Maximum fluctuations of charged particle densities in narrow pseudorapidity space at ultrarelativistic nuclear collisions

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A study of multiparticle correlations on the basis of the maximum fluctuation of the charged particle density in narrow pseudorapidity intervals in Monte Carlo background particles has been carried out with ^{16}O-AgBr interactions at 60*A* GeV and ^{32}S-AgBr interactions at 200*A* GeV. The study reveals the existence of dynamical multipion correlation in the pseudorapidity interval 0.1–1 for both data sets. Further study suggests that in each case the maximum charged particle density in a given pseudorapidity interval increases linearly with charged particle multiplicity.

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Nowadays, various theoretical models [1] have been put forward to understand the underlying dynamics of multipion production in hadron-hadron, hadron-nucleus, and nucleus-nucleus collisions at relativistic and ultrarelativistic energies. Experimental evidence shows that the produced particles prefer to be emitted in a correlated fashion [2]. The reason for such a correlation effect, explained by different theorists, may be the production of resonance phenomena, hot multinucleon fireballs, or the formation of a quark-gluon plasma, etc. Study of the experimental data [3] prompted the scientists to conclude that the formation of heavier intermediate states, clusterization, etc., may be the cause of such a correlation effect. So a detailed study on the correlation and clusterization of secondary particles in multiparticle production processes is needed to extract the actual reason behind such an effect. Very recently, the intermittent behavior of the multiplicity fluctuation [4,5] has also been interpreted by some workers to be the possible manifestation of such a short range correlation in high-energy interactions. Whatever may be the reason for such phenomena, it had recently been felt strongly that the commonly used method of the standard correlation function is not sufficient enough to come to a conclusion beyond ambiguity. So the need for an in-depth analysis in this field has arisen.

In this paper we will study multiparticle correlation phenomena of the produced pions on the basis of the maximum density fluctuation of the charged particles in narrow pseudorapidity intervals. Though several studies [6–10] in this field have been reported for hadron-hadron, hadron-nucleus, and low energy nucleus-nucleus interactions, up to now no detailed analysis of such phenomena has been carried out at ultrarelativistic nuclear collisions. Data of ^{16}O-AgBr interactions at 60*A* GeV and ^{32}S-AgBr interactions at 200*A* GeV are used here for the analysis.

The details of the exposure of the plates, scanning of events, angle measurement, etc., are given in Refs. [11,12].

In this paper we adopted the method as followed by Sarkisyan *et al.* [13]. For each event the ordered pseudorapidity $\eta = -\ln\tan\theta/2$ (θ is the emission angle of the particle) is scanned, with a fixed pseudorapidity window/bin ($\delta\eta$) across the full η range of the event. The maximum density of particles as defined by [13] is equal to $\rho_{\max} = \delta n_{\max}/\delta\eta$, where $\delta n_{\max}$ is the maximum number of particles within the interval $\delta\eta$ in each event. $\rho_{\max}$ for all N events is then calculated and the distribution $dN/d\rho_{\max}$ with respect to $\rho_{\max}$ is analyzed. The same procedure has been followed with the correlation free events generated by Monte Carlo simulations. The Monte Carlo data are generated following the assumptions: (i) The pions are emitted independently. (ii) The multiplicity distribution of the ensemble of the Monte Carlo events is the same as the multiplicity spectrum of the experimental ensemble. (iii) The single-particle spectrum $d\sigma/d\eta$ of the simulated interactions reproduces the experimental $d\sigma/d\eta$ distribution.

The distribution $dN/d\rho_{\max}$ (with experimental data sets) and $(dN/d\rho_{\max})_{\mathrm{MC}}$ (with Monte Carlo–simulated data sets) of ^{16}O-AgBr interactions at 60*A* GeV for $\delta\eta$ (window

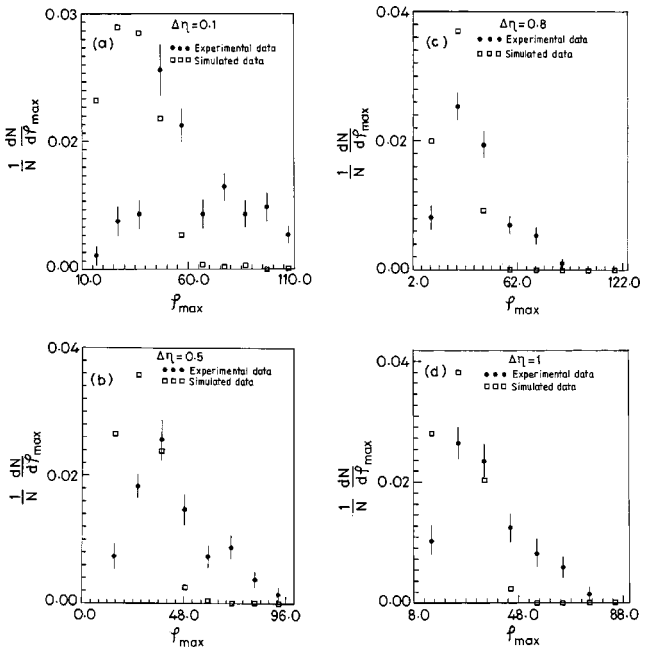

FIG. 1. Plot of the normalized $\rho_{\max}$ distribution for ^{16}O-AgBr interactions at 60*A* GeV in pseudorapidity windows $\delta\eta$=(a) 0.1, (b) 0.5, (c) 0.8, and (d) 1, respectively.

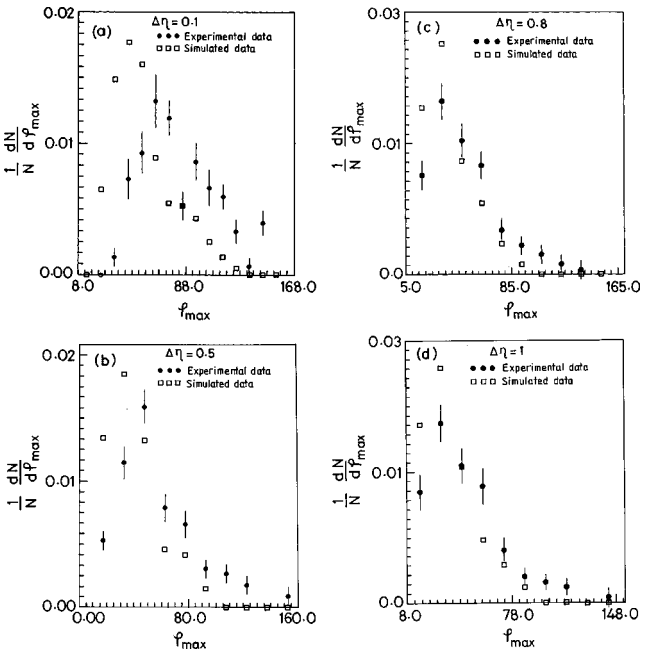

FIG. 2. Plot of the normalized $\rho_{\max}$ distribution for ^{32}S-AgBr interactions at 200*A* GeV in pseudorapidity windows $\delta\eta$= (a) 0.1, (b) 0.5, (c) 0.8, and (d) 1, respectively.

sizes) = 0.1, 0.5, 0.8, and 1 is shown in Figs. 1(a), 1(b), 1(c), and 1(d), respectively. The same for ^{32}S-AgBr interactions at 200*A* GeV are shown in Figs. 2(a)–2(d). The forms of the distributions are similar for different scanning intervals as well as for different interactions. From the figures it can be visualized that there exist remarkable deviations between experimental and simulated data sets in all the cases, which suggests that the pions are emitted in a correlated fashion. We have also calculated (not shown here) χ^2 per degrees of freedom ($\chi^2/N_{\rm df}$) for all the cases [$\chi^2 = \Sigma(($simulated value − experimental value)/error$)^2$]. Sufficiently high $\chi^2/N_{\rm df}$ values also support the presence of a correlation in the experimental data sets. Thus we can infer that for a wide energy range (60–200 *A* GeV) there exists dynamical multiparticle correlation and clusterization for the pseudorapidity interval $\delta\eta = 0.1-1$.

The dependence of average maximum particle density on the charged multiplicity for the entire pseudorapidity range have also been studied extensively. To carry out the above study, we have divided the multiplicity region into six multiplicity intervals (20–37, 38–55, 56–73, 74–91, 92–109, 110–127) for ^{16}O-AgBr interactions and (38–69, 70–101, 102–133, 134–165, 166–197, 198–229) for ^{32}S-AgBr interactions. For any particular multiplicity (n) interval the weighted average of n is given by $\bar{n} = \Sigma P_n \cdot n$, where P_n represents the probability of getting an event with multiplicity n. We have determined $\langle\rho_{\max}\rangle$ for all the events over the above six multiplicity intervals for window sizes 0.1, 0.3, 0.5, and 0.8. In both ^{16}O-AgBr interactions at 60*A* GeV and ^{32}S-AgBr interactions at 200*A* GeV the $\langle\rho_{\max}\rangle$ value is found to increase linearly with $\bar{n}$ for all pseudorapidity window sizes. For each case we also have performed a least-squares fit of the form $\langle\rho_{\max}\rangle = a\bar{n} + b$. Here χ^2/degrees of freedom for each fit are found to be 1 except for $\delta\eta = 0.3$ in both cases. The slope values a of all window sizes for both interactions are given in Table I. From the table we can see that with an increase of energy for a particular $\delta\eta$ the slope value a decreases. Thus an energy-dependent linear relation between average maximum particle density and shower particle multiplicity has been observed in the case of ultrarelativistic nucleus-nucleus interactions over a wide range of energies.

TABLE I. The slopes obtained in least-squares fits of the form $\langle\rho_{\max}\rangle = a\bar{n} + b$ for ^{16}O-AgBr interactions at 60*A* GeV and ^{32}S-AgBr interactions at 200*A* GeV for $\delta\eta = 0.1$, 0.3, 0.5, and 0.8.

Type of interaction → window size ↓	^{16}O-AgBr interaction at 60*A* GeV	^{32}S-AgBr interaction at 200*A* GeV
$\delta\eta = 0.1$	1.01	0.62
$\delta\eta = 0.3$	0.95	0.53
$\delta\eta = 0.5$	0.82	0.50
$\delta\eta = 0.8$	0.71	0.46

Hence we can conclude the following. (i) The data reveal the existence of correlation and clusterization of the charged pions produced in nucleus-nucleus interactions over a wide range of ultrarelativistic energies (60*A* and 200*A* GeV) in the pseudorapidity interval $\delta\eta = 0.1-1$. It may be mentioned here that in case of hadron-nucleus interactions [9] this correlation exists for a pseudorapidity interval of shorter range, $\delta\eta = 0.1-0.5$. (ii) A linear rise of average maximum track density with multiplicity is revealed by all types of interactions. In the case of hadron-hadron and hadron-nucleus interactions, the linear relation exists, independent of the incident energy over a wide range of energies, but energy-dependent linear relations exist in ultrarelativistic nucleus-nucleus type of interactions. The slope values for hadron-nucleus and hadron-hadron interactions [9] are found to be very close to each other, but they differ quite significantly from those of the nucleus-nucleus ones. The slope values for comparatively low-energy nucleus-nucleus interactions, i.e., ^{16}O-AgBr interactions at 60*A* GeV are found to be more than those for higher-energy nucleus-nucleus interactions, i.e., ^{32}S-AgBr interactions at 200*A* GeV.

These data are interesting and may serve as input for formulating the necessary model for particle production.

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