PHYSICAL REVIEW D VOLUME 25, NUMBER 9 1 MAY 1982

Three-component model of hadron-nucleus multiparticle production

R. E. Gibbs
Department of Physics, Eastern Washington University, Cheney, Washington 99004

J. J. Lord, R. L. Rosenbladt, and R. J. Wilkes
Department of Physics, University of Washington, Seattle, Washington 98195
(Received 28 September 1981; revised manuscript received 11 January 1982)

A phenomenological model of hadron-nucleus interactions is proposed which includes particle contributions from three sources: target-nucleon fragmentation, projectile fragmentation, and central-region "pionization." The model is consistent with the energy-independent features of angular distributions and average charged-particle multiplicities. $R=\langle n_s\rangle/\langle n_{\rm H}\rangle$ (where n_s is the minimum-ionizing multiplicity on nuclei and $n_{\rm H}$ is the multiplicity at equal energy on hydrogen) is energy dependent and asymptotically proportional to $\bar{\nu}$, the average number of collisions in the target nucleus. We conclude that, in *p-p* interactions, target and projectile fragmentation each account for 1.5 charged particles independent of primary energy, so that the energy dependence of $\langle n_{\rm H}\rangle$ resides solely in the central-region contribution.

INTRODUCTION

Recent analyses of hadron-nucleus interactions have revealed new features inconsistent with current models.[1] Andersson, Otterlund, and Stenlund[2] have shown that $R=\langle n_s\rangle/\langle n_{\rm H}\rangle$ (where n_s is the minimum-ionizing multiplicity on nuclei and $n_{\rm H}$ is the multiplicity at equal energy on hydrogen) is energy dependent and asymptotically essentially proportional to $\bar{\nu}$, the number of collisions in the target nucleus. Our analysis of angular distributions shows that the quantity

$$\delta\eta=\langle\eta\rangle_{\rm H}-\langle\eta\rangle_x=1.74\pm0.06$$

is independent of energy, target nucleus, and projectile. In this relation $\langle\eta\rangle_x$ is the average pseudorapidity of particles in excess of the hydrogen-target pseudorapidity distribution, while $\langle\eta\rangle_{\rm H}$ represents the hydrogen-target case. Thus we see that $\langle\eta\rangle_x$ grows as a function of energy at the same rate as $\langle\eta\rangle_{\rm H}$, i.e., as 0.5 ln E. These results strongly suggest a model in which an energy-dependent central-region contribution to the multiplicity eventually dominates energy-independent contributions from target and projectile fragmentation.

THE MODEL

Our approach is a modification of the scheme originally suggested by Gottfried.[3] Although our model is extremely simple and involves an extension of ideas regarding hadron-hadron multiparticle production which have been widely discussed for some time[4], we know of no previous explicit application of these ideas to hadron-nucleus interactions. Figure 1 illustrates the main features of the model. In Fig. 1(a), a single collision occurs and the distributions for target fragmentation (n_t), projectile fragmentation (n_p), and the central region (n_c) are indicated, drawn as rectangles for simplicity. We assume that the fragmentation multiplicities are energy independent and equal. Each subsequent collision reproduces the target and central particle distributions, but the projectile contribution occurs only once, as shown in Fig. 1(b) in which three collisions are considered. However, techniques for measuring such interactions fail to observe very-low-energy particles, so we have indicated a group of ϵ uncounted particles in Fig. 1(b). These tracks may be distributed more widely over the pseudorapidity range than is indicated in the figure. We might expect ϵ to depend on the experimental technique used. As primary energy increases, the central region becomes longer, and increases slowly in height, but no other changes occur.

It is clear that the energy independence of $\delta\eta$ is built into this model, and that asymptotically R is proportional to $\bar{\nu}$. We can now derive R as a function of $\bar{\nu}$. In this derivation all quantities are average values. From Fig. 1(a),

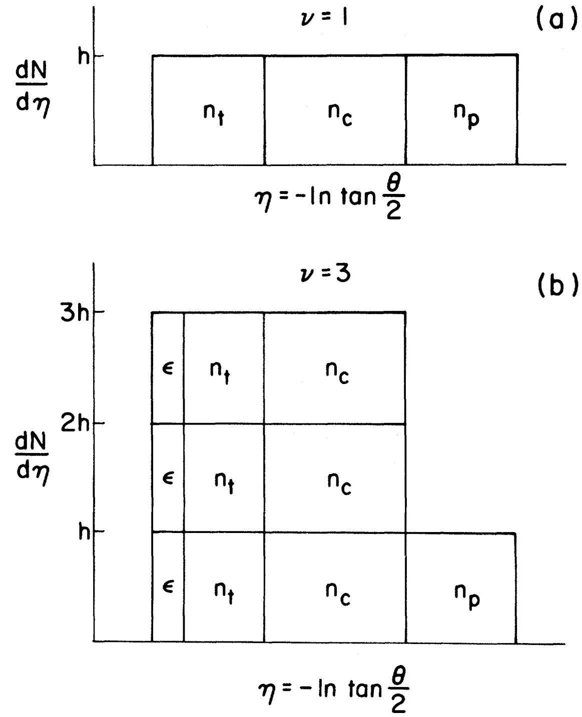

FIG. 1. Pseudorapidity distributions for the three-component model.

$$n_H = n_t + n_c + n_p \ . \quad (1)$$

From Fig. 1(b), for $\bar{\nu}$ collisions,

$$n_s = \bar{\nu}(n_t + n_c - \epsilon) + n_p$$
$$= \bar{\nu} n_H + (n_p - \bar{\nu} n_p - \bar{\nu}\epsilon) \ , \quad (2)$$

so

$$R = \bar{\nu} + [n_p - \bar{\nu}(n_p + \epsilon)]/n_H \ . \quad (3)$$

For proton collisions in emulsion, Andersson, Otterlund, and Stenlund[2] find

$$R = (2.34 \pm 0.03) - 4.12/n_H \ . \quad (4)$$

Comparing Eqs. (3) and (4) suggests $\bar{\nu} = 2.34 \pm 0.03$. This is in excellent agreement with the values determined by Elias *et al.*,[5] where $\bar{\nu} = 2.32$ at 50 GeV and 2.39 at 200 GeV. Changes in $\bar{\nu}$ due to the rising cross section are ignored in Eq. (4) and $\bar{\nu}$ is treated as a constant. Andersson, Otterlund, and Stenlund[2] then estimated $\bar{\nu} = 2.47$ for *p*-emulsion collisions, and derived the following result:

$$R = 0.12 + 0.90\bar{\nu} + (1.53 - 2.29\bar{\nu})/n_H \ . \quad (5)$$

Consistent with Eqs. (3) and (4) and the data of Ref. 5, we feel that $\bar{\nu} = 2.34$ is a better choice than $\bar{\nu} = 2.47$. So we have modified Eq. (5) to account for the different value of $\bar{\nu}$. The result is

$$R = \bar{\nu} + (1.53 - 2.42\bar{\nu})/n_H \ . \quad (6)$$

Equation (6) with $\bar{\nu} = 2.34$ is numerically identical to Eq. (5) with $\bar{\nu} = 2.47$. Comparing this result to Eq. (3) we find $n_p = 1.53$ and $\epsilon = 2.42 - 1.53 = 0.89$.

At very low η, our model does not reproduce the data of Ref. 5. However the data of Florian *et al.*[6] and Lee *et al.*[7] where observations were made in nuclear emulsion, agree with the model in this region. The latter experiments should yield more accurate data on particles emitted at large angles.

We have deliberately avoided giving any explicit picture of the space-time development of the interaction process. The most obvious interpretation of Fig. 1 is that only the projectile interacts, but does not itself fragment until after leaving the nucleus. However any space-time scenario which leads to Fig. 1 would be equally acceptable under the model described here.

TESTING THE MODEL

Our model is based on the assumption that the multiplicity ratio R is energy dependent, asymptotically approaching a constant at high energy. This view is supported by examination of the emulsion[2] and neon-filled bubble-chamber results.[8–11] However, Elias *et al.*,[5] using the results of a counter experiment, and defining the multiplicity ratio as $R_A = \langle n_s \rangle / (\langle n_H \rangle - 0.5)$, find R_A energy independent in the range 50–200 GeV.

The quark-parton model of Brodsky, Gunion, and Kuhn (BGK)[12] is in good agreement with the data of Ref. 5, and thus disagrees with Ref. 2 and the picture proposed here.

The R values for the π^--Ne data[13] are shown in Fig. 2, along with curves representing our model, the BGK model, and the constant-R_A hypothesis of Ref. 5. In our model, ϵ is treated as a free parameter, and we find $\epsilon = 0.60$ provides the best fit to the bubble-chamber data. For the BGK model, the fit is poor unless one includes the effects of $\epsilon = 0.5$ undetected tracks per intranuclear collision. In these model calculations, we have used $\bar{\nu}$ values from Ref. 5. Figure 2 shows that the data demand stronger energy dependence than the constant-R_A curve provides.

A plot of $\langle n_s \rangle$ vs $\langle n_H \rangle$ for *p*-emulsion interactions is shown in Fig. 3. The solid line, equivalent to Eq. (4) above, represents the fit of Andersson *et al.*[2] to a world collection of emulsion data in the

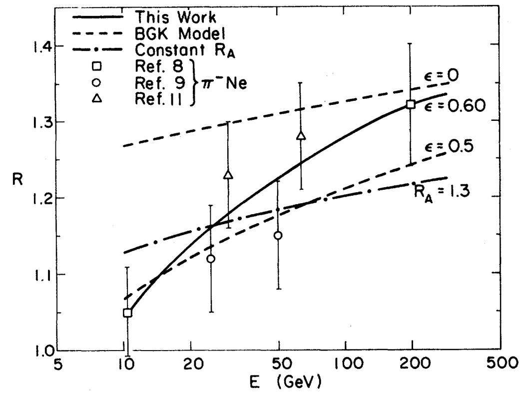

FIG. 2. Multiplicity ratio R for π^--neon bubble-chamber data. See text for explanation.

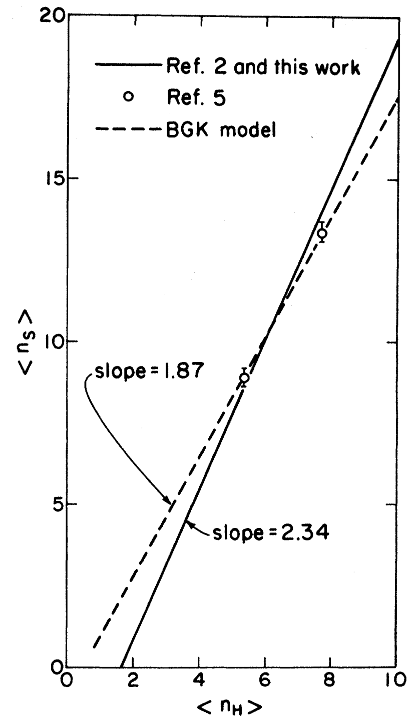

FIG. 3. $\langle n_s \rangle$ vs $\langle n_H \rangle$ for p-emulsion data. Solid line: Ref. 2 and this work; dashed line: Ref. 5 and Ref. 12.

energy range 1—400 GeV. This line, with slope 2.34, is also the prediction of our model, which takes the work of Andersson *et al.* as its starting point. The nonzero intercept makes R a function of $\langle n_H \rangle$ and thus energy dependent. Also shown in Fig. 3 are the emulsion data of Ref. 5 (where a passive emulsion target was used in a counter experiment). Taken alone, these two points are in excellent agreement with the slope of 1.87 predicted by the BGK model.

CONCLUSIONS

We have described a simple phenomenological model of hadron-nucleus multiparticle production which is in excellent agreement with important features of the emulsion and bubble-chamber data. However, our model does not agree with some results from the recent comprehensive counter experiment of Elias *et al.*

We of course expect the data to show small deviations from the predictions of this model. For example, energy conservation requires that successive intranuclear interactions would slightly deplete the extreme forward pseudorapidity region, an effect which has been noted.[14] However, this simple model is surprisingly accurate, and is a good starting point for more sophisticated and complete models of hadron-nucleus collisions.

ACKNOWLEDGMENTS

We thank J. Gunion, K. Moriyasu, and D. Rees for helpful discussions. This work was supported by the U. S. Department of Energy Contract No. DEAC0681ER40048/KA0101. R. E. G. was supported by the U. S. National Science Foundation and Eastern Washington University.

[1]R. E. Gibbs, J. J. Lord, and R. J. Wilkes, Phys. Rev. D 24, 1112 (1981).
[2]B. Andersson, I. Otterlund, and E. Stenlund, Phys. Lett. 84B, 469 (1979); I. Otterlund, Nucl. Phys. A335, 507 (1980).
[3]K. Gottfried, Phys. Rev. Lett. 32, 957 (1974).
[4]H. Harari and E. Rabinovici, Phys. Lett. 43B, 49 (1973); L. Van Hove, Phys. Lett. 43B, 65 (1973).
[5]J. E. Elias *et al.*, Phys. Rev. D 22, 13, (1980); W. Busza, in *Proceedings of the VII International Colloqium on Multiparticle Reactions, Tutzing-Munich, 1976,* edited by J. Benecke *et al.* (Max-Planck- Institut für Physik und Astrophysik, Munich, 1976), p. 545.
[6]J. R. Florian *et al.*, Phys. Rev. D 13, 558 (1976).

[7]M. Y. Lee, J. J. Lord, and R. J. Wilkes, Phys. Rev. D 19, 55 (1979).
[8]W. M. Yeager *et al.*, Phys. Rev. D 16, 1294 (1977); J. R. Elliott *et al.*, Phys. Rev. Lett. 34, 607 (1975).
[9]B. S. Yuldashev *et al.*, Acta Phys. Pol. B9, 513 (1978).
[10]T. H. Burnett *et al.*, in *Proceedings of the XI International Symposium on Multiparticle Dynamics,* Bruges, Belgium, 1980, edited by E. DeWolf and F. Verbeure (University of Antwerp, Antwerp, 1980), p. 161.
[11]Seattle-Strasbourg-Warsaw collaboration, D. Rees (private communication).
[12]S. J. Brodsky, J. F. Gunion, and J. H. Kuhn, Phys. Rev. Lett. 39, 1120 (1977).
[13]Values for $\langle n_{\rm H} \rangle$ were taken from a fit presented in J. Whitmore, Phys. Rep. 27C, 187 (1976). For the 200 GeV data from Ref. 8, we have assumed $\langle n_s \rangle = \langle n_\pi \rangle + 0.6$, as suggested by the data of Ref. 10.
[14]T. Ferbel, in *Proceedings of the First Workshop on Ultrarelativistic Nuclear Collisions,* Berkeley, California, 1979 (LBL, Berkeley, 1979), p. 1.