Brief Reports

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Determination of cluster size in particle-nucleus interactions at 50 and 400 GeV

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We have investigated the formation of clusters and their sizes in 50-GeV π^--nucleus and 400-GeV proton-nucleus interactions. The maximum multiplicity of charged shower particles constituting the clusters at the two incident energies is observed to be four. Furthermore, the cluster size has been found to be independent of the grey-particle multiplicity and hence the target mass. The cluster size has also been observed to be independent of the energy and identity of the impinging hadrons.

(i) Introduction. For investigating the mechanism of multiparticle production in high-energy particle-nucleus interactions, the correlations amongst the secondary charged shower particles emitted at various values of rapidity are studied; a tendency of the final-state charged shower particles to be grouped in clusters has been observed by several workers.[1-4] Recently, Shivpuri and Gupt[3] have suggested an analytical method for determining the sizes and hence masses of the clusters. They[3] have also been able to show by means of two-, three-, four-, and n-particle correlations that clusters of different sizes are formed in nucleon-nucleon reactions in the energy range ~ 1 TeV. Furthermore, they have reported the existence of correlations in nucleon–light-nuclei interactions at the same energy. However, no work has yet been done to investigate the dependence of the cluster size on the number ν of collisions made by the impinging hadron inside the target nucleus in high-energy particle-nucleus interactions. Quite interesting and useful results are expected to be obtained on the formation of clusters and their sizes at accelerator energies because the projectile energy and rapidity of the secondary charged shower particles may be determined with far greater accuracy in hadronic interactions than in cosmic-ray interactions. Hence, the dependence of the cluster size on the energy and nature of the incident particle may be precisely determined, which may throw further light on the dynamics of cluster formation at relatively higher energies. In the present work, we have, therefore, attempted to study the cluster formation and dependence of its size on the energy and nature of the incident hadron and ν in particle-nucleus interactions at 50 and 400 GeV, using the model-independent approach as suggested by Shivpuri and Gupta.[3]

(ii) Experimental details. Two different types of emulsion stacks, one of them exposed to 50-GeV negative pions at Serpukhov, U.S.S.R., and the other exposed to 400-GeV protons at Fermilab, have been used in the present experiment. The details of the stacks used, the methods of measurements, and the selection criteria, etc., have been presented in our earlier publications.[5]

(iii) Method of analysis. Let the multiplicity of charged shower particles in an event be ten; then for analyzing the experimental data, particles 1 and 10 which lie on the two extreme ends of the rapidity space are not considered, as they constitute the leading and the target particles and we are interested in studying the correlations for only the nondiffractive components of the cross section. In order to study two-particle correlations, the rapidity differences r_2 of all the adjacent charged shower particles are considered. Next, for determining the three-particle correlations, a bunch of three particles numbered 2, 3, and 4 is considered. The basis for envisaging the existence of three-particle correlations, as done by Shivpuri and Gupt,[3] is the fact that if particles 2, 3, and 4 are the decay products of a single cluster, then the rapidity differences between 2 and 3, between 3 and 4, and also between 2 and 4 would be quite small. This means that particles 2, 3, and 4 must be closely spaced in the rapidity space. Thus n-particle correlations are searched for by histogramming pseudorapidity differences between nth nearest neighbors.

(iv) Experimental results and discussion. The present investigation has been carried out using random samples consisting of 875 and 873 disintegrations having $N_h \geq 2$, where N_h denotes the number of tracks with $\beta \leq 0.7$ produced in 50-GeV π^--nucleus and 400-GeV p-nucleus interactions, respectively.

For the relativistic charged shower particles the pseudorapidity η is defined as

$$\eta = -\ln \tan(\theta/2) \ , \tag{1}$$

where θ is the space angle of the secondary charged shower particle with respect to the mean direction of the incident hadron. The rapidity differences for two, three, four, and five particles have been determined for all the events considered by us at the two incident energies. Furthermore, for studying the dependence of these correlations on the number of encounters made by the impinging hadron inside the nucleus, ν, the data have been divided in different n_g bins, i.e., $N_g = 0$, 1, 2–3, 4–5, 6–8, and ≥ 9; the events have been divided in different N_g bins because of the fact that ν is not measurable experimentally and it is commonly believed that the grey-particle multiplicity n_g is a reasonably good measure of the number of collisions made by the in-

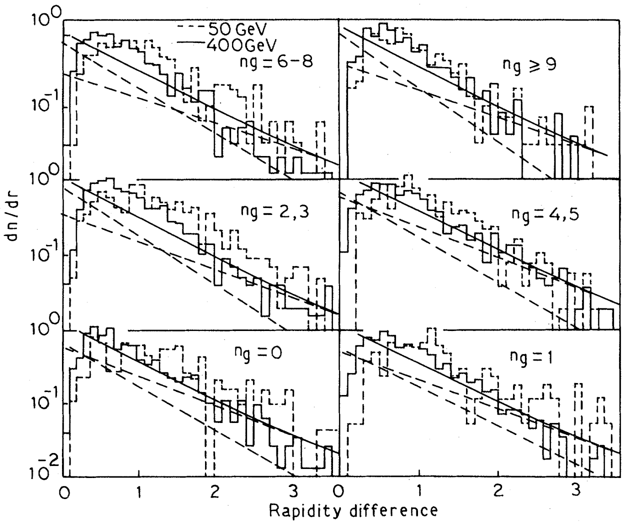

FIG. 4. Rapidity-gap distributions of first and fifth charged shower particles at 50 and 400 GeV.

correlations are significantly far away from the solid curves obtained on the basis of the two terms of Eq. (2). But in the case of two-, three-, and four-particle rapidity-difference distributions plotted in Figs. 1–3, the dashed lines corresponding to the short-range correlations almost coincide with the solid curves. Similar trends have been observed in the case of 50-GeV π^--nucleus collisions also. We thus, observe that in the case of two-, three-, and four-particle rapidity-difference distributions, the short-range correlation plays a predominant role as compared to the long-range correlation. It may also be noted that the values of the parameter A for five-particle rapidity-difference distributions given in Table I are quite small ~ 0.8, whereas the values of this parameter for two-, three-, and four-particle correlations have been found to lie between ~ 2 and 4. Since the short-range correlation has been observed to play a predominant role for two-, three-, and four-particle rapidity-difference distributions but not in the case of five-particle rapidity-difference distributions, it may, therefore, be concluded that two-, three-, and four-particle correlations are present and five-particle correlation does not exist.

For examining the distribution of the uncorrelated production further, analytical curves corresponding to the Wigner distribution [Eq. (4) of Ref. 8], which is one of the nearest neighbors of the Gaussian-orthogonal-ensemble-(GOE) type distribution, have been plotted in Fig. 5 for different n_g bins at the two incident energies. It is clear from the figure that the GOE-type distribution fits reasonably well the five-particle rapidity-difference distributions obtained by us at 50 and 400 GeV. The values of χ^2/DF for each fit are tabulated in the last column of Table I.

It may be seen in Table I that the values of the parameter D remain essentially constant ~ 0.7–1.0 and hence it may not be regarded as a sensitive parameter. A similar behavior of the parameter D was reported earlier[3,4] too. It may be noted that Daftari *et al.*[9] have observed that the parameter D depends on the target mass. Thus our result is in disagreement with those of Daftari *et al.*[9] It may also be seen in Table I that the values of the slope B, which provide a measure of the strength of the correlation in the first re-

TABLE I. Values of various parameters obtained in particle-nucleus interactions at different energies.

Type of interactions	Energy (GeV)	n_g bins	Two particle A	B	C	D	χ^2/DF	Three-particle A	B	C	D	χ^2/DF	Four-particle A	B	C	D	χ^2/DF[a]	Five-particle A	B	C	D	χ^2/DF[b]	χ^2/DF
π^--nucleus	50	0	3.00	4.50	0.20	0.70	1.01	2.75	3.40	0.30	0.70	4.39	2.30	2.01	0.50	1.00	1.67	0.89	1.27	0.85	0.99	2.02	1.73
		1	3.50	4.60	0.15	0.71	1.62	4.00	3.45	0.40	0.75	8.73	2.95	1.99	0.60	0.99	2.04	0.89	1.27	0.85	0.99	2.83	1.40
		2–3	3.45	4.55	0.19	0.80	2.96	3.00	3.42	0.25	0.73	7.58	2.15	2.00	0.25	1.01	4.34	0.89	1.27	0.85	0.99	2.96	3.31
		4–5	3.40	4.52	0.15	0.77	1.94	2.49	3.43	0.29	0.71	5.69	3.20	1.93	0.27	0.98	1.60	0.89	1.27	0.85	0.99	3.74	1.91
		6–8	3.29	4.57	0.10	0.72	1.65	3.30	3.41	0.26	0.72	3.50	1.90	1.98	0.30	0.97	1.87	0.85	1.25	0.60	1.00	1.73	1.71
		≥9	3.60	4.50	0.12	0.73	0.77	3.70	3.44	0.24	0.74	3.92	2.10	1.96	0.29	0.99	1.93	0.91	1.30	0.45	0.97	2.14	1.54
p-nucleus	400	0	3.90	4.80	0.09	0.90	2.23	2.25	3.50	0.20	0.80	4.35	2.40	1.95	0.20	0.99	1.33	0.65	1.25	0.59	1.01	2.26	5.58
		1	4.25	4.79	0.08	0.87	2.63	2.60	3.60	0.15	0.85	7.58	1.80	1.99	0.25	1.00	3.29	0.60	1.26	0.57	1.00	3.77	4.05
		2–3	4.20	4.81	0.07	0.89	2.57	3.50	3.55	0.14	0.83	5.88	2.10	1.96	0.20	0.97	2.73	0.75	1.30	0.35	1.02	10.78	8.31
		4–5	4.30	4.80	0.05	0.91	2.24	3.40	3.51	0.08	0.81	4.38	2.25	1.92	0.24	0.90	1.82	0.60	1.26	0.57	1.00	2.89	6.91
		6–8	4.15	4.82	0.09	0.85	0.67	3.20	3.57	0.20	0.84	2.52	1.90	1.97	0.10	0.98	1.93	0.73	1.29	0.30	1.01	6.83	7.15
		≥9	4.00	4.83	0.08	0.90	0.86	3.27	3.54	0.29	0.82	1.29	2.35	1.98	0.25	0.97	1.17	0.75	1.30	0.35	1.01	1.83	2.54
Nucleon-nucleon[c]	>1000		4.20	5.11	0.30	1.00		2.60	2.80	0.20	0.80		1.90	1.90	0.20	0.80							

[a]Excluding first three experimental points.
[b]Excluding first four experimental points.
[c]From Ref. 3.

cident hadron inside the nucleus.[6]

Several workers[1-4] have reported that at high energies the rapidity-gap distribution in hadronic interactions may be represented quite well by the two-channel generalization of the Chew-Pignotti model[7] of the form

$$\frac{dn}{dr} = A\exp(-Br) + C\exp(-Dr) \ , \qquad (2)$$

which is expected on the basis of the multiperipheral model. We have determined the correlations between adjacent particles in various n_g bins which have been shown by rapidity-difference r_2 $(=\eta_2-\eta_1)$ distributions in Fig. 1, where η_1 and η_2 are the rapidities of the two adjacent particles; the rapidity differences r_2 at the two incident energies in different n_g bins lie between ~ 500 and 2400. The presence of sharp peaks at relatively smaller values of r_2 in the figures clearly indicates the existence of two-particle correlations in 50- and 400-GeV particle-nucleus interactions. A similar trend is also observed for the rapidity-gap distributions between two alternate particles in different n_g intervals, r_3 $(=\eta_3-\eta_1)$, shown in Fig. 2. The numbers of r_3 considered in different n_g intervals vary between 466 and 2357. The sharp peaks at relatively smaller values of r_3 present in these figures clearly demonstrate the existence of three-particle correlations.

For examining the existence of four- and five-particle correlations, four- and five-particle rapidity-difference distributions in different n_g intervals at the two incident energies have been determined and plotted in Figs. 3 and 4; the numbers of rapidity gaps at the two energies in different n_g intervals lie between 358 and 2151 for four-particle and 291 and 1884 for five-particle rapidity-difference distributions.

The values of the coefficients A, B, C, and D occurring in Eq. (2) for different n_g bins at the two energies are given in

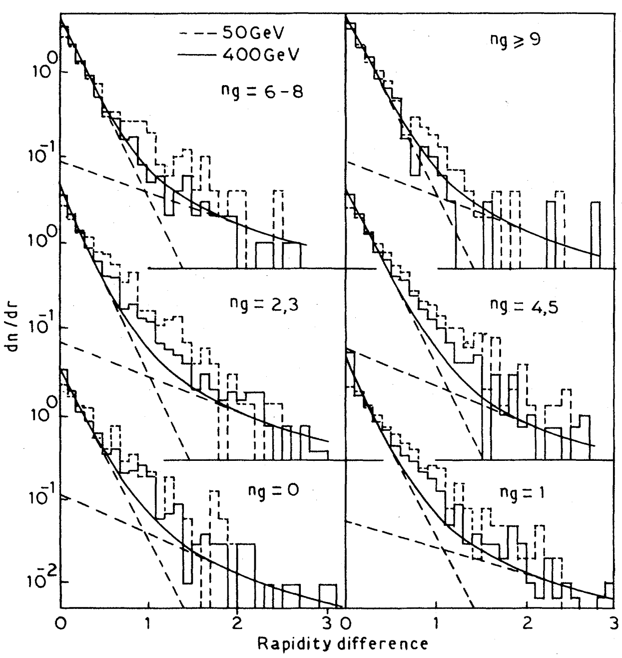

FIG. 1. Rapidity-gap distributions of two adjacent charged shower particles in different n_g intervals in 50-GeV π^--nucleus and 400-GeV p-nucleus interactions.

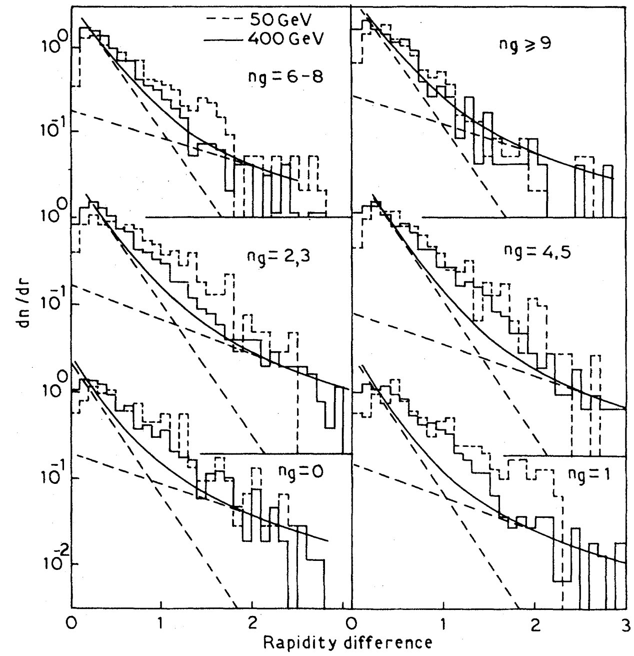

FIG. 2. Rapidity-gap distributions for the first and third charged shower particles in various n_g groups at 50 and 400 GeV.

Table I. The solid curves in Figs. 1–4 correspond to Eq. (2) for 400-GeV p-nucleus data. The dashed lines in the figures show the contributions of the two exponential terms individually. It may be noted that to avoid confusion the curves corresponding to Eq. (2) for 50-GeV π^--nucleus interactions are not shown in Figs. 1–4. However, the values of χ^2/DF have been calculated for two-, three-, four-, and five-particle rapidity-difference distributions at the two incident energies and are given in Table I.

It may be seen that the dashed lines in Fig. 4 for 400-GeV p-nucleus collisions corresponding to the short-range

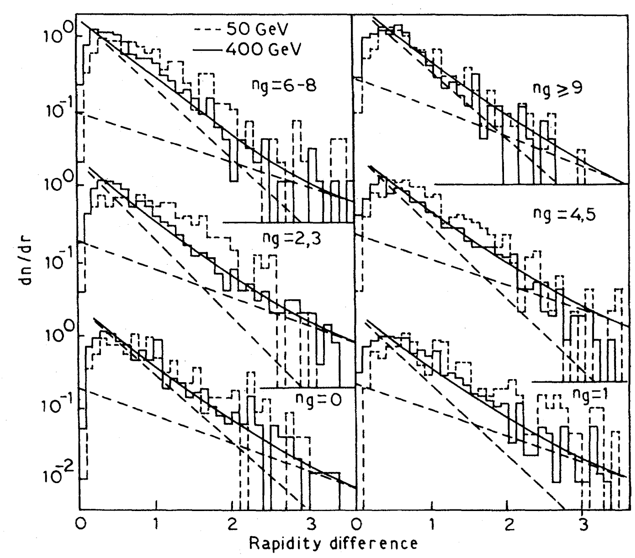

FIG. 3. Rapidity-gap distributions of charged shower particles for the first and fourth particles at 50 and 400 GeV.

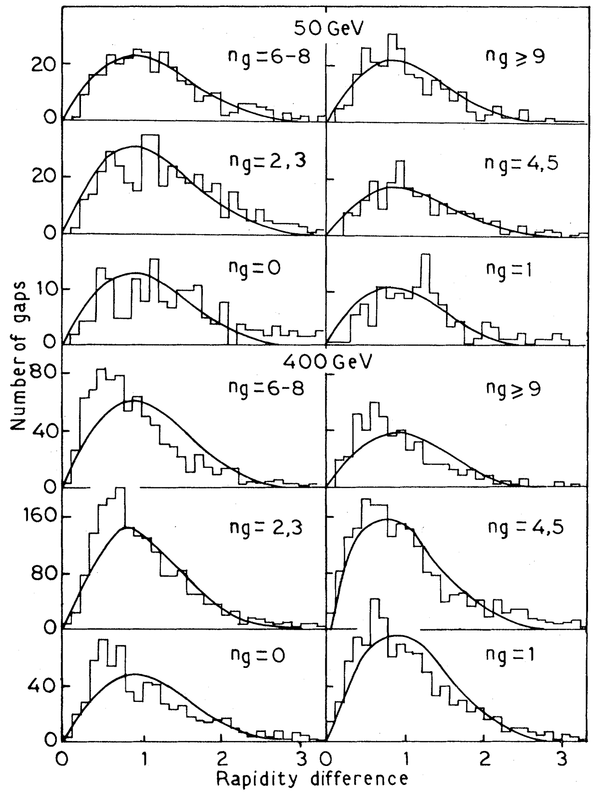

FIG. 5. Five-particle rapidity-difference distributions at 50 and 400 GeV; the solid curves correspond to Eq. (4) of Ref. 8.

gion of the rapidity-gap distribution, decrease from 5 to 2 as the number of particles constituting a cluster increases.

The dependence of the cluster size on the number ν of encounters made by the impinging hadron inside the nucleus has also been investigated. It is interesting to note in Table I that the parameters B and D do not change appreciably with the increase in the value of n_g and hence ν.

On comparing the findings of the present work with those obtained in the case of nucleon-nucleon interactions of cosmic-ray energies,[3,4] it is observed that the cluster size in particle-nucleus collisions is exactly the same as those observed in hadron-nucleon interactions and the values of the parameters B and D are also nearly the same in both hadron-hadron and hadron-nucleus interactions.

(v) Conclusion. On the basis of the findings of the present work we conclude that the maximum number of charged shower particles constituting a cluster in 50-GeV π^--nucleus and 400-GeV p-nucleus interactions is four and the size of the cluster is independent of the nature and energy of the impinging hadron. It may also be concluded that the cluster size is independent of ν as well as the target size. These results, therefore, tend to suggest that the mechanism of multiparticle production in hadron-nucleus interactions is perhaps not much different from those operating in hadron-hadron interactions.

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