AGeV), on the degree of asymmetry of the interacting nuclei (it is not detected in interactions of the sulfur nuclei with light emulsion nuclei), and on the initial state of interaction (it is not detected in peripheral collisions). The events of complete destruction of the projectile nucleus are characterized by a high multiplicity of secondary particles and narrow peak in the region of small values of average pseudorapidity.

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