STUDY OF PSEUDO-RAPIDITY DISTRIBUTIONS OF SECONDARY PARTICLES AT HIGH ENERGIES*

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According to the theoretical predictions, a mixed phase of the quark–gluon plasma must be formed in the energy range from 4 to 11 GeV. In this work, a joint study of the collisions of Au-197 projectiles at 10.6 AGeV and Pb-208 projectiles at 158 AGeV with heavy (AgBr) and light (HCNO) targets present in a nuclear emulsion (Em, NIKFI BR-2) was carried out. To search for non-statistical clusters of secondary particles, we analyzed both secondary particles emitted from the interaction region and fragments of the projectile-nucleus and target-nucleus. To study pseudo-rapidity correlations, the Hurst method was used. According to the behavior of the Hurst curve, events were divided into two types: correlated and uncorrelated. Events of various types differ significantly in the fragmentation of the projectile-nucleus, multiplicity of secondary particles, and pseudo-rapidity distribution. Some correlated-type events have an "anomalous" pseudo-rapidity distribution: two streams of secondary particles are formed with significantly different pseudo-rapidity. In such events, several multi-charged fragments are detected.

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1. Introduction

The study of quark–gluon plasma (QGP) [1] has mainly focused on two complementary directions. The first direction is associated with studies of interactions of heavy ions at the maximum available energies for the study of nuclear matter at very high temperatures and low baryon densities [2, 3]. The second direction is focused on the search for the critical point of the phase transition of hadronic matter into the QGP state. It is assumed to be in the energy range from several GeV to several tens of GeV. First, it is

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considered that the investigations nearby the critical point of the phase transition into the quark–gluon plasma will give a possibility to get the quality new results on the process dynamics. Second, according to the theoretical predictions, a mixed phase of the 'excited hadronic matter', which includes both the free quarks and gluons, and the protons with neutrons, must be formed within the range of the energies from 4 to 11 GeV per nucleon [4, 5].

The difficulty in identifying the formation of quark–gluon plasma is mainly due to the fact that it is formed against a large background due to the usual processes of strong interaction [6]. The initial state, about which there is usually very little direct experimental information, leads to significant fluctuations in the distribution of secondary particles and fragments [7, 8]. To understand the initial state of the interaction, the fragmentation of the projectile- and target-nuclei is essential. In experiments with colliding beams, information on projectile fragmentation is usually not available [9]. Therefore, experiments with the fixed target have more advantages for studying the initial state of the interaction [10–13]. The fixed target mode also allows us to study rare processes and measure the parameters needed to analyze cosmic ray data [14–17].

In this work, we analyzed both secondary particles emitted from the interaction region and fragments of the projectile-nucleus and target-nucleus to search for non-statistical clusters of secondary particles.

2. Multi-particle correlations and event-by-event fluctuations in pseudo-rapidity distribution

The analyzed set included experimental data on interactions of lead nuclei (Pb-208, 158 AGeV) and gold nuclei (Au-197, 10.6 AGeV) with NIKFI BR-2 emulsion nuclei [18, 19]. All charged secondary particles were divided into the following groups in accordance with the generally accepted terminology of emulsion experiments [20]: N_{f} — fragments of the projectile nuclei, including one-charge and multi-charge; N_h — fragments of the target nucleus, the so-called h-particles, consisting of fast g-particles (one-charge target fragments) and slow b-particles (multi-charge target fragments); n_{s} — shower particles emitted from the interaction region.

In a peripheral collision, the interacting nuclei do not overlap completely, and therefore the resulting fireball expands asymmetrically in different directions. Thus, depending on the geometry of the collision, fluctuations in the average value of the pseudorapidity distribution of secondary particles should be detected. To study these fluctuations in each event, the average value of the pseudorapidity $\langle\eta\rangle$ of all shower particles was calculated. After that, the distribution of the average pseudorapidity calculated in each individual event was constructed. The results are shown in figure 1 (a).

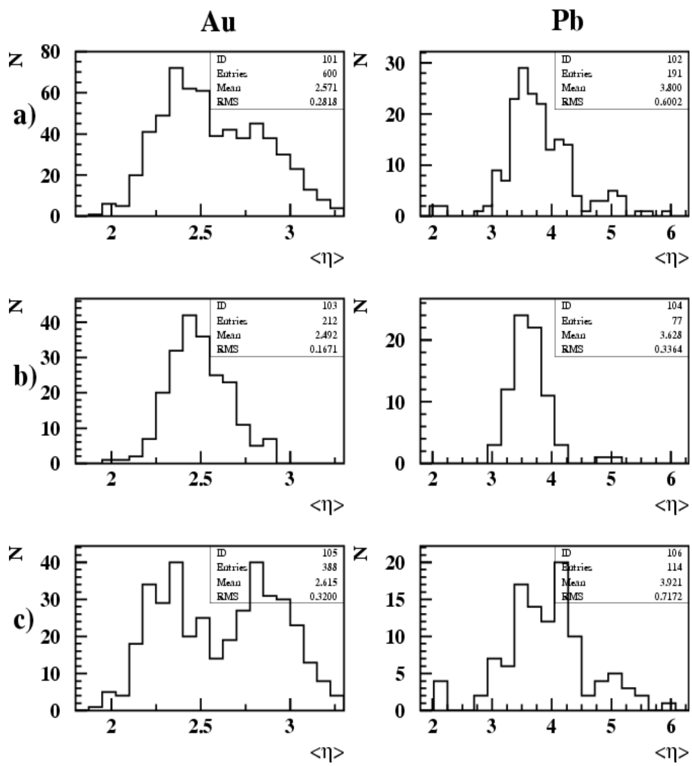

Fig. 1. Distribution of the average pseudo-rapidity for events with a different Hurst index: (a) all events; (b) $h < 0.64$; (c) $h \geq 0.64$.

As can be seen from figure 1 (a), the $\langle\eta\rangle$ distribution for the interactions Au+Em 10.6 AGeV is of an asymmetric type. It appears to be two overlapping distributions with mean $\langle\eta\rangle \sim 2.35$ and $\langle\eta\rangle \sim 2.85$. In contrast, the $\langle\eta\rangle$ distribution for Pb+Em 158 AGeV does not have such a large characteristic bump in the region of large $\langle\eta\rangle$.

For a more detailed study of this feature, the search for correlated groups of secondary particles was carried out. To study correlations, we used the Hurst method [21]. Analysis of the behavior of the Hurst curve makes it possible to distinguish stochastic fluctuations associated with statistical effects from correlated distributions and to estimate the "strength" and "length" of multi-particle correlations in the pseudo-rapidity distribution of secondary particles [22]. The separation of events with correlated and uncorrelated pseudo-rapidity distribution was carried out on the basis of the Hurst index $h = 0.64$. The criterion $h < 0.64$, as was shown in [23], corresponds to a pseudo-rapidity distribution in which there are no multi-particle correlations (two-particle correlations and stochastic fluctuations predominate). Based on event-by-event analysis of pseudo-rapidity correlations by the Hurst method, all events were divided into 2 types: correlated and uncorrelated. As can be seen from figure 1 (b), the distributions of average values of pseudo-rapidity of secondary particles in events of uncorrelated type in Pb+Em interactions and in Au+Em interactions have a Gaussian-like distribution. At the same time, a significant difference is observed for events of a correlated type (figure 1 (c)). In Au+Em interactions, the $\langle\eta\rangle$ distribution has practically two equivalent "humps". The $\langle\eta\rangle$ distribution for Pb+Em 158 AGeV does not have such a large characteristic "hump" in the region of large $\langle\eta\rangle$.

For a more detailed study of this feature, we analyzed the pseudorapidity distributions of individual events (Au+Em 10.6 AGeV) with $\langle\eta\rangle$ in the intervals from 2.3 to 2.4 and from 2.8 to 2.9, comparing them with each other. The distributions for two characteristic events for each of these intervals are shown in figure 2.

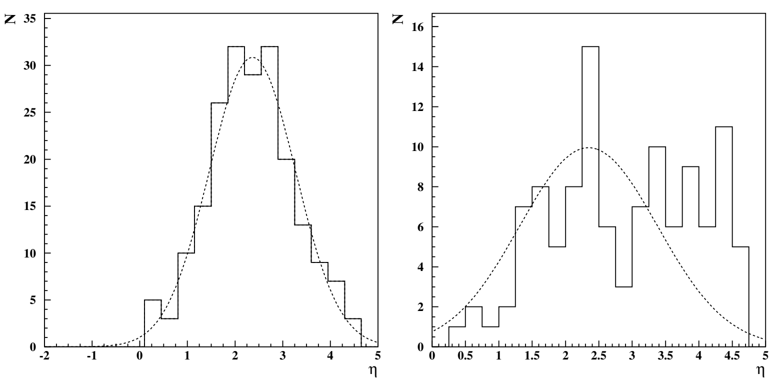

Fig. 2. Pseudo-rapidity distribution for two events Au+Em 10.6 AGeV. Left: with $\langle\eta\rangle$ in the range from 2.3 to 2.4; Right: with $\langle\eta\rangle$ in the range from 2.8 to 2.9.

The event shown in figure 2 (left) a was fitted with a Gaussian function (dotted line). For comparison, the same fit (normalized to the multiplicity of secondary particles in the event) was superimposed on figure 2 (right). As can be seen from figure 2 (left), events from the first interval have a Gaussian-like structure with an average pseudo-rapidity $\langle\eta\rangle \sim 2.35$. Events with an average pseudo-rapidity in the range from 2.8 to 2.9 (figure 2 (right)) have a more complex structure, resembling a two-hump distribution. In addition to the "standard" group of particles with an average pseudo-rapidity in the region of $\langle\eta\rangle \sim 2.35$, a significant group of particles with $\langle\eta\rangle \sim 4$ is found.

To study the features of the appearance of such "anomalous" events on the degree of centrality of the collision and on the degree of asymmetry of the interacting nuclei, we analyzed the correlations between the values of the pseudo-rapidity distribution of s-particles and the total charge of all fragments of the projectile nucleus (Q), taking into account the number of fragments of the target nucleus. The results of the study showed that the majority of events with a two-hump pseudo-rapidity distribution are events with several multi-charged fragments ($N_{\mathrm{f}} \geq 2$). The number of Au+Em events with $N_{\mathrm{f}} \geq 2$ is about 55% of the total number of events. In Pb+Em, there are significantly fewer such events — 38.3%. Significant features are also found in the multiplicity of secondary particles. The results are presented in Table 1.

Table 1. Average number of shower particles $\langle n_{\mathrm{s}} \rangle$, fast $\langle n_g \rangle$, and slow $\langle n_b \rangle$ target-nucleus fragments for Au+Em and Pb+Em events with different numbers of multi-charged fragments N_{f}.

N_{f}	Au			Pb		
	$\langle n_{\mathrm{s}} \rangle$	$\langle n_g \rangle$	$\langle n_b \rangle$	$\langle n_{\mathrm{s}} \rangle$	$\langle n_g \rangle$	$\langle n_b \rangle$
1	46 ± 4	4.5 ± 0.4	3.4 ± 0.2	83 ± 12	3.4 ± 0.4	4.2 ± 0.4
2	60 ± 5	5.3 ± 0.5	3.6 ± 0.3	172 ± 31	3.8 ± 0.8	3.2 ± 0.4
3	68 ± 6	5.4 ± 0.7	4.2 ± 0.5	160 ± 36	4.0 ± 1.2	3.9 ± 0.9
4	58 ± 7	5.1 ± 0.8	3.3 ± 0.5	180 ± 58	5.1 ± 1.8	3.2 ± 1.1
5	51 ± 9	6.3 ± 1.5	4.5 ± 1.1	158 ± 61	5.3 ± 2.5	4.3 ± 2.6
6	64 ± 14	5.3 ± 3.0	4.5 ± 2.1	149 ± 56	5.0 ± 2.6	4.5 ± 2.4

As expected, the multiplicity of shower particles for interactions with much higher energies (Pb+Em) is much higher. At the same time, it should be noted that the multiplicity in events $N_{\mathrm{f}} = 1$ in Pb+Em is approximately two times lower than the multiplicity of events with $N_{\mathrm{f}} \geq 2$. In Au+Em interactions, the change in multiplicity between events with one multi-charged fragment and events with several multi-charged fragments is about 30 percent.

3. Conclusion

The joint study of the collisions of Au-197 projectiles at 10.6 AGeV and Pb-208 projectiles at 158 AGeV with heavy (AgBr) and light (HCNO) targets present in a nuclear emulsion (NIKFI BR-2) was carried out. We analyzed both secondary particles emitted from the interaction region and fragments of the projectile-nucleus and target-nucleus. To study pseudo-rapidity correlations, the Hurst method was used. According to the behavior of the Hurst curve, events were divided into two types: explosive and cascade-evaporative. Events of various types differ significantly in the fragmentation of the projectile-nucleus, multiplicity of secondary particles and pseudo-rapidity distribution. Some explosive-type events have an "anomalous" pseudo-rapidity distribution: two streams of secondary particles are formed with significantly different pseudo-rapidity. In such events, several multi-charged fragments are detected.

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