LETTERS TO THE EDITOR

SEQUENTIAL DECAY MODEL IN THE NUCLEAR MATTER

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A sequential decay model developed for hadron-hadron multiparticle production has been extended to production taking place in the nuclear matter. Consequences for the hadron-nucleus production processes are discussed.

A probabilistic sequential decay model (SDM) for high energy multiparticle production has been recently developed [1, 2]. In its scheme, two colliding hadrons give origin to a "fireball" which keeps emitting clusters in a sequential way, till its final elastic decay (Fig. 1); each of the clusters in turn decays sequentially into final particles. This description

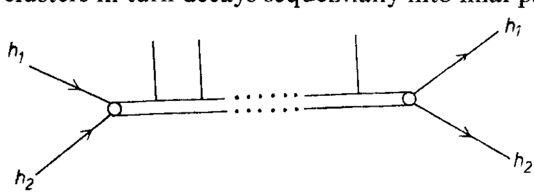

Fig. 1. Process of cluster formation in the SDM

leads to a well defined set of integral equations from which one can calculate all the physical quantities in terms of two unknown functions: the probability of emission of a cluster by the fireball, and the probability of emission of a final particle by a cluster.

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One of the most striking predictions of the SDM is that at increasing energy a finite number of clusters is produced. Under the only assumptions that the leading particle effect is still valid at very high energy, and that

$$\lim_{s\to\infty} \frac{\sigma_{el}(s)}{\sigma_{tot}(s)} \equiv \lim_{s\to\infty} P_{el}(s) = P_{el} \neq 0,$$

the asymptotic SDM prediction for the mean number $\langle N(s)\rangle$ of clusters produced in a hadronic collision with c.m. energy $\sqrt{s}$ is [2]

$$\langle N(s)\rangle \sim \frac{1-P_{el}}{P_{el}} = \lim_{s\to\infty} \frac{\sigma_{in}(s)}{\sigma_{el}(s)}. \tag{1}$$

The SDM scheme was developed for hadron-nucleon interactions in the vacuum. Now we would like to extend this scheme to the hadron-nucleon interactions inside the nuclear matter. The question we ask ourselves is to what extent the SDM scheme and its predictions, like (1), are modified by the presence of nuclear matter. As, in practice, nuclear matter means a heavy nucleus, this results in applying the SDM scheme to hadron-nucleus scattering.

Our picture will be the following. In the SDM $h-h$ scattering the decaying fireball must, at each step of its decay chain (Fig. 1), "choose" between two possibilities: the emission of a cluster (an inelastic decay) and an elastic decay, with probabilities $P_{in}(s) = \sigma_{in}(s)/\sigma_{tot}(s)$ and $P_{el}(s) = \sigma_{el}(s)/\sigma_{tot}(s)$, respectively. This, together with the already mentioned assumptions, leads to result (1). Now we simply assume that the presence of the nuclear matter results in changing the probability of ending the chain (and, as a conse-

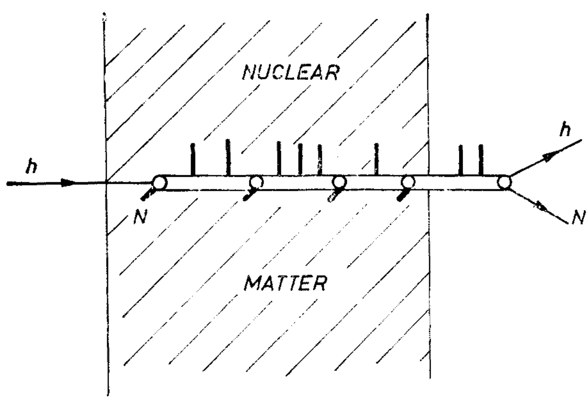

Fig. 2. Example of cluster formation in the presence of the nuclear matter

quence, of inelastic emission) due to a new possibility — the rescattering of the fireball. After rescattering the fireball starts again emitting clusters, as a newly created $h-h$ scattering fireball, and so on. In the case when the chain should finish with an elastic decay it would be the leading particle which creates a new fireball and so on. As before, the whole chain will finally end with an elastic decay outside of the nuclear matter. Fig. 2 is a schematic example of our picture. For simplicity reason we assume that the emitted clusters, or particles, do not rescatter in the nuclear matter, but behave as in the $h-h$ case. This type of assumptions is rather common in the subject-matter of h-nucleus interactions [7].

The sequential decay chain is now composed of ν subchains, ν is the number of successive scatterings (including the first) inside the nuclear matter. Let us suppose now that if s is the c.m. squared energy of the h-nucleon first collision, αs (with $\alpha < 1$) will be the squared energy taken away by the fireball after the 1-st rescattering and so on. This is in some sense equivalent to the leading particle effect in the case of $h-h$ collision. If we now consider the fireball decay in one of the sub-chains (suppose the n-th) it has all the same features of a $h-h$ fireball decay apart from the different value of the probability of ending the emission of clusters which is no more $P_{el}(\alpha^{n-1}s)$ but $P_E(\alpha^{n-1}s)$ (the sum of the elastic and the rescattering probability), and the probability of inelastic decay inside the nuclear matter which is $1-P_E(\alpha^{n-1}s)$. If we also suppose that

$$\lim_{s\to\infty} P_E(\alpha^{n-1}s) = P_E; \qquad P_{el} < P_E < 1; \qquad n = 1, 2, \ldots, \nu-1 \tag{2}$$

the same arguments that in the SDM lead to Eq. (1) now lead to:

$$\langle N_n(\alpha^{n-1}s)\rangle \sim \frac{1-P_E}{P_E}; \qquad n = 1, 2, \ldots, \nu-1. \tag{3}$$

$\langle N_n(\alpha^{n-1}s)\rangle$ is the mean number of clusters emitted by the fireball of squared energy $(\alpha^{n-1}s)$ in the n-th sub-chain, inside the nuclear matter.

The mean number of clusters emitted by the fireball after ν scatterings inside the nuclear matter is now given by

$$\langle N(s, \nu)\rangle_{hA} = \sum_{n=1}^{\nu-1} \langle N_n(\alpha^{n-1}s)\rangle + \langle N(\alpha^{\nu-1}s)\rangle$$

$$\underset{s\to\infty}{\sim} (\nu-1)\cdot\frac{1-P_E}{P_E} + \langle N\rangle, \tag{4}$$

where the last term is just the mean number of clusters produced by the fireball going out of the nuclear matter which is given by Eq. (1).

In the SDM, at least in its simplest version in which, at a given energy, only one kind of clusters of mass $M(s)$ is emitted, the actual particle multiplicity $\langle n(s)\rangle$ is linked to the average number of clusters $\langle N(s)\rangle$ and to the mean number of pions inside a cluster $\langle k(M(s))\rangle$, by the simple relation [3]

$$\langle n(s)\rangle = \langle N(s)\rangle\, \langle k(M(s))\rangle. \tag{5}$$

From (5) and (1) we observe that the high energy increase of $\langle k(M(s))\rangle$ has the same functional dependence on s as that of $\langle n(s)\rangle$. The mean number of pions produced in ν scatterings inside the nuclear matter can then be obtained from (5) and (4) as

$$\langle n(s, \nu)\rangle_{hA} = \sum_{n=1}^{\nu-1} \langle N_n(\alpha^{n-1}s)\rangle\, \langle k(M(\alpha^{n-1}s))\rangle + \langle N(\alpha^{\nu-1}s)\rangle\, \langle k(M(\alpha^{\nu-1}s))\rangle. \tag{6}$$

Denoting now by $P(\nu, A)$ the probability that there are ν scatterings inside a nucleus of atomic number A we get the following asymptotic result for a logarithmic increase of $\langle n(s)\rangle$ with s ($\bar{\nu}$ means the mean number of scatterings for this nucleus):

$$R_A(s) \equiv \sum_{\nu} P(\nu, A)\,\frac{\langle n(s,\nu)\rangle_{hA}}{\langle n(s)\rangle} \sim 1+(\bar{\nu}-1)\,\frac{1-P_{\mathrm{E}}}{\langle N\rangle P_{\mathrm{E}}}. \tag{7}$$

The same result can be obtained for any power logarithmic asymptotic increase of $\langle n(s)\rangle$. An eventual power increase, as $\langle k(M(s))\rangle \sim s^{\beta}$, would lead instead to

$$R_A(s) \sim \sum_{\nu} P(\nu, A)\left[\alpha^{(\nu-1)\beta}+\frac{1-\alpha^{(\nu-1)\beta}}{1-\alpha}\cdot\frac{1-P_{\mathrm{E}}}{\langle N\rangle P_{\mathrm{E}}}\right]. \tag{8}$$

Eq. (7) agrees well with the experimental behaviour of $R_A(s)$ [4]. It contains the mean number of clusters in $h-h$ collisions as given by (1) and the unknown parameter P_{E} defined before. (It is worth noticing that a value of $P_{\mathrm{E}} = P_{\mathrm{el}}$ would give $R_A \sim \bar{\nu}$, in disagreement with data. This means that it is necessary to take into account the possibility of the fireball rescattering, that is $P_{\mathrm{E}} > P_{\mathrm{el}}$.) A value of $\langle N\rangle = 4$ [2] and $P_{\mathrm{E}} = 1/3$ would result in

$$R_A(s) \sim \tfrac{1}{2}+\frac{\bar{\nu}}{2} \tag{9}$$

for p-nucleus scattering which is in good agreement with data [4]. In our scheme, however, we can link the value of P_{E} to physical quantities in a rather simple way. Comparing Fig. 2 and Fig. 1 it is easy to realize that asymptotically the only substantial difference is that inside the nuclear matter we have a longer chain. In the $h-h$ language it means a smaller probability P_{el}^{A} of ending the chain with an elastic decay due to the presence of the nuclear matter. This probability is given, in analogy to the $h-h$ case, by

$$\lim_{s\to\infty} \sigma_{\mathrm{el}}^{hA}(s)/\sigma_{\mathrm{tot}}^{hA}(s) \equiv P_{\mathrm{el}}^{A}, \tag{10}$$

where $\sigma_{\mathrm{el}}^{hA}$ and $\sigma_{\mathrm{tot}}^{hA}$ are, respectively, the elastic and total cross sections for h-nucleus collisions. Then asymptotically (supposing $P_{\mathrm{el}}^{A} \neq 0$)

$$\langle N(s)\rangle_{hA} \sim \frac{1-P_{\mathrm{el}}^{A}}{P_{\mathrm{el}}^{A}}. \tag{11}$$

From that and Eq. (4) we obtain

$$P_{\mathrm{el}}^{A} = \frac{1}{1+\langle N\rangle+(\bar{\nu}-1)\,\dfrac{1-P_{\mathrm{E}}}{P_{\mathrm{E}}}}, \tag{12}$$

and

$$P_{\mathrm{E}} = \frac{1}{1+\dfrac{1}{\bar{\nu}-1}\left[\dfrac{1-P_{\mathrm{el}}^{A}}{P_{\mathrm{el}}^{A}}-\langle N\rangle\right]}. \tag{13}$$

For $A = \bar{\nu} = 1$ we have then, recalling (1), the obvious result $P^1_{el} = P_{el}$. Taking as before $\langle N \rangle = 4$ and $P_E = 1/3$ one has the prediction for proton-nucleus collisions

$$\lim_{s\to\infty} \frac{\sigma^{pA}_{el}(s)}{\sigma^{pA}_{tot}(s)} = \frac{1}{2\bar{\nu}+3}. \tag{14}$$

Now we are able to obtain a simple asymptotic prediction for $R_A(s)$ with all involved quantities measurable

$$R_A \sim \lim_{s\to\infty} \frac{\sigma^{hA}_{in}(s)}{\sigma^{hA}_{el}(s)} \cdot \frac{\sigma_{el}(s)}{\sigma_{in}(s)}. \tag{15}$$

Unfortunately we could not find any high energy experimental data on $h-A$ cross sections to check the validity of Eq. (14) and (15).

Also inclusive rapidity distributions could, at least qualitatively, be explained by our picture. They should be a superposition, at high energy, of flat plateaus, each of them shorter and shorter (due to the energy conservation). This would result in a distribution peaked at low rapidities, the peak moving to the left with increasing $\bar{\nu}$ and fixed energy, as experimental data confirm [4].

To summarize, the SDM scheme can be rather straightforwardly extended, as far as its basic asymptotic predictions are concerned, to the h-nucleus collisions. The results are in agreement with present trends of data in what concerns R_A and the rapidity distributions. They are similar to those obtained in other approaches based on different hh collision schemes [5–7]. It was not intention of this paper to use all the technical machinery of SDM to fit data and obtain more detailed predictions. We think that this is possible, but we regard as more important the fact that the simplest possible extension of SDM to the h-nucleus scattering results in quite reasonable predictions when compared with present trend of data.

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