Multiplicity, rapidity, and rapidity correlations in 800-GeV proton-nucleus interactions

R. K. Shivpuri and Anita Kotha
Department of Physics and Astrophysics, University of Delhi, Delhi 110007, India
(Received 29 September 1986)

In interactions of 800-GeV protons with emulsion nuclei, the multiplicity and rapidity distributions of charged secondary particles are studied. The existence of strong short-range correlations among the secondary particles is found. Evidence of independent emission of low-multiplicity clusters is presented.

One of the most attractive features to study at high energies is the mechanism of multiparticle production. Although several models have been proposed to explain this phenomenon, one of the most widely accepted is the cluster model.[1] The reason for its general acceptance has been the observation of correlations among the secondary particles in hadron-hadron and hadron-nucleus interactions at high energies. Several features of this subject,[2,3] such as the determination of cluster size, the strength of correlation, dependence of cluster size upon other parameters such as inelasticity, multiplicity, etc., have been investigated. It would be interesting to investigate the phenomenon of cluster production at the highest available machine energy, which is double the energy that was available earlier for fixed-target experiments.

We present below the first experimental results on 800-GeV proton-nucleus interactions. The existence of strong short-range correlations among the secondary particles has been observed. The data suggest production of two-particle clusters which seems to be the predominant mode of multiparticle production in the interactions.

A stack consisting of 40 G5 emulsion pellicles of dimensions $10\times 8\times 0.06$ cm was exposed to a proton beam of energy 800 GeV at Fermilab. The beam flux was 8.7×10^4 particles/cm^2 and the distribution of the primary energy was $<0.05\%$. The emulsion plates were carefully area scanned for inelastic events. All of the interactions were scanned twice by each observer and the average scanning efficiency was found to be $\sim 96\%$. Scanning was done at a distance of 1 cm from the leading edge of the emulsion. In order to select the events due to the primary protons, the following criteria were followed. (a) The primary of each interaction was followed up to the entry point in emulsion and there should be no interaction due to a secondary track. (b) The primary particle should make an angle $<2°$ with the mean beam direction. Events lying up to 25 μm from the surface or glass side of the emulsion pellicle were not considered. Taking the above criteria into account, a total of 1005 events were obtained. Following the usual emulsion terminology,[2] the secondary particles having $\beta(v/c)\geq 0.7$ and $\beta<0.7$ were designated as shower and heavy tracks, respectively. The total number of shower tracks obtained here is $\sim 17\,000$. The multiplicity of shower and heavy tracks is designated by n_s and n_h, respectively. The value of n_h has been used to designate[4] the type of target nucleus in emulsion. Events with $n_h=0,1$ mostly belong to H target nuclei or effectively with a single target nucleon, while events with $2\leq n_h\leq 5$ belong to the light (CNO) nuclei category and those with $n_h\geq 9$ belong unambiguously to the heavy (AgBr) group of nuclei. Events with $n_h=6$—8 were discarded as they are ambiguous; they can belong to the light or heavy group of nuclei. The number of events which belong to $n_h=0,1$, $n_h=2$—5, and $n_h\geq 9$ are found to be 134, 213, and 494, respectively. The angles of the shower particles were determined accurately by the coordinate method yielding an uncertainty in the value of the space angle (θ) to be $=8\times 10^{-4}$ rad.

The values of x, y, and z at the vertex and at two points on the beam and on each shower track were determined. The values of pseudorapidity (η) of all the secondary shower particles were determined from the relation $\eta=-\ln\tan\theta/2$ which is a good approximation to the rapidity, $y=-\frac{1}{2}\ln(E+P_L/E-P_L)$ at very high energies. The pseudorapidity is hereafter called rapidity. The reactions considered here are the semi-inclusive processes as the characteristics of only the charged secondary particles were studied.

Figure 1 shows the multiplicity distribution of shower tracks in the present interactions and at 400 GeV (Ref. 5) for the same number of events. It is seen that the multiplicity distribution at 800 GeV is shifted towards higher values compared to that at 400 GeV. There is also a lower production of low-n_s events in the former interac-

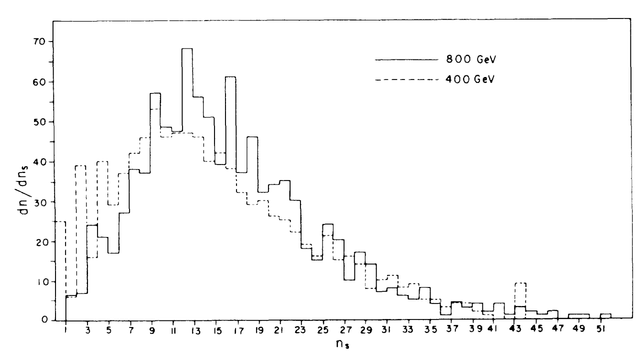

FIG. 1. Multiplicity distributions of shower particles at 800 GeV (solid line) and at 400 GeV (dotted line).

tions as compared to the latter interactions. This is expected since the shower-particle multiplicity shows a logarithmic dependence upon the primary energy. The mean values of n_s for emulsion target at 800 and 400 GeV (Ref. 5) are 17.84 ± 0.56 and 16.42 ± 0.17, respectively. The mean values of n_h at 800 and 400 GeV (Ref. 5) are 9.48 ± 0.29 and 7.65 ± 0.14, respectively. The mean values of n_s for different target nuclei, viz., nucleon, light (CNO), and heavy (AgBr) group are 13.81 ± 1.14, 14.81 ± 0.97, and 20.89 ± 0.89, respectively. The value of mean normalized multiplicity R, which is the ratio of multiplicity in hadron-nucleus to hadron-nucleon interactions is found to be 1.74 ± 0.13 for all the emulsion nuclei. The value of mean multiplicity for hadron-nucleon collisions ($\langle n_{\rm ch}\rangle_{hN}$) is determined from the following relation given by Slansky:[1]

$$\langle n_{\rm ch}\rangle_{hN}=(-3.8\pm0.4)+(1.88\pm0.07)\ln S+[(6.4\pm0.7)/\sqrt{S}\,]\ . \qquad (1)$$

This relation reproduces the observed value of $\langle n_{\rm ch}\rangle$ in p-p collisions at 405 GeV (Ref. 6). The above value of R is found to be in agreement with the values reported earlier[7] from 200 to 8000 GeV and R remains constant in this energy range. The low value of R signifies nuclear transparency at very high energies. The value of R for the CNO and AgBr group of nuclei is found to be 1.45 ± 0.14 and 2.04 ± 0.17, respectively. The value of R for the light group of nuclei shows that the proton interactions with such nuclei behave like proton-nucleon interactions. This is in strong agreement with the earlier results[8] obtained from rapidity-difference distribution in nucleon-light nuclei interactions at cosmic-ray energies (TeV region). The larger value of R for the AgBr group of nuclei shows that there is some contribution to the multiplicity from more than one nucleon during the collision process. However, the low value of R even for the heavy group of target nuclei precludes the formation of an intranuclear cascade in the present interactions.

Figure 2(a) shows the rapidity distribution of the secondary particles. The distribution does not show any double-hump structure for which weak evidence has been reported at 400 GeV (Ref. 5). Boos *et al.*[5] have suggested that the double-hump structure strongly supports the models of repeated intranuclear collisions. The clear absence of such a structure in the present work disfavors the intranuclear cascade model.

DeTar[9] has suggested that the single-particle rapidity distribution will have a limiting form and the distribution will exhibit a plateau in the central region at high energies. The rapidity distributions shown in Fig. 2(b) for different values of n_h which correspond to interactions with the nucleon, CNO, and AgBr group of nuclei exhibit a limiting behavior in the projectile fragmentation region. The projectile fragmentation region is independent of the

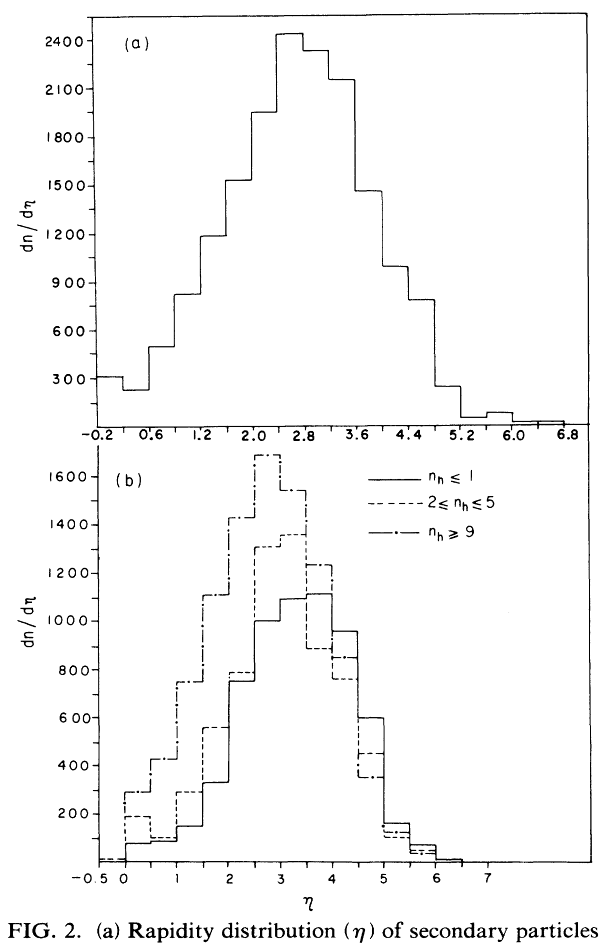

FIG. 2. (a) Rapidity distribution (η) of secondary particles at 800 GeV. (b) Rapidity distributions of secondary particles for different groups of target nuclei.

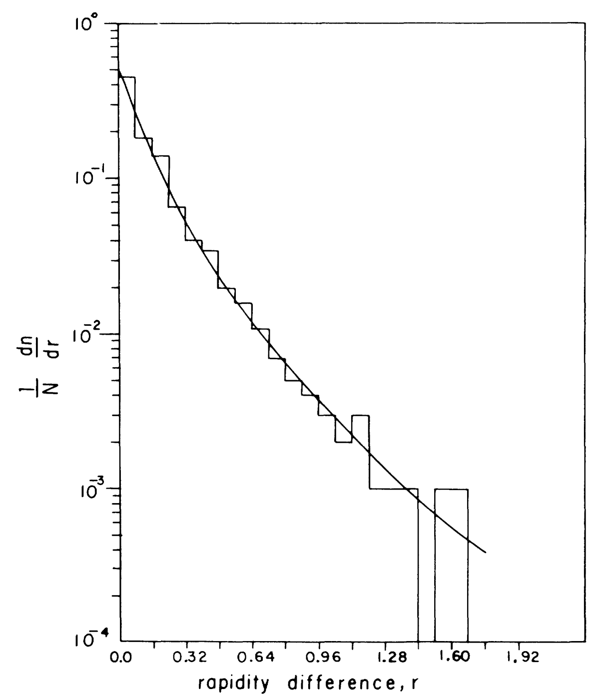

FIG. 3. The rapidity-difference (r) distribution for adjacent charged secondary particles. The theoretical curve is given by Eq. (2) in the text.

TABLE I. Values of the parameters A, B, C, and D for nucleon, CNO, and AgBr targets.

Target type	A	B	C	D
Nucleon	1.14±2.62	6.57±4.75	0.10±0.45	2.45±1.62
CNO	1.41±2.18	8.59±6.48	0.12±0.74	2.35±1.75
AgBr	1.46±2.19	8.90±6.65	0.19±0.67	3.48±2.18

target mass. The width of the central region is nearly the same for the three target nuclei. The multiperipheral model[9] predicts that the central region is generated by particles that decouple from distant parts of the multiperipheral chain, hence the spectrum in the central region must be independent of both beam and target. Our results on η distribution [Fig. 2(b)] are in agreement with the above description regarding independence of central region with respect to the target.

Using the two-channel Chew-Pignotti[10] model, Snider[11] has described the two-particle correlations in terms of the rapidity-difference distributions for the nondiffractive component of the hadronic cross section at high energies. A two-particle correlation implies that a distribution of rapidity difference between two adjacent particles must have a sharp peak at small values of the rapidity difference (r). The secondary particles in the central region have been considered here and the two leading particles on each end of the rapidity space have been neglected. Thus the contribution of a Pomeron at the ends of the rapidity distribution is eliminated. Figure 3 shows the rapidity-difference distribution of adjacent secondary particles and the solid curve represents a distribution of the form given by

$$dn/dr = Ae^{-Br} + Ce^{-Dr} , \quad (2)$$

where

$$A=0.78,\ B=9.99,\ C=0.11,\ \text{and}\ D=3.26 .$$

The value of χ^2/degree of freedom using the above distribution is = 16.46/21. A single exponential distribution which implies no correlation was also tried to fit the above distribution and yielded a high value of χ^2/degree of freedom = 1987/21. Thus, it can be concluded that there are two-particle correlations among the secondary particles in the central region. Using the method given earlier,[2] the correlations among more than two particles were investigated. The double exponential fit to the three and four particle r distributions of the secondary particles yielded the high values of χ^2/degree of freedom = 428/25 and 874/31, respectively. Hence, it can be concluded that the predominant contribution to multiparticle production is from low-mass clusters.

It has been shown[2] that the value of slope of the first exponential term (B) in rapidity-difference distribution measures the strength of correlation. The value of B in the present work is 9.99±5.08 which is found to have nearly the same value as at cosmic-ray energies.[2,3] The r distribution of secondary particles for nucleon, CNO, and AgBr target nuclei have been found to follow the following relations, respectively:

$$dn/dr = 1.14e^{-6.57r} + 0.10e^{-2.45r} ,$$

$$dn/dr = 1.41e^{-8.59r} + 0.12e^{-2.35r} ,$$

$$dn/dr = 1.46e^{-8.90r} + 0.19e^{-3.48r} .$$

The values of the parameters in the above distributions for nucleon, CNO, and AgBr targets are given in Table I. It is found that the three distributions are similar and the values of the parameter B are consistent (within errors). Thus it appears that the rapidity-difference distribution of the secondary particles is not modified by nuclear effects. The reason for this may be that the fast particles are produced in elementary hadron-hadron collisions, the rest of the nucleons in the nucleus remain spectators during the collision. This is also supported by the low value of R obtained in the present interactions. An important question suggested by Quigg, Pirila, and Thomas[1] for investigation was the energy dependence of the cluster parameters. They have shown that at 100—400 GeV/c the number of charged particles per cluster is 2 which is the same as that found in the present work. Thus, the high-multiplicity events are due to a large number of small size clusters rather than a small number of large size clusters. The cluster characteristics have been found to remain independent of the target nucleus and the primary energy. The existence of two-particle correlations has been established at machine energies up to 800 GeV as well as at cosmic-ray energies (TeV region). This shows the "universality" of this description of the phenomenon of multiparticle production.

We are grateful to Fermi National Accelerator Laboratory, Illinois, for exposure facilities at the Tevatron and to Dr. Ray Stefanski for help during exposure of the emulsion stack. We would like to thank Dr. R. Wilkes for processing facilities and A. Prasad, P. Vikas, and D. Kaul for help in microscope work and computer programming. Financial assistance provided by University Grants Commission, New Delhi, is gratefully acknowledged.

[1]C. Quigg, P. Pirila, and G. H. Thomas, Phys. Rev. Lett. **34**, 290 (1975); T. Kafka *et al.*, *ibid.* **34**, 687 (1975); A. Arneodo and G. Plaut, Nucl. Phys. **B107**, 262 (1976); R. Slansky, Phys. Rep. **11C**, 99 (1974); E. L. Berger, Nucl. Phys. **B85**, 61 (1975); L. Foa, Phys. Rep. **22C**, 1 (1975); J. Whitmore, *ibid.* **27C**, 187 (1976); P. Pirila, G. H. Thomas, and C. Quigg, Phys. Rev. D **12**, 92 (1975); C. Bromberg *et al.*, *ibid.* **15**, 1215 (1977); P. K. Sengupta *et al.*, *ibid.* **20**, 601 (1979); R. K. Shivpuri, *ibid.* **15**, 1926 (1977). Detailed references are given in the above papers.

[2]R. K. Shivpuri and Chandra Gupt, Phys. Rev. D **15**, 3332 (1977).

[3]Chandra Gupt and R. K. Shivpuri, Phys. Rev. D **19**, 2135 (1979).

[4]Chandra Gupt, R. K. Shivpuri, N. S. Verma, and A. P. Sharma, Phys. Rev. D **26**, 2202 (1982).

[5]E. G. Boos *et al.*, Nucl. Phys. **B143**, 232 (1978).

[6]C. Bromberg *et al.*, Phys. Rev. Lett. **31**, 1563 (1973).

[7]A. Gurtu *et al.*, Phys. Lett. **50B**, 391 (1974).

[8]R. K. Shivpuri and Chandra Gupt, Phys. Rev. D **17**, 1778 (1978).

[9]C. E. DeTar, Phys. Rev. D **3**, 128 (1971).

[10]G. F. Chew and A. P. Pignotti, Phys. Rev. D **176**, 2112 (1968).

[11]D. R. Snider, Phys. Rev. D **11**, 140 (1975).