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LETTERS TO THE EDITOR

PARTICLE PRODUCTION IN HADRON-NUCLEUS COLLISIONS AND THE QUARK MODEL

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Particle production in hadron-nucleus and nucleus-nucleus collisions in the high energy limit is estimated assuming that hadrons are built from "elementary" constituents. The increase with A of the density of particles produced in the plateau region is a sensitive function of the "effective" number of constituents.

In this note we investigate the consequences of hadron structure on particle production in hadron-nucleus collisions at very high energies. We argue that the very fact of the existence of few constituents in the hadron can account for an increase in particle production from nuclear targets as compared to hydrogen target.

Our argument is based on two assumptions.

Assumption 1. A hadron a is made of N_a constituents.

Assumption 2. An inelastically interacting constituent of high energy produces the same number of particles, independently of the target with which the interaction takes place, provided the following condition is satisfied:

$$\frac{1}{E-\boldsymbol{k}\cdot\boldsymbol{v}} \gg L. \tag{1}$$

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Here E and $\boldsymbol{k}$ are energy and momentum of the produced particle, $\boldsymbol{v}$ is the velocity of the constituent and L is the length of the target.

The condition (1) ensures that the "formation zone" [1, 2] is greater than the length of the target and therefore it is a necessary condition for our Assumption 2 to be correct (obviously this assumption cannot be true e. g. in the fragmentation region of the target). It is however not known whether Eq. (1) is also a sufficient condition for Assumption 2. For the discussion of this and closely related problems we refer the reader to the literature on the subject [1–5]. In the present paper we do not intend to discuss the validity of Assumption 2 but rather to consider it as a condition which enables us to study exclusively the effects of the structure of the hadrons on particle production from nuclei[1].

Consider now the interaction of a hadron a with a target T. According to our Assumption 2 the number of the produced particles is proportional to the number of hadronic constituents which interacted with the target. This number, called the number of "wunded" constituents (W_{aT}), was calculated in Ref. [6]. It is given by the formula

$$W_{aT} = \frac{N_a \sigma_{cT}}{\sigma_{aT}} \tag{2}$$

where σ_{cT} is the inelastic cross section of the constituent with the target T and σ_{aT} is the inelastic cross section of the incident hadron a with the target T. Thus the ratio of the density of particles (in the region defined by Eq. (1)) produced on nuclear target with atomic number A to the density of particles produced on the hydrogen target is

$$R_A(\boldsymbol{k}) = \frac{n_A(\boldsymbol{k})}{n_H(\boldsymbol{k})} = \frac{N_a \sigma_{cA}}{\sigma_{aA}} : \frac{N_a \sigma_{cH}}{\sigma_{aH}} . \tag{3}$$

Using the formula for the average number of collisions of the hadron a in the nucleus A [6]

$$\nu_a = \frac{A \sigma_{aH}}{\sigma_{aA}} , \tag{4}$$

we can rewrite the Eq. (3) in the form

$$R_A = \nu_a \frac{\sigma_{cA}}{A \sigma_{cH}} . \tag{5}$$

This formula is our main result. Several comments can be made.

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[1] It should be stressed that our arguments can be justified only in the plateau region, thus at very high energies where the plateau is well developed. Most of the presently available data [7] are at lower energies where the very existence of plateau is questionable. At these energies one should take into account several other effects: (a) the leading particle decay, (b) the production of particles in the nuclear target fragmentation region and (c) the energy momentum conservation. All these effects are expected to modify significantly the simple predictions valid for the plateau region. In the present paper we do not intend to discuss these problems. Consequently our predictions are not directly applicable to the data of Ref. [7].

(a) The only dependence of R_A on the incident hadron is through the factor ν_a, provided the constituents of different hadrons have the same cross sections σ_{cH} with the proton. Thus Eq. (5) explains the relevance of ν_a as observed in experiment [7].

(b) The factor multiplying ν_a is determined only by σ_{cH}, the cross section of the hadronic constituent c on hydrogen. This is not exactly known but it can be reasonably estimated from the formula

$$\sigma_{cH} = \frac{\sigma_{aH}}{N_a}, \tag{6}$$

where σ_{aH} is the hadron a — proton cross section.

(c) It follows from (6) that R_A can vary from 1 ($N_a = 1$) to $\nu_a(N_a \to \infty)$.

In figure 1 we plot R_A for proton-nucleus collisions versus ν for various N_H, using Eq. (6) to determine σ_{cH}. The inelastic proton-proton cross section σ_{HH} was taken 30 mb. The constituent c–nucleus cross section is calculated from multiple scattering formula with nuclear densities as given in Ref. [6]. We also calculated R_A for pion-nucleus collision and found for the snme σ_{cH} as in calculations of proton-nucleus collisions and for $\sigma_{\pi p} = 20$ mb virtually the same curves as shown in Fig. 1.

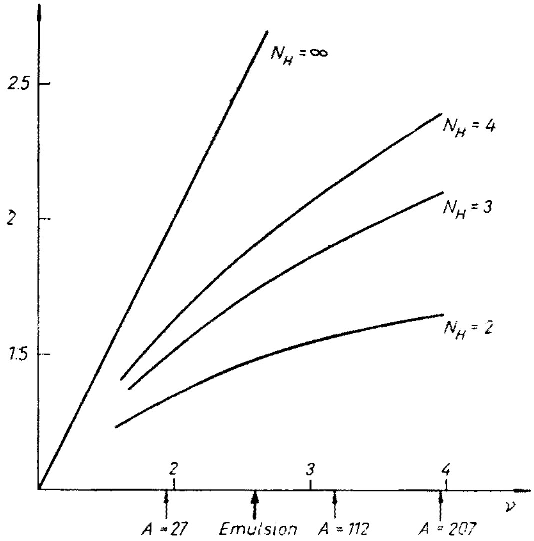

Fig. 1. Ratio R_A for proton-nucleus interactions vs ν_H for various N_H. One arrow indicates the "average" emulsion nucleus

We see from Fig. 1 that R_A depends rather sensitively on the effective number of constituents in the proton. Thus the precise measurements of R_A at high energies provide direct information about the average number of the constituents. It is of great interest to see whether this number depends on $p_\perp$ of the produced particles for $p_\perp$ below ~ 0.5 GeV[2].

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[2] As pointed out by Stodolsky [2] the large $p_\perp$ data of Ref. [8] do not satisfy the condition (1), hence are outside of our discussion.

For example the parton picture suggests an increase of R_A with increasing $p_\perp$, whereas in the simple quark model one expects to find R_A independent of $p_\perp$ in this region.

The physical meaning of the formula (5) can perhaps be better illuminated by considering the production in the restframe of the projectile. Since the number of produced particles cannot depend on the reference frame, an immediate consequence of Assumption 2 is that any composite system interacting with *one* constituent produces the same density of particles. Consequently, the density of produced particles in the collisions of the projectile A with hadron a is proportional to the ratio of the number of wounded constituents in A in the collision with target a to the number of wounded constituents in A in the collision with one constituent c. Similarly, the density of particles produced in collision of high energy proton with hadron a at rest is proportional to an analogous ratio where the incident particle is hydrogen. Thus the ratio R_A can be written as follows:

$$R_A = \frac{\nu_a W_{Ha}}{W_{Ac}} : \frac{W_{Ha}}{W_{Hc}} = \nu_a \frac{W_{Hc}}{W_{Ac}} = \nu_a \frac{N_H \sigma_{cc}}{\sigma_{Hc}} \frac{\sigma_{Ac}}{N_H A \sigma_{cc}} = \nu_a \frac{\sigma_{cA}}{A\sigma_{cH}}, \tag{7}$$

and we recover the formula (5). Note that calculation leading to Eq. (5) was simpler because the projectile in the two considered processes was identical (hadron a) and, consequently, the number of constituents in a wounded in collision with constituent c were the same and dropped out.

We may give the following physical interpretation of the above algebra: the "unit" of particle production is the number of wounded constituents in the projectile colliding with one constituent, hence it varies from projectile to projectile, and it may be visualized as a tube cut out from the projectile by one constituent going through along a straight line.

Finally, let us discuss the nucleus-nucleus collisions. Consider the inelastic interaction of high-energy nucleus A with nucleus B at rest. Using the arguments which led to Eq. (5) the ratio of densities of produced particles in this process to the density produced in collision of A with hydrogen can be written as

$$\frac{n_{AB}(k)}{n_{AH}(k)} = \frac{N_A \sigma_{cB}}{\sigma_{AB}} : \frac{N_A \sigma_{cH}}{\sigma_{AH}} = \frac{\sigma_{cB}\sigma_{AH}}{\sigma_{cH}\sigma_{AB}}. \tag{8}$$

Thus, using Eqs (3) and (5) we can calculate the ratio of the density of particles produced in collisions of A with B to that produced in pp collisions:

$$R_{AB} = \frac{n_{AB}(k)}{n_{HH}(k)} = \nu_{AB} \frac{\sigma_{cA}}{A\sigma_{cH}} \frac{\sigma_{cB}}{B\sigma_{cH}}, \tag{9}$$

where $\nu_{AB} = \dfrac{AB\sigma_{HH}}{\sigma_{AB}}$ is the number of collisions of nucleons in $A-B$ collisions [6].

Our conclusion is that the structure of hadrons has important consequences for particle production on nuclear targets. Therefore, such processes might provide us with some important information about this structure.

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REFERENCES

[1] L. D. Landau, I. Ya. Pomeranchuk, *Dokl. Akad. Nauk SSSR* **92**, 535, 735 (1953).

[2] L. Stodolsky, Proceedings of the VII International Colloquium on Multiparticle Reactions, Oxford, July 1975; A. Białas, L. Stodolsky, *Acta Phys. Pol.* **B7**, 845 (1976).

[3] V. N. Gribov, *Zh. Eksp. Teor. Fiz.* **56**, 892 (1969).

[4] V. A. Abramovskii, V. N. Gribov, O. V. Kancheli, *Yad. Fiz.* **18**, 595 (1973).

[5] J. Koplik, A. H. Mueller, *Phys. Rev.* **D12**, 3638 (1975).

[6] A. Białas, M. Błeszyński, W. Czyż, *Nucl. Phys.* **B111**, 461 (1976).

[7] W. Busza, *Acta Phys. Pol.* **B8**, 333 (1977); W. Busza et al., *Phys. Rev. Lett.* **34**, 836 (1975).

[8] J. W. Cronin et al., *Phys. Rev.* **D11**, 3105 (1975).