Multiplicity in hadron-hadron inelastic reactions and inelastic interactions with a nucleus

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A connection between the inclusive cross sections in inelastic interactions of fast hadrons with nuclei and the cross sections for interactions with hadrons is obtained within the framework of the parton model.

A fast hadron, as shown by recent investigations, can be represented as a system of interacting degrees of freedom of quantum fields with scales λ in the interval $\mu^{-1} > \lambda > p^{-1}$. Here μ is the pion mass, p is the hadron momentum, and $\hbar = c = 1$. In parton models[1,2] it is assumed that the corresponding degrees of freedom are particles with definite momentum and mass, namely partons. We do not use the concrete properties of the degrees of freedom, and characterize them only by a scale λ, retaining the terminology of the parton model. Two assumptions are used: 1) the fluctuations of the parton excitation have a cascade character—excitation from the smallest scale p^{-1} to a specified scale passes through stages of successively increasing scales; 2) hadron collisions change mainly the excitations of the largest scale.

In this case, however, the coherence of the patron system becomes violated—a "hole" appears in the patron system. As the system assumes an equilibrium state ("gathering" of the fluctuations,[2] redistribution of the excitation), particles are emitted with a spectrum

$$dn_i = f_i(k, E)\frac{dk_{\parallel}\, dk_{\perp}^2}{\epsilon_i(k)}; \tag{1}$$

The subscripts i designates the type of particle, k is the particle momentum $\epsilon(k)$ is the particle energy, and E is the energy of the incident particle in the lab system. The spectrum (1) corresponds to the decay of the "hole" into real particles. In the c.m.s. of the two colliding hadrons, the spectrum of the produced particles corresponds to the decay of two "holes."

We consider now the collision of a fast hadron with a nucleus containing A nucleons (see also[3]). The incident hadron interacts with $\nu(A) = \text{const}\cdot A^{1/3}$ nucleons of the nucleus, which are contained in a tube of diameter $\sim \mu^{-1}$ (the parton dimension) along the trajectory of the hadron. To determine the large-scale parton structure of the nucleus, we change over to a system in which the incident hadron is at rest. A system of $\nu(A)$ nucleons, owing to the Lorentz contraction by a factor $\gamma = E/m$ in the longitudinal direction, generates a system of large-scale partons via the cascade process. A characteristic feature of the cascade process is that the details of the initial state are "forgotten" after a sufficiently large number of steps. It is natural to expect therefore the large-scale parton state to be the same as would be produced by a single hadron having the energy νE of the entire tube, since a state of ν "protons" can be produced in the cascade process of excitation transfer from such a hadron. There is, of course, a difference in the baryon charge, etc., but this seems immaterial to us in this case. After collision of the large-scale partons, a "hole" is produced just as in the collision (in the rest system of one hadron) between a hadron at rest and a hadron of energy νE. For the spectrum of the produced particles we obtain in the new c.m.s. ($E \approx s/2m$)

$$f_{Ah}(k, E) = f_{hh}(k, \nu E) \tag{2}$$

and for the multiplicity $n(E)$ we get

$$n_{Ah}(E) = n_{hh}(\nu E). \tag{3}$$

The laboratory energy E is increased effectively by ν times! In simple parton models we have $n_{hh} \approx c \ln E$. In this case

$$n_{Ah} \approx n_{hh} + \frac{c}{3}\ln A\,. \tag{4}$$

We can also visualize, however, a more general case $n_{hh}(E) \sim E^{\alpha}$. Then

$$n_{Ah}(E) = \text{const}\, A^{\alpha/3}\, n_{hh}(E). \tag{5}$$

The experimental data seem to favor $\alpha = 1/3$. We note also certain consequences of the foregoing representations:

(a) Events connected with collisions of partons whose scale is $\lambda \gg \gamma\mu^{-1}A^{1/3}$ have the same correspondence properties as (2)—(3), namely, their cross sections take the form (in the new c.m.s.!)

$$\sigma_{Ah}(E) = k\sigma_{hh}(\nu E); \qquad k = \frac{\sigma_{tot\,Ah}}{\sigma_{tot\,hh}} \sim A\nu^{-1}. \tag{6}$$

(b) At an energy $E \gg \alpha\mu^2$, the large-scale partons of different nuclei located at distances α from one another become "collectivized." The same boundary separates the start of the effect for a given nucleus at $\alpha \sim \mu^{-1}A^{1/3}$.

(c) For deep-inelastic leptonic processes, a similar effect becomes manifest in the cross section and multiplicity of the scattering of collectivized partons by a virtual γ quantum.

(d) If it is assumed that the universality of the spectrum of the decay of the "hole" takes place also in the momentum region close to the momentum of the fictitious particle representing the $\nu(A)$ hadrons of the tube, then this explains in natural fashion the cumulative effect[4] of production of particles in the direction of motion of an accelerated nucleus, with energy larger than the energy of one nucleon of the nucleus.

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