PHYSICAL REVIEW D VOLUME 29, NUMBER 1 1 JANUARY 1984

Study of R_3-$\langle \nu' \rangle$ relationship from 400-GeV p-nucleus interactions

D. P. Goyal, P. K. Sengupta, and S. Singh
Department of Physics and Astrophysics, University of Delhi, Delhi 110007, India

N. S. Arya
All India Jat Hero Memorial College, Rohtak, India

(Received 25 May 1983)

New data from 400-GeV p-nucleus interactions are analyzed to investigate the variation of normalized created-charged-particle multiplicity (R_3) as a function of effective number of projectile encounters ($\langle \nu' \rangle$) calculated by using the additive quark model. The data, combined with other available data from p-nucleus and π^--nucleus reactions, confirm the projectile independence of the R_3-$\langle \nu' \rangle$ relationship, first observed by Kumar *et al.*

I. INTRODUCTION

Recently we reported[1] a study of normalized created-charged-particle multiplicity (R_3) in hadron-nucleus (h-A) interactions as a function of the effective number of projectile encounters ($\langle \nu' \rangle$) calculated using the additive quark model.[2] The analysis of the data on the π^--nucleus (π^--A) and p-nucleus (p-A) interactions obtained from emulsion and counter experiments in the energy range 50 to 300 GeV suggested a new kind of scaling whereby the R_3-$\langle \nu' \rangle$ relationship is projectile independent. For this purpose, 18 data points from π^--A interactions at 50, 60, and 100 GeV, and 6 data points from p-A interactions at 67, 100, 200, and 300 GeV, were available to us.[1] We had realized that the data on p-A interactions were meager and would need augmentation. With this in view, we have now analyzed p-emulsion data at 400 GeV and this has given us 9 new data points. With the availability of this data, we find that the R_3-$\langle \nu' \rangle$ scaling suggested by our previous analysis[1] can be placed on a firm footing, and this analysis is reported here.

II. EXPERIMENTAL DETAILS

The present data originated from an emulsion stack consisting of 50 K5 pellicles, each of size $15\times10\times0.06$ cm^3, exposed to a proton beam of energy 400 GeV at Fermilab. A flux of $\sim5\times10^4$ particles per cm^2 entered the emulsion stack. The stack was area scanned under $53\times$ objective. The interactions were picked up after 1 cm from the leading edge but within a maximum distance of 3 cm along the beam direction. About 75% of the scanned data is confined to the first 1 cm. Every region was scanned by at least two independent observers.

Each interaction was looked at under $100\times$ objective for the presence of a primary beam track. In order to ensure that the sample of stars does not include interactions from secondary tracks of other interactions, all primary "beam" tracks were followed backwards up to the leading edge of the pellicle. The event was rejected if its beam track originated from another interaction or it left the pellicle before reaching the leading edge, or its inclination either in the projected or azimuth plane was $>3°$ to the mean beam direction in the pellicle. Further, events within a 20-μm distance from the top or botton of the emulsion pellicles were rejected. This was done to avoid inclusion of steeply dipping secondary tracks, as in such interactions the angular and other measurements are difficult.

Each interaction was scrutinized by two independent observers and the total number of charged particles emitted was recorded. Each track was classified as a shower (N_s), gray (N_g), or black (N_b) according to their ionization relative to the ionization of the beam track (b_p). Thus shower tracks have ionization $\leq 1.4b_p$, gray tracks have ionization $>1.4b_p$ but $\leq 10b_p$, and for black tracks ionization is $>10b_p$. The black and gray tracks are collectively designated as heavy tracks (N_h).

The combined efficiency of area scan by two independent

TABLE I. The values of $\langle N_h \rangle$ and percentage frequency of events in different N_h groups for 400-GeV p-emulsion interactions.

	$\langle N_h \rangle$	Percentage frequency $N_h=0$	$N_h=1$	$2\leq N_h\leq5$	$N_h\geq6$
Tsai-Chu *et al.* (Ref. 3) (line-scan data)	7.4 ±0.2	16.5 ±1.2	9.8 ±0.9	28.3 ±1.6	44.9 ±2.0
Present work (area-scan data)	8.1 ±0.2	14.5 ±1.3	6.2 ±0.9	29.7 ±1.9	49.6 ±2.6
Corrected values	(7.6 ±0.2)	(16.5 ±1.3)	(9.8 ±1.0)	(27.6 ±1.8)	(46.1 ±2.4)

scanners for white stars ($N_h = 0$) is estimated to be $\simeq 97\%$ while for black stars ($N_h \geq 1$), it is nearly 100%. In the present work, we have used 1071 stars which have $N_h \geq 1$ as only these can represent p-A interactions.

In order to check the quality of our area-scan data, we have compared it with the line-scan data of Tsai-Chu *et al.*[3] In Table I we have shown the fraction of events in different N_h bins for the two sets of data. It may be noted that our percentage frequency of $N_n \geq 2$ events is slightly higher, while for $N_h \leq 1$ it is slightly lower than the corresponding ones obtained by Tsai-Chu *et al.*[3] This indicates that in our data some of the high-N_h (≥ 2) events have been preferentially picked up at the cost of low-N_h (≤ 1) ones. Therefore, to correct for this relative loss of $N_h \leq 1$ events, we have normalized our data in the bins $N_h = 0$ and $N_h = 1$ to the corresponding line-scan data. The resulting frequencies in various N_h bins are shown in parentheses in Table I. With this correction, the corrected number of p-A interactions becomes 1153.

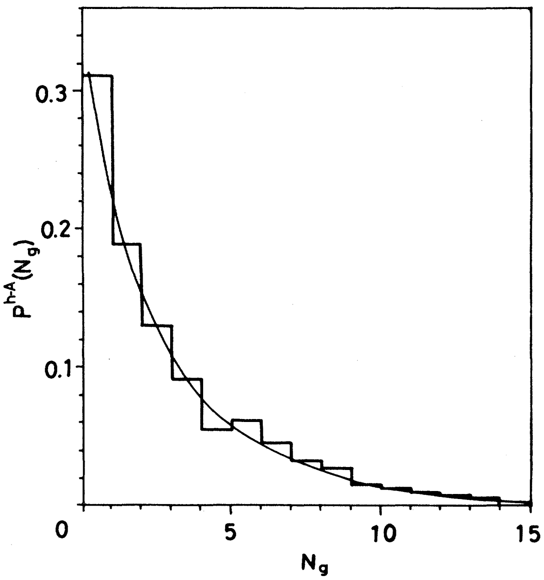

FIG. 1. Experimental gray-particle distribution from 400-GeV p-nucleus interactions. The solid curve is calculated on the basis of the model of Andersson, Otterlund, and Stenlund (Ref. 4).

III. RESULTS AND DISCUSSION

As before,[1] we define the various relevant parameters as follows. The normalized created-charged-particle multiplicity (R_3) is defined as

$$R_3 = (\langle N_s \rangle_{h,A} - \alpha_A)/(\langle N_{ch} \rangle - \alpha_H) ,$$

where α_A and α_H are leading-particle multiplicities[1] in h-A and h-p collisions, respectively, and $\langle N_{ch} \rangle$ is the mean charged-particle multiplicity in a h-p collision at the same energy. The number of projectile encounters within the target nucleus calculated from the experimental gray-particle distribution and using the model of Andersson, Otterlund, and Stenlund[4] is designated by ν, whereas this number calculated on the basis of the additive quark model[2] is designated by ν'. The full details of the method used for evaluating R_3, ν, and ν' may be found in our previous paper.[1]

The experimental distribution of gray particles for our 400-GeV p-A data is shown in Fig. 1. This is compared with the calculated distribution on the basis of the model of Andersson, Otterlund, and Stenlund.[4] A good agreement between theory and experiment is clearly visible. Therefore, for purposes of calculating ν, we are justified in using the 400-GeV p-A data along with other data on p-A interactions reported earlier.[1] The various quantities pertaining to the 400-GeV p-A data are shown in Table II.

In what follows, the variation of R_3 with $\langle \nu \rangle$ and $\langle \nu' \rangle$ is studied separately. The values of R_3 vs $\langle \nu \rangle$ for p-A and π^--A reactions obtained from our previous work[1] along with the values from our current p-A data at 400 GeV are plotted in Fig. 2. We note that the 400-GeV p-A data show the same trend as found for the earlier[1] p-A data at 67, 100, 200, and 300 GeV. It is further noted that the π^--A and

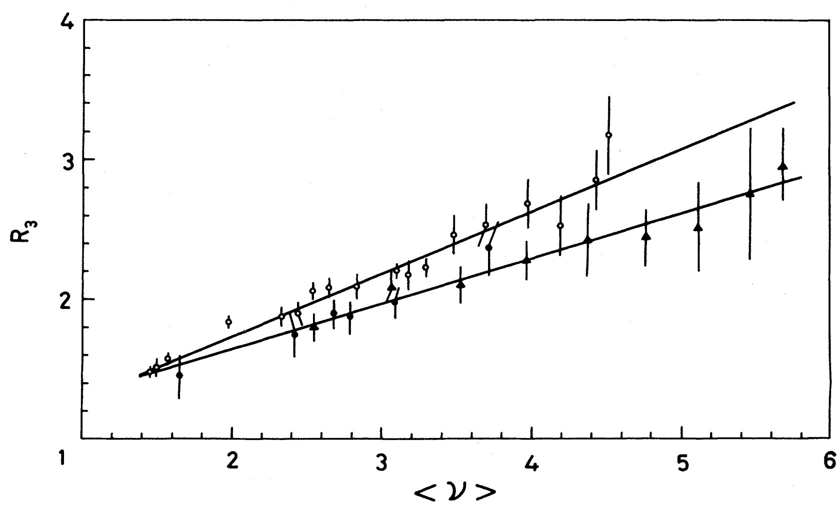

FIG. 2. The variation of R_3 as a function of $\langle \nu \rangle$ for π^--A and p-A reactions. The straight lines represent the best fits to the data. The π^--A data points are shown by ○, p-A data points from previous paper (Ref. 1) are shown by ●, and the new data points at 400 GeV, p-A are shown by ▲.

TABLE II. The values of different parameters from 400-GeV p-nucleus data.

N_g	$\langle N_s \rangle$	$\langle N_{ch} \rangle$	R_3	$\langle \nu \rangle$	$\langle \nu' \rangle$
2	15.50 ±0.64	8.99 ±0.14	1.80 ±0.10	2.55	1.52
3	17.64 ±0.91	8.99 ±0.14	2.09 ±0.12	3.06	1.69
4	17.80 ±1.08	8.99 ±0.14	2.11 ±0.14	3.53	1.84
5	19.09 ±1.16	8.99 ±0.14	2.27 ±0.15	3.98	1.99
6	20.36 ±1.32	8.99 ±0.14	2.43 ±0.26	4.39	2.13
7	20.64 ±1.61	8.99 ±0.14	2.47 ±0.20	4.78	2.26
8	21.07 ±1.63	8.99 ±0.14	2.52 ±0.22	5.13	2.38
9	22.90 ±2.26	8.99 ±0.14	2.74 ±0.51	5.46	2.49
≥10	24.68 ±1.63	8.99 ±0.14	2.96 ±0.27	5.89	2.63

p-A data points fall on two separate lines. The straight-line fits to the data are represented by

$$R_3=(0.32 \pm 0.03)\langle \nu \rangle +(1.03 \pm 0.12) \qquad (1)$$

for p-A data, with $\chi^2/\mathrm{DF}=6.33/13$ and

$$R_3=(0.43 \pm 0.02)\langle \nu \rangle +(0.88 +0.05) \qquad (2)$$

for π^--A data, with $\chi^2/\mathrm{DF} = 16.32/16$. These fits are clearly resolvable from each other and confirm our earlier conclusion[1] that the R_3-$\langle \nu \rangle$ relationship is linear but projectile dependent.

We next investigate the projectile dependence of R_3 within the framework of the additive quark model.[2] For this, the variation of R_3 is studied as a function of $\langle \nu' \rangle$, and this variation is shown in Fig. 3 for both π^--A and p-A data points. Here we find that the trend of all the data points is toward a single straight line. The combined p-A and π^--A data are therefore fitted to a straight line and this gives

$$R_3=(0.88 \pm 0.04)\langle \nu' \rangle +(0.44 \pm 0.07) \qquad (3)$$

with $\chi^2/\mathrm{DF}=37.11/31$. The level of resolution between the p-A and π^--A data points has been adjudged by doing straight-line fits to each set of data separately. These give

$$R_3=(0.96 \pm 0.10)\langle \nu' \rangle +(0.39 \pm 0.18) \qquad (4)$$

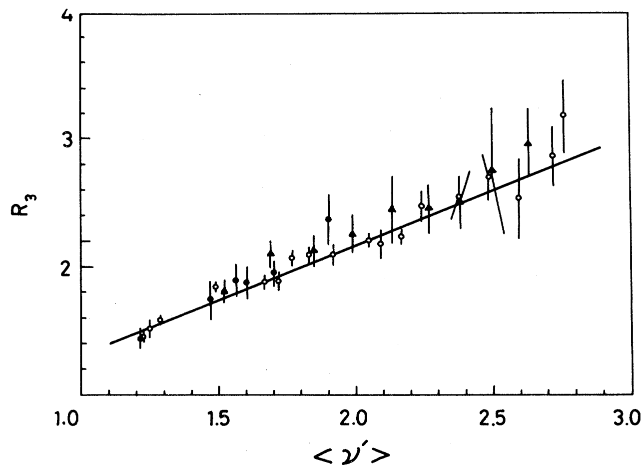

FIG. 3. The variation of R_3 as a function of $\langle \nu' \rangle$ for π^--A and p-A reactions. The straight line represents the best fit to the combined data. The π^--A data points are shown by ○, p-A data points from previous paper (Ref. 1) are shown by ●, and the new data points at 400 GeV, p-A are shown by ▲.

for p-A data, with $\chi^2/\mathrm{DF}=6.16/13$ and

$$R_3=(0.86 \pm 0.05)\langle \nu' \rangle +(0.46 \pm 0.08) \qquad (5)$$

for π^--A data, with $\chi^2/\mathrm{DF}=14.50/16$. Within experimental errors, fits (4) and (5) are in good agreement with each other. This shows that the resolution between p-A and π^--A data points is statistically not significant and therefore separate fits to them are not warranted.

On the basis of the above discussion, we therefore confirm the linearity and projectile independence of R_3-$\langle \nu' \rangle$ relationship previously reported by Kumar *et al.*[1]

ACKNOWLEDGMENTS

The authors are grateful to Professor E. Goldwasser, Professor L. Voyvodic, and other staff of Fermilab for the exposure of the emulsion stack and to Professor R. R. Daniel, Professor S. Biswas, P. J. Kajrekar, and other staff of the Tata Institute of Fundamental Research, Bombay, for providing the facilities for processing the emulsion stack. Thanks are also due to M. A. Roberts for help in the assembly of the stack. The painstaking effort of S. Goel and M. Sen in scanning the plates is gratefully acknowledged.

[1] V. Kumar *et al.*, Phys. Rev. D 22, 2784 (1980).

[2] N. N. Nikolaev and A. Ya. Ostapchuk, CERN Report No. TH-2541, 1978 (unpublished); CERN Report No. TH-2575, 1978 (unpublished).

[3] Tsai-Chu *et al.*, Lett. Nuovo Cimento 20, 257 (1977).

[4] B. Andersson, I. Otterlund, and E. Stenlund, Phys. Lett. 73B, 343 (1978).