PHYSICAL REVIEW LETTERS

VOLUME 39 12 DECEMBER 1977 NUMBER 24

Energy Dependence of the Pseudorapidity Distributions in Proton-Nucleus Collisions between 50 and 200 GeV/*c*

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(Received 21 April 1977)

Pseudorapidity distributions for proton-nucleus interactions are presented. The data cover twelve nuclei ranging from carbon to uranium and three incident proton momenta, 50, 100, and 200 GeV/c.

The study of hadron-nucleus collisions at high energies[1] has shown that the time scales involved in hadronic production are large and that the nucleus can serve as a useful analyzer of the properties of hadrons in the early stages of development. With the hope of imposing stronger constraints on the possible mechanisms of particle production,[2] we have measured the energy, incident-particle, and target dependences of the pseudorapidity distributions in hadron-nucleus collisions.[3] In this Letter we briefly describe the experiment and discuss the energy and target dependences of the proton data. Comparison of results obtained with different incident particles will be published elsewhere.

The experiment was performed in the M6W beam line of the meson area at Fermilab. Data were obtained at 50 and 100 GeV/c for incident π^-, K^+, and p and at 200 GeV/c for incident π^+, π^-, p, and $\bar{p}$. Targets ranging from carbon to uranium were used and hydrogen data were obtained for $CH_2 - C$ differences. Three gas Cherenkov counters were used to identify the incident particle. Wide-angle products of the interaction were detected in four annular Lucite hodoscopes, each subtending a different range of polar angle, θ_L. Forward products were counted in a high-resolution Cherenkov counter[4] using pulse-height techniques. The use of Lucite for detecting particles imposed a selection of velocities greater than $0.85c$. No neutral secondaries were intentionally detected and no identification of charged secondaries was carried out. Targets of several lengths were used for each material to permit an extrapolation to zero target length. To obtain finer θ_L bins than those subtended by the hodoscopes, data were taken for each target with several different relative positions of target and detectors. As a result, data were effectively collected for twelve ranges of pseudorapidity, η

$= -\ln(\frac{1}{2}\tan\theta_L)$.

The apparatus was triggered when either one particle at a wide angle or two or more forward particles resulted from an interaction. In the data analysis, events were rejected which contained less than three particles or in which a downstream beam veto counter fired. This counter subtended a solid angle of 2 μsr corresponding to $\eta \gtrsim 7.0$. In addition to the extrapolation to zero target thickness, the probability of two or more particles passing through one hodoscope counter was taken into account. Corrections for secondary interactions, γ conversions from π^0, δ rays, acceptance, etc., were applied. The missing zero-, one-, and two-charged-particle events were estimated by comparing the measured interaction rates with known absorption cross sections,[5] and corrected for by assuming that the pseudorapidity distribution was multiplicity independent.[6]

After all the corrections, the raw data were reduced to a three-dimensional multiplicity distribution $N(E, A, \Delta\eta)$. We denote by $N(E, A, \Delta\eta)$ the average multiplicity of all charged relativistic ($\beta > 0.85c$) particles produced in a pseudorapidity range $\Delta\eta$ when an incident proton of energy E collided inelastically with a nucleus of atomic number A. To facilitate theoretical analysis, we have parametrized $N(E, A, \Delta\eta)$ in the form of $N(E, A, \Delta\eta) = f + g\bar{\nu} + h\bar{\nu}^2$, where $\bar{\nu}$ $(= A\sigma_{pp}/\sigma_{pA})$ is the average number of absorption mean free paths seen by a proton passing through the nucleus.[7] In Table I we give the fitted values of f, g, and h. The errors quoted include contributions from statistical and systematic effects.

We now illustrate in graphical form some of the features of these data and discuss their possible significance. Figure 1 shows how at 200 GeV/c the pseudorapidity distribution changes as the average thickness of the nucleus increases from one to four mean free paths. The data at 50 and 100 GeV have similar features. If the pseudorapidity distributions are integrated over η and the average multiplicity $\langle n\rangle_A$ is obtained as a function of $\bar{\nu}$, the data can be parametrized adequately as $R_A = \langle n\rangle_A/\langle n\rangle_p = a + b\bar{\nu}$, with $a = 0.51$ and $b = 0.49$ at 50 GeV/c; $a = 0.45$ and $b = 0.53$ at 100 GeV/c; and $a = 0.39$ and $b = 0.63$ at 200 GeV/c.[8] The explicit A dependence is more apparent in Fig. 2 where, for various regions of pseudorapidity, $N(A, \Delta\eta)$ is plotted as a function of $\bar{\nu}$. The decrease of the slope of $N(A, \Delta\eta)$ as η increases is evidence, though not conclusive,[9] that the creation time of particles increases with their rapidity. In the target-fragmentation region there is a clear indication of cascading, showing that the slowest particles are created well inside the nucleus. The almost complete target independence of the forward-going particles suggests that the asymptotic final state of the fast particles is reached in distances $\gtrsim$ 10 fm. Another noteworthy feature in Fig. 2 is the indication of some

TABLE I. Multiplicity $N(E, A, \Delta\eta)$ parametrized in the form $N(E, A, \Delta\eta) = f + g\bar{\nu} + h\bar{\nu}^2$. The tabulated error is the percentage error on $N(E, A, \Delta\eta)$.

Range of η ($\Delta\eta$)	50 GeV/c				100 GeV/c				200 GeV/c			
	f	g	h	error	f	g	h	error	f	g	h	error
−0.67 to −0.38	−0.11	0.10	0.00	33	−0.12	0.11	0.00	20	−0.07	0.06	0.00	25
−0.38 to 0.56	−0.31	0.34	0.06	14	−0.47	0.49	0.03	8	−0.25	0.25	0.08	8
0.56 to 0.92	−0.07	0.19	0.03	14	−0.12	0.26	0.01	8	−0.05	0.16	0.03	7
0.92 to 1.39	0.01	0.33	0.02	12	−0.13	0.45	0.01	8	0.01	0.25	0.06	8
1.39 to 1.99	0.22	0.51	0.01	9	0.04	0.62	0.02	6	0.05	0.51	0.06	6
1.99 to 2.25	0.16	0.24	−0.01	9	0.14	0.25	0.00	7	0.05	0.30	0.00	7
2.25 to 2.76	0.29	0.54	−0.06	9	0.40	0.49	−0.03	6	0.22	0.60	−0.02	6
2.76 to 3.08	0.25	0.26	−0.04	11	0.31	0.29	−0.02	7	0.18	0.41	−0.03	6
3.08 to 3.38	0.38	0.08	−0.01	8	0.29	0.25	−0.03	7	0.17	0.39	−0.04	6
3.38 to 4.08	1.00	−0.07	0.01	8	0.69	0.43	−0.06	5	0.44	0.85	−0.10	5
4.08 to 5.28	0.65	0.00	0.00	14	1.08	0.05	0.00	6	1.25	0.50	−0.06	6
5.28 to 7.00	0.26	0.00	0.00	5	0.50	0.00	0.00	4	0.80	0.07	0.00	3

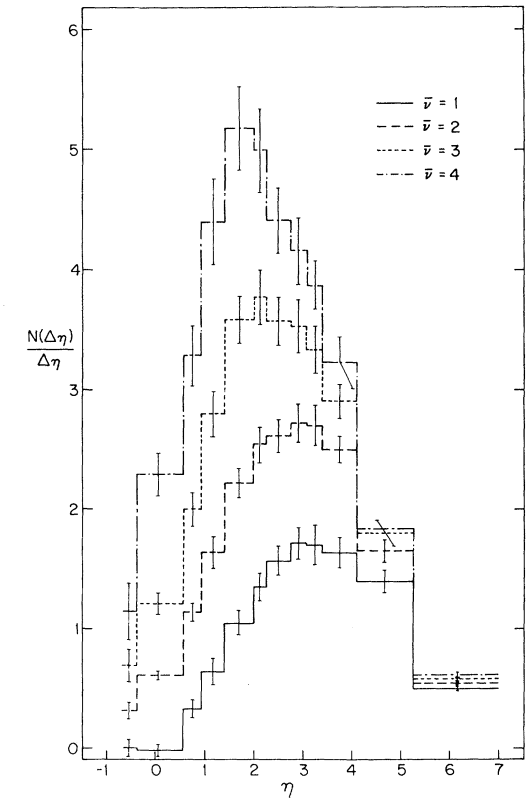

FIG. 1. Pseudorapidity distributions for various values of $\bar{\nu}$ in 200-GeV/c proton-nucleus interactions.

saturation of $N(A, \Delta\eta)$ as $\bar{\nu}$ increases for $\eta \gtrsim 2.5$. There is no evidence in our data of a decrease of multiplicity with A for $\eta \gtrsim 5$ as suggested by several emulsion experiments.[10]

The energy dependence of the pseudorapidity distributions is illustrated in Fig. 3. If a comparison is made of our data with the 3-TeV emulsion data obtained with cosmic rays,[11] it appears that at all energies it is only the forwardmost two units of the pseudorapidity distribution that are approximately A independent.

Since R_A does not decrease with energy, and the region of rapidity where $N(\Delta\eta)/\Delta\eta$ is target dependent moves out in η as energy increases, the data are incompatible with all models which have only short-range order. Thus parton models where the proton is made of only a single chain of partons or multiperipheral models without cuts are incompatible with the data.[12] The data favor the more recent versions of these models.[13] The rate at which the A-dependent part of the rapidity distribution moves out in η with E is faster than that predicted by the energy-flux cascade model.[14]

In conclusion, the data presented here have put

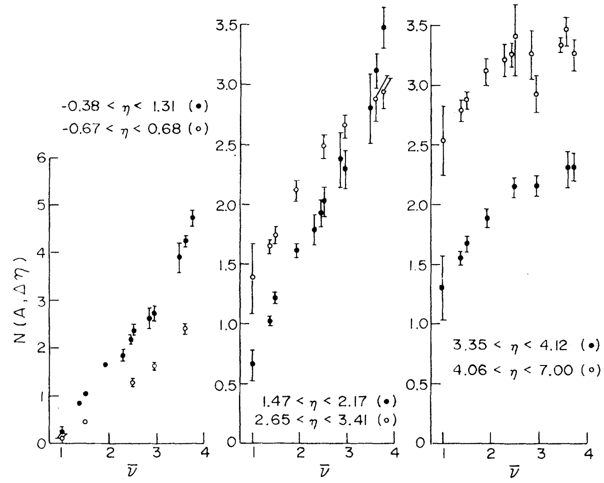

FIG. 2. $N(A,\Delta\eta)$ as a function of $\bar{\nu}$ for various regions of pseudorapidity in 200-GeV/c p-A interactions. Errors on the data points include both systematic and statistical effects.

constraints on the possible mechanisms of multiparticle production. It is now important to study carefully to what extent these restrictions are compatible with the various theoretical models which have been proposed to explain data on particle production in hadron-nucleon collisions.

We wish to thank the staff of the Meson Laboratory of Fermilab for their cooperation and assistance. The help of the staff of the Laboratory for

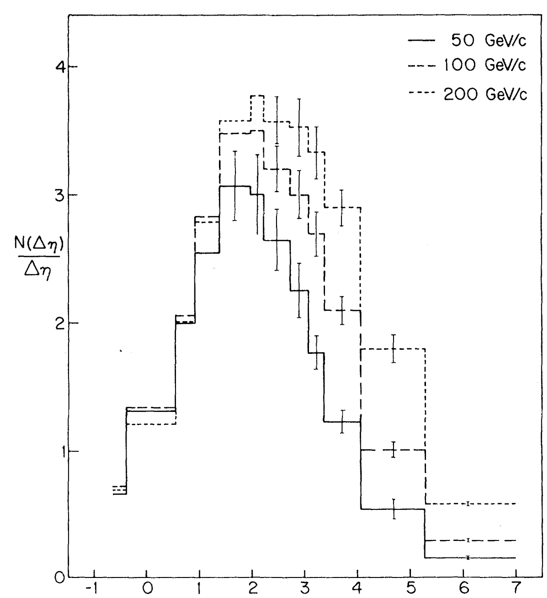

FIG. 3. Energy dependence of pseudorapidity distributions for the $\bar{\nu} = 3$ data. In the interest of clarity, only typical errors are shown.

Nuclear Science at the Massachusetts Institute of Technology is greatly appreciated, in particular that of Craig Bolon. One of us (C.H.) wishes to express his appreciation to E. P. Hincks for support and encouragement. This work was supported in part by the U. S. Energy Research and Development Administration under Contract No. EY-76-C-02-3069, and in part by the National Research Council of Canada.

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[1]For a recent review of experimental data on hadron-nucleus collisions, see C. Halliwell, in Proceedings of the Seventh International Colloquium on Multiparticle Reactions, Kaysersberg, June 1977 (to be published).

[2]See, for example, W. Busza, in Proceedings of the Twelfth Rencontre de Moriond, March 1977 (to be published).

[3]Preliminary results of this experiment were presented in *Proceedings of the Eighteenth International Conference on High Energy Physics, Tbilisi, U. S. S. R., 1976,* edited by N. N. Bogolubov *et al.* (The Joint Institute for Nuclar Research, Moscow, 1977).

[4]W. Busza *et al.*, in *Proceedings of the Topical Meeting on High Energy Collisions Involving Nuclei, Trieste, 1974,* edited by G. Bellini, L. Bertocchi, and T. Rancoita (Compositori, Bologna, 1975).

[5]S. P. Denisov *et al.*, Nucl. Phys. B61, 62 (1973).

[6]To check this assumption, the Michigan-Rochester 100-GeV pp bubble chamber exposure (T. Ferbel, private communication) was analyzed by imposing cuts identical to those in this experiment. A distortion in the pseudorapidity distribution of less than 5% resulted. This distortion is expected to fall to ~ 1% for heavier elements.

[7]In the expression $\bar{\nu}$ $(=A\sigma_{pp}/\sigma_{pA})$, A is the atomic number of the nucleus, and σ_{pp} and σ_{pA} are the measured inelastic cross section of protons on a nucleon and the nucleus A, respectively. For σ_{pA} we have used the data of Denisov *et al.*, Ref. 5. $\bar{\nu}\approx 0.70A^{0.31}$ for proton-induced interactions.

[8]We do not quote errors on a and b since they are correlated. Using the values of these parameters as quoted, the typical error on R_A is 7% at 50 GeV/c, 4% at 100 GeV/c, and 4% at 200 GeV/c.

[9]An alternative explanation of the data, based on the assumption that in hadron-nucleus collisions many nucleons in the target act collectively, has been put forward by G. Berlad *et al.*, Phys. Rev. D 13, 161 (1976); by S. Fredriksson, Royal Institute of Technology, Department of Theoretical Physics Report No. TRITA-TFY-76-4; and by A. Z. Patashinskii, Pis'ma Zh. Eksp. Teor. Fiz. 19, 654 (1974) [JETP Lett. 19, 338 (1974)].

[10]This lack of evidence could be due to the correction applied for the missing zero-, one-, and two-charged-particle events. By use of data mentioned in Ref. 6, multiplicity in pp interactions was lowered by ~ 10% in the forward region when a similar correction was applied. For heavier targets the correction is expected to have a smaller effect. For a review of emulsion data, see I. Otterlund, in Proceedings of the Topical Meeting on Multiparticle Production from Nuclei at Very High Energies, Trieste, 1976 (to be published).

[11]J. Babecki *et al.*, Phys. Lett. 52B, 247 (1974).

[12]For a review of theoretical models see, for example, B. Anderson, in Proceedings of the Seventh International Colloquium on Multiparticle Reactions, Tutzing, 1976 (to be published); and N. Nikolaev, to be published.

[13]See, for example, A. Capella and A. Krzywick, Phys. Lett. 67B, 84 (1977); Nikolaev, *op. cit.* Ref. 12; A. Mueller, Columbia University Report No. Co-2271-90, 1976 (to be published); G. Bialkowski *et al.*, Phys. Lett. 68B, 451 (1977).

[14]K. Gottfried, Phys. Rev. Lett. 32, 957 (1974).