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MAXIMUM PSEUDORAPIDITY GAP ANALYSIS IN NUCLEAR INTERACTIONS FROM A FEW GeV TO FEW HUNDRED GeV

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This paper presents new results on the maximum gap (Δ_{max}) in the pseudorapidity distribution of charged particles in individual events in ^{24}Mg-AgBr, ^{16}O-AgBr and ^{32}S-AgBr interaction in the energy range $4.5 - 200$ AGeV. The location of the Δ_{max} in an event and the experimental Δ_{max} distribution at all energies has been studied in details. It has been observed that Gaussian distribution can describe the experimental data satisfactorily over the entire energy range.

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1. *Introduction*

The study of the nucleus-nucleus interaction at high energies has been the subject of major attention by high-energy physicists. The reason is obvious because it offers a unique possibility for studying properties that can not be observed by studying hadron-hadron and hadron-nucleus interactions. The nuclei can provide valuable information on spatiotemporal development of multiparticle production process, which is of prime interest in view of the recent developments in quantum chromodynamics.

Further investigation of nucleus-nucleus collisions allows us to study the extended state of matter under extremes of density and temperature as in the hot early Universe. Such collisions can create highly energetic regions of deconfined matter, hence, the normal forces that confine quarks and gluons in an individual hadron are expected to overcome to form an extended quark-gluon plasma (QGP) state [1]. The QGP is formed when the temperature and/or the baryon number density become sufficiently high [2−3]. Some experiments and theoretical analysis have been performed to understand the dynamics of the multiparticle production process through data on nuclear production.

In this context, two important parameters are usually investigated – the pseudorapidity distribution of pions and the pseudorapidity gap distribution. One of the most interesting questions in many-particle interaction is the nature of pseudorapidity correlation among the produced particles. It is still an open question whether the particle production processes in question are basically weakly correlated phenomena or whether strong correlations are present. The matter is further complicated by the fact that conservation laws impose certain kinematical correlation which can not always be trivially separated from correlations of a more dynamical nature. The study of correlations among the particle produced provides significant features of nuclear interaction and is a rich source of information. The analysis of rapidity correlation could be helpful for AA interaction, focusing on particle production mechanisms, thermalization QGP as evident from recent papers in this area [4−8]. In this respect, another very important characteristic of muliparticle production that deserves special attention is the maximum pseudorapidity gap distribution. Several authors [9−10] have given some predictions regarding the existence of large gaps in rapidity between neighboring particles. The maximum pseudorapidity gap distribution was generally used as a proposed means of determining the amount of diffractive dissociation (pomeron exchange) in the data. It was observed that the distribution does separate into two regions where either the diffractive or non-diffractive mechanism dominates [11]. Some works in this line on maximum pseudorapidiy gap distribution have been reported for hadron-hadron and hadron-nucleus collisions [12−15]. It is also interesting to study the characteristics of the maximum gap in nucleus-nucleus interactions. For nucleus-nucleus interaction, no data are available in this regard to this date. In view of this, we report a detailed study on the maximum pseudorapidity gap distribution in the case of nucleus-nucleus collisions in approximately the entire accelerator energy that was available ($4.5 - 200$ AGeV).

2. *Method of analysis*

The rapidity (Y) of a charged secondary particle produced in an inelastic interaction is defined as

$$Y = \frac{1}{2} \ln \frac{E + P_{11}}{E - P_{11}}, \tag{1}$$

where E and P_{11} are the energy and longitudinal momentum of the secondary particle, respectively. For $P_{11} > P_{\mathrm{T}} > m_\pi$ (where P_{T} and m_π denote the transverse momentum and mass, respectively) Eq. (1) becomes

$$Y = -\ln\tan\frac{\theta}{2} \quad (=\eta),$$

where θ is the spatial emission angle (η is called the pseudorapidity of the particle). By ordering the pseudorapidity of each charged particle in an event, i.e.,

$$\eta_1 < \eta_2 < \eta_{\mathrm{I}} < \ldots . < \eta_{\mathrm{n}}, \tag{2}$$

where n is the charged multiplicity in rapidity space, one can define the maximum pseudorapidity gap ($\Delta_{\max}$) as the maximum difference between pseudorapidity values of adjacent charged particles; i.e. $\Delta_{\max} = \max[\eta_{i+1} - \eta_i]$.

From the study of the $\Delta_{\max}$ distribution, one hopes to get information about the nature of the particle production process. We present here our extensive data on the characteristics of $\Delta_{\max}$ in ^{24}Mg-AgBr, ^{16}O-AgBr and ^{32}S-AgBr interactions in the entire energy range of the accelerator (from 4.5 AGeV to 200 AGeV).

3. Experimental details

The data used in the present investigation have been obtained from sets of photoemulsion plates exposed to ^{24}Mg beam with energy 4.5 AGeV at JINR, Dubna and ^{16}O beam with incident energy 60 AGeV and ^{32}S beam with energy 200 AGeV at CERN, Geneva.

A Leitz Metaloplan microscope with a 10× objective and 10× ocular lens provided with a semi-automatic scanning stage has been used to scan the plates. The final measurements are done using an oil-immersion 100× objective. The microscope and the measuring system fitted with it has a 1 μm resolution along the X and Y axes and 0.5 μm resolution along the Z axis.

The events chosen for the analysis were selected by utilizing the following criteria: (i) the beam track must be $< 2^\circ$ to the mean beam direction in the pellicle and (ii) the interaction should not be within the top or bottom 20 μm thickness of the pellicle. Further, all primary beam tracks were followed back to be sure that the events chosen did not include interaction from the secondary tracks of another interaction. The primaries originating from other interactions were observed and the corresponding events were removed from the sample. The shower tracks were selected according to the criterion $b^* < 1.4$, where b^* is the normalized blob density. We finally analysed 800 events of ^{24}Mg-AgBr, 250 events of ^{16}O-AgBr and 140 events of ^{32}S-AgBr interactions [16 − 18]. To ensure that the target nuclei in the emulsion are silver or bromine nuclei, only the events with $N_{\mathrm{h}} > 8$ were chosen. The spatial emission angles of all shower particles in an event were obtained by measuring x, y and z coordinates of the interaction vertex, three points on the beam track, and three points on the shower track. In this way, the rapidities (actually pseudorapidities), $Y = -\ln(\tan\theta/2)$, were calculated for all showers.

4. *Results and discussion*

4.1. *Location of the maximum pseudorapidity gap in events*

By ordering the pseudorapidity of each shower in an event [2], we find the maximum gap, $\Delta_{\max}$, and the corresponding pseudorapidity values within the rapidity-space distribution. Most of the $\Delta_{\max}$ are not uniformly distributed in the interval, rather in most of the events $\Delta_{\max}$ occurs at extreme intervals, either for $i = 1$ or for $i = (n - 1)$ at all energies in nucleus-nucleus interactions. This tendency increases with increasing multiplicity. We have seen the same behaviour for hadron-nucleus interaction [19]. On the other hand, it has been observed that in the case of hadron-hadron interactions, the small values of Δ ($\Delta < 1$) are uniformly distributed in the interval i, while large $\Delta_{\max}$ occur mainly at the extreme intervals of $i = 1$ and $i = n - 1$ [15]. There are events due to nucleus-nucleus interaction where the location of $\Delta_{\max}$ occurs at different places, the details of which are shown in Tables 1, 2 and 3.

*TABLE 1. Maximum rapidity gap for ^{24}Mg-AgBr interaction at 4.5 A*GeV.

Event No.	No. of Tracks	Maximum rapidity gap	Pseudorapidity value
1	15	0.20	0.512
2	22	0.90	0.787
3	20	0.21	0.640
4	15	0.10	0.700
5	22	0.14	0.588
6	17	0.15	0.947
7	21	0.12	0.653
8	15	0.16	0.611

*TABLE 2. Maximum rapidity gap for ^{16}O-AgBr interaction at 60 A*GeV.

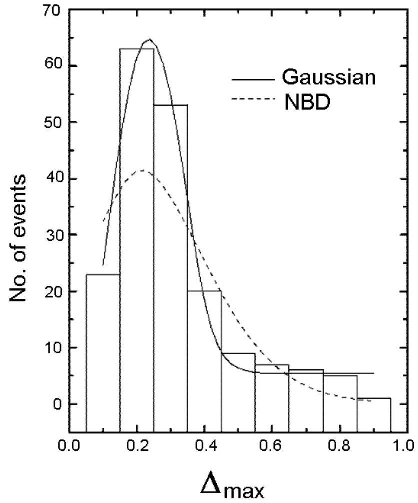
Event No.	No. of Tracks	Maximum rapidity gap	Pseudorapidity value
1	67	0.24	1.33
2	52	0.40	2.46
3	36	2.59	3.97
4	75	0.95	1.24
5	48	0.35	2.69
6	85	1.55	3.43
7	50	2.13	0.04
8	42	0.60	1.23
9	72	0.28	2.35

*TABLE 3. Maximum rapidity gap for ^{32}S-AgBr interaction at 200 A*GeV.

Event No.	No. of Tracks	Maximum rapidity gap	Pseudorapidity value
1	128	0.24	5.43
2	111	0.40	2.15
3	103	2.59	3.07
4	92	0.95	4.94
5	51	0.35	3.47
6	111	1.55	3.27
7	45	2.13	2.46
8	37	0.60	3.26
9	228	0.28	2.45
10	66	0.24	4.69

4.2. Distributions of maximum rapidity gap

We calculated the maximum pseudorapidity gap, $\Delta_{\rm max} = (\eta_{i+1} - \eta_i)$, for each event. The use of η instead of Y is not important because the energies are very high. The experimental distributions of $\Delta_{\rm max}$ for ^{24}Mg-AgBr, ^{16}O-AgBr and ^{32}S-AgBr events are shown in Figs. 1, 2 and 3 respectively. The following interesting features are revealed:



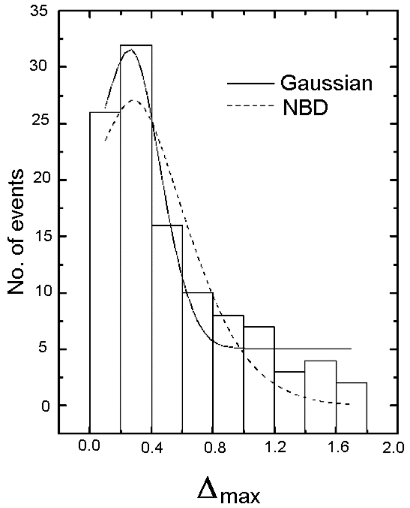


Fig. 1 (left). Negative binomial distribution and Gaussian distribution of maximum pseudorapidity interval in ^{24}Mg-AgBr *interaction at 4.5 A*GeV.

Fig. 2. Negative binomial distribution and Gaussian distribution of maximum pseudorapidity interval in ^{16}O-AgBr *interaction at 60 A*GeV.

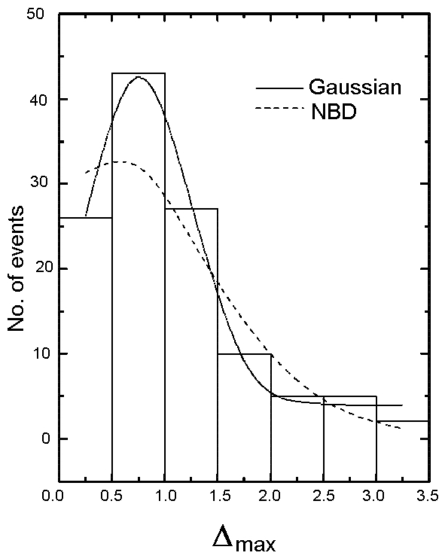


Fig. 3. Negative binomial distribution and Gaussian distribution of maximum pseudorapidity interval in ^{32}S-AgBr *interaction at 200 A*GeV.

i) At all energies, there is a prominent peak in the small $\Delta_{\max}$ region and the distribution falls off rapidly.

ii) The nature of the distribution changes insignificantly with increasing energy.

iii) The peak position for ^{24}Mg-AgBr, ^{16}O-AgBr and ^{32}S-AgBr interactions are given in Table 4. It is very interesting to observe that the peak positions depend linearly on the incident beam energy (Fig. 4). For comparison, the peak positions for hadron-nucleus interactions at available comparable energies are shown in Table 5. It is observed that in nucleus-nucleus collisions, the peak occurs at much lower values than in hadron-nucleus interactions at all energies [19]. The maximum gaps appear near the ends of the rapidity intervals what indicates the presence of the leading-particle effect (and/or spectator protons). This is supported by the fact that the peak position in rapidity increases with energy.

TABLE 4. Position of peak of $\Delta_{\max}$ *for nucleus-nucleus interaction at different energies.*

Interaction	Energy (*A*GeV)	Peak Position
Mg-AgBr	4.5	0.2
O-AgBr	60	0.3
S-AgBr	200	0.75

iv) We have tried to examine which standard statistical distribution can be fitted to the experimental data, Gaussian distribution or negative binomial distribution (NBD). The NBD belongs to the family of Poisson transforms of some important probability density functions, frequently used in statistical physics [20]. For exam-

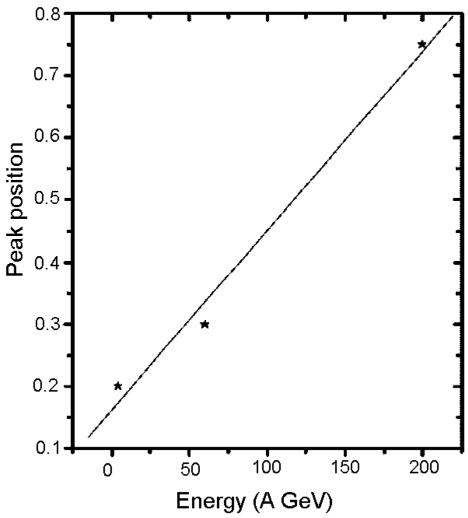


Fig. 4. The peak positions of $\Delta_{\max}$ for ^{24}Mg-AgBr, ^{16}O-AgBr and ^{32}S-AgBr interactions depend linearly on the incident beam energy .

TABLE 5. Position of peak of $\Delta_{\max}$ for hadron nucleus interaction at different energies.

Interaction	Energy (AGeV)	Peak Position
p-AgBr	22.6	0.9
p-AgBr	70	1.9
p-AgBr	200	1.1

ple, the negative binomial distribution (NBD) is studied in particle physics. It also describes the counting distribution of photons in thermal light, epidemic diseases, etc. The NB distribution and the Gaussian distribution of maximum pseudorapidity interval are shown in Figs. 1, 2 and 3 for different energies. The analysis speaks in favour of the Gaussian distribution over the NB distribution.

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ANALIZA MAKSIMALNIH PROCIJEPA PSEUDORAPIDITETA U NUKLEARNIM SUDARIMA NA PAR DO NEKOLIKO STOTINA GeV

Predstavljamo nove ishode mjerenja maksimalnih procijepa ($\Delta_{\rm max}$) u raspodjeli pseudorapiditeta nabijenih čestica u pojedinačnim sudarima ^{24}Mg-AgBr, ^{16}O-AgBr i ^{32}S-AgBr na energijama $4.5-200$ AGeV. Podrobno smo odredili položaje ($\Delta_{\rm max}$) za pojedine sudare i proučili njihovu eksperimentalnu raspodjelu na tim energijama. Opažamo da Gaussova raspodjela može dobro opisati eksperimentalne podatke u cijelom području energija.