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ON THE RANGE OF APPLICABILITY OF SPACE-TIME "GATHERING" MECHANISM OF CUMULATIVE PROCESSES

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К вопросу о пределах применимости пространственно-временного "собирательного" механизма кумулятивных процессов

Обсуждаются возможности исследования области применимости пространственно-временной модели, ранее сформулированной авторами. Модель хорошо описывает эксперимент по ряду основных характеристик спектров различных по массе и другим квантовым числам кумулятивных частиц в области $P^{in} \leq 40$ ГэВ/с. Однако, вопрос о ее применимости в таком же объеме при энергиях, на порядок больших, в достаточной мере пока не изучен. Проведены расчеты-предсказания для инвариантных инклюзивных сечений кумулятивных π^--, K^--мезонов и $\bar{P}$-антипротонов на различных ядрах при $P^{in} = 400$ ГэВ/с. Сравнение с экспериментом позволит установить, возникает ли при столь высоких энергиях необходимость модификации модели, вызванной возможными проявлениями деталей структуры адронов.

Работа выполнена в Лаборатории теоретической физики ОИЯИ.

Сообщение Объединенного института ядерных исследований. Дубна 1979

Kalinkin B.N., Cherbu A.V., Shmonin V.L. **E2 - 12209**

On the Range of Applicability of Space-Time "Gathering" Mechanism of Cumulative Processes

The range of applicability of a space-time model formulated earlier by the authors is discussed. The model describes well the experimental trends in main spectrum characteristics of cumulative particles with different masses and other quantum numbers for initial momenta $P^{in} < 40$ GeV/c. However, its applicability to processes of this type at very high energies (say, $P^{in} = 400$ GeV/c) is studied insufficiently. Calculations-prescriptions are performed for invariant inclusive-production cross sections of cumulative π^--, K^--mesons and $\bar{p}$-antiprotons on different nuclei at $P^{in} = 400$ GeV/c. The comparison with experiment will allow us to establish what modifications in the model caused by a possible manifestation of hadron substructure at so large energies are needed.

The investigation has been performed at the Laboratory of Theoretical Physics, JINR.

Communication of the Joint Institute for Nuclear Research. Dubna 1979

1. INTRODUCTION

In the framework of the space-time approach to processes of the cumulative type[1,2] with two parameters only we describe a large amount of characteristics: the invariant cross section, the slope of the spectrum, the angular distribution, the energy and A-dependence of the invariant cross section*. Moreover we do not need any special information on the nucleus except for its well known density. We do not use the assumptions concerning the character of two-, three-, and so on internucleon correlations at small distances.

The approach[1,2] is based on the two assumptions:

1. We suppose that in a small number of events the hadron interaction leads to the formation of the unique compound-system. Having the finite lifetime $\bar{\tau}_0$ it increases its mass during the movement inside the nucleus as a result of the nuclear nucleon capture. In effect this "gathering" mechanism is a limiting case of the scheme proposed earlier to the description of the multiple pro-

* Note that the model[3] also with two parameters pretends to describe the cumulative spectrum slope only.

duction process in hadron-nucleus interactions[4]. Thus there arise compound-systems containing three and greater number of nucleons, and this provides the conditions for particle creation in the cumulative (inaccessible in nucleon-nucleon interaction) momentum range. In ref.[1] the compound-system is characterized by the formation cross section σ_c ($\sigma_c \ll \sigma^{in}_{NN}$) and lifetime $\bar{\tau}_0$. The study of cumulative processes allows one to determine the parameters σ_c and $\bar{\tau}_0$.

It should be noted that here we observe an important and more general channel of hadron-hadron interaction which exists not only in processes of the cumulative type.

2. It is supposed also that the inclusive spectrum $F(s,x)$ of particles generated both in hadron-hadron and in above formulated collective hadron interactions is the same when the masses of intermediate systems are equal (the "identity" hypothesis). The "identity" hypothesis transforms into the scale invariance provided that

$$F(s,x) \simeq \text{const}(s)$$

at sufficiently large energy for a given type of particles.

From the space-time point of view the realization of cumulative processes gives a good possibility for studying the two above-mentioned interesting and important signs of strong interaction dynamics.

To establish their generality and the range of applicability of the model it is important to enlarge the model prescriptions and comparison[1,2] with experiment. First, it seems interesting to apply the model

a) to the cumulative particles differing from π -mesons both in their masses and in other quantum numbers;

b) to the cumulative particle production at very high energies.

We shall briefly discuss these questions.

2. CUMULATIVE K° AND Λ° -PARTICLES

Recently detailed data have been obtained on the spectrum and angular distribution of cumulative K° -mesons[5]. An experiment has been performed in the propane-xenon chamber for the process:

$$\pi + A \to K^\circ + X \quad (P^{in}_{\pi} = 2.9 \text{ GeV/c}) \quad . \qquad (1)$$

The model[1,2] admits the estimation of cumulative K° -meson production. However in this case it is necessary to make a natural correction. In ref.[2] it is shown that the compound-system-formation cross section σ_c grows with decreasing initial momentum in the range $P^{in} \leq 6$ GeV/c. In particular at $P^{in}_p = 2.9$ GeV/c in the reaction

$$p + A \to \pi + X \qquad (2)$$

this cross section is

$$\sigma_c \simeq 0.5\, \sigma^{in}_{NN} \ . \qquad (3)$$

It is quite natural to expect that in the case of process (1) (when incident particle is π-meson) σ_c must be

$$\sigma_c \simeq 0.5\, \sigma^{in}_{NN} \ . \qquad (4)$$

As the invariant density of the inclusive spectrum for the process $\pi + p \rightarrow K^{\circ} + X$ (in accordance with the hypothesis of identity) we have used the data obtained in ref. [6].

Figure 1 represents the results of the theory and experiment [5] on the spectra of cumulative K° -mesons in different angular intervals of the backward hemisphere (σ_c is given by (4)). The comparison of the theory and experiment shows good agreement.

Now let us pass to the creation of cumulative Λ° -particles. In ref. [2] we have already made the crude estimations for the process [7],

$$\pi + A \rightarrow \Lambda^{\circ} + X . \qquad (5)$$

The data in ref. [7] have been obtained on the basis of poor statistics and absolute normalization is absent.

In recent work [5] there is larger and more exact information on cumulative Λ° -particles. The theoretical estimations were performed in analogy with the case of K° -meson production. The data on the invariant density for process $\pi + p \rightarrow \Lambda^{\circ} + X$ were taken from [6].

Figure 2 shows the comparison of the model predictions with experimental data on cumulative Λ°-particles for different angular intervals in the backward hemisphere. We see the agreement is also good in this case.

Let us emphasize once more that in Figs.1,2 the theoretical results are given in absolute normalization.

The polarization mechanism in the collective hadron interaction has been considered in ref. [8] for the Λ° -particle case. Hence

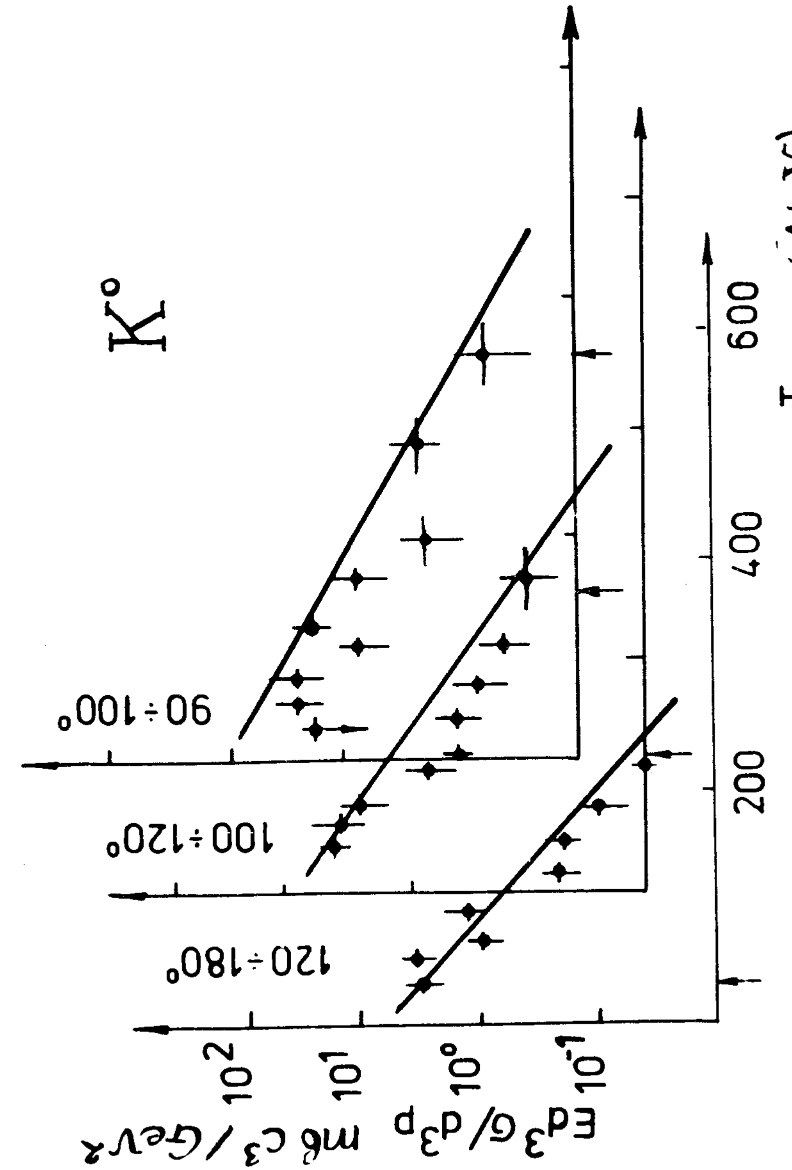

Fig. 1. The spectral-angular characteristics of cumulative K°-mesons.

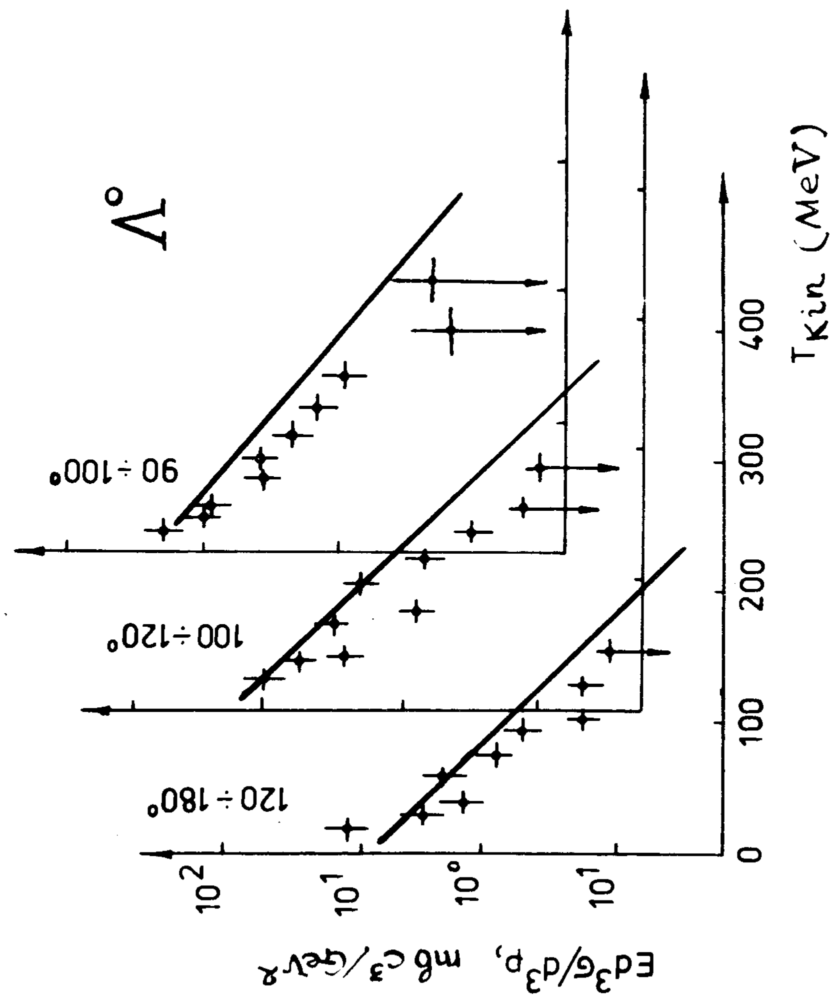

Fig. 2. The spectral-angular characteristics of cumulative Λ° -hyperons.

there are no reasons to state that the appearance of Λ° -particles is caused by the rescattering mechanism.

3. THE CUMULATIVE PARTICLE PRODUCTION AT HIGH ENERGIES

In paper /2/ the estimations of cumulative π -meson yield for $P^{in} > 10$ GeV/c have been made, in particular for the process /9/

$$p + Ta \to \pi\ (\theta = 180^{\circ}) + X\ (P_p^{in} = 28.5\,\mathrm{GeV/c}). \qquad (6)$$

The analogous estimation may be obtained for the process:

$$\pi + C \to \pi\ (\theta > 90^{\circ}) + X;\ (P_{\pi}^{in} = 40\,\mathrm{GeV/c}). \qquad (7)$$

From these estimations one can conclude that

$$\sigma_c\ (P^{in} > 10\,\mathrm{GeV/c}) \simeq \mathrm{const}\,(P^{in}) \simeq 0.25\,\sigma^{in}\ , \qquad (8a)$$

and the lifetime of the compound-system with respect to the cumulative process at these values of the initial momenta as before (at $P^{in} < 10$ GeV/c) is determined by the law:

$$\bar{\tau}_0 = \tau_0 \,/\, \sqrt{S_n}\ ; \qquad \tau_0 = 5\,\mathrm{GeV \cdot c \cdot sec}\ . \qquad (8b)$$

(Hereafter the quantities and notation introduced in refs. /1,2/ are used).

Besides, under the assumption that our mechanism contributes to the reaction with large $p_{\perp}$ -particle production calculation has been made for the process:

$$p + A \to \pi\ (p_{\perp}\ \mathrm{large}) + X \qquad (P_p^{in} = 300\,\mathrm{GeV/c}). \qquad (9)$$

In this case the better correspondence with experiment takes place when:

$$\sigma_c = 0.25\ \sigma^{in}_{pp}\ , \qquad (10)$$
$$\bar{\tau}_0 = 15\ \text{GeV}\cdot c\cdot \text{sec}\ .$$

For details of these calculations see ref. /2/. There also an argument is given that at high energies the parameter set (10) has some advantage over the parameter set (8a,b).

However on the whole, these estimations are not sufficient and convincing.

First, in (6) and (7) the initial energies are not very different from that ($E^{in} \le$ $\le$ 10 GeV) interval in which the most of present experiments have been performed.

Second, the estimations of the inclusive cross section of π-meson production with large $p_\perp$ at $P^{in} = 300$ GeV (see ref. /2/) are performed for the process occurring under the conditions which, strictly speaking, are not equivalent to those for the pure cumulative process: the observed $p_\perp$ values are not kinematically forbidden also in NN-interactions. Therefore the parameter set ($\sigma_c, \bar{\tau}_0$) obtained in this case cannot be considered to be reliable.

Third, it is desirable to obtain the results not only for π-mesons, but also for other heavier particles, i.e., to give prescriptions for the qualitative composition of cumulative particles and its dependence on energy up to very high values ($E^{in} \approx 400$ GeV).

All these questions are interesting because at present such an experiment is carried out. The comparison with experimental data will permit us to prove the model predictions and possibly to refine it.

From the methodical point of view it is useful to determine approximately the energy dependence of cumulative light- and heavy-particle-production cross section. Perhaps it is better to study the behaviour of the quantities:

$$R^{(n)}_A\ (\theta = 180^\circ,\ \ T = \text{const};\ P^{in}) = F(x_n)\ W^{(n)}_A\ , \qquad (11)$$

which are the partial inclusive cross sections of particle production on nucleus A, with kinetic energy T, in n-th order of cumulation at $\theta = 180^\circ$.

For simplicity we suppose that the total cross section of the compound system formation in n-th order of cumulation in the nucleus with mass number A does not depend on the initial momentum

$$W^{(n)}_A \simeq \text{const}\,(P^{in})\ , \qquad (12)$$

that is, for $W^{(n)}_A$ we can use the results obtained in paper /1,2/. Let us choose the following conditions:

$$\left.\begin{array}{l} A = 208\ (\text{Pb-nucleus}),\ T = 0.2\ \text{GeV} \\ \text{The cumulative particles are } \pi\text{-mesons and antiprotons} \end{array}\right\} \qquad (13)$$

and the F(x) will be functions given in ref. /10/ (we suppose that in this case scale invariance takes place). It is natural that in the kinematics of the antiproton production we take into account the simultaneous creation of the proton, which enters into the compound-system.

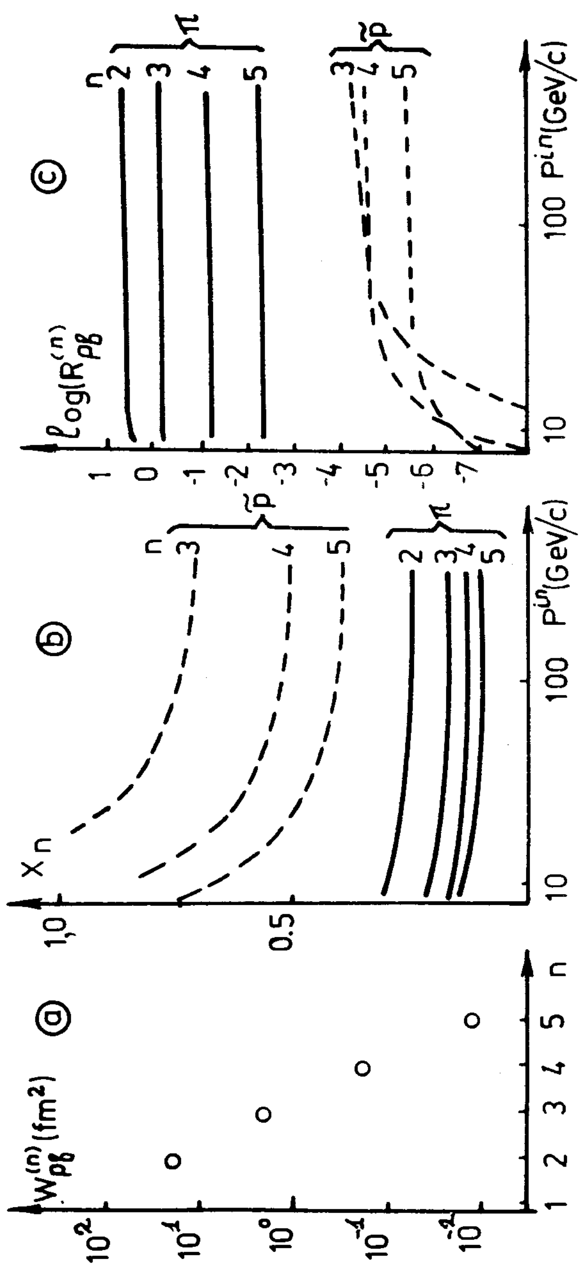

Fig. 3. The energy behaviour of the qualitative composition of cumulative particles ($\theta = 180°$, T = 0.2 GeV, A = 208).

In Fig. 3a and 3b the values of $W_{Pb}^{(n)}$ and $x_n^{(\pi,p)}(P^{in})$ are given. Figure 3c shows the behaviour of $R_{Pb}^{(n)}$ ($\theta = 180°$, T = 0.2 GeV, P^{in}) obtained from the data in Figs. 3a,b and $F^{(\pi,\tilde{p})}(x)$ which falls very rapidly with increasing x (ref./10/).

We see that in contrast to the case of π-mesons for which the function $R^{(n)}$ has the asymptotical behaviour even at momenta $P^{in} \gtrsim$ 5-8 GeV/c, such a regime takes place for the antiproton production only at $P^{in} \gtrsim$ 70 GeV/c.

Besides for $[R]_{\tilde{p}} = \sum_n [R^{(n)}]_{\tilde{p}}$ we have

$$[R(P^{in} = 70\,GeV/c)]_{\tilde{p}} / [R(P^{in} = 8\,GeV/c)]_{\tilde{p}} \approx 10^3 .$$

The small R for antiproton production at initial momenta equal to several GeV/c is caused (see Fig. 3) both by large x_n and by small cross sections $W^{(n)}$ contributing effectively at these values of P^{in}.

Hence, the search for the cumulative particles which are components of the heavy pair must be done at high energies.

Now we represent the results of more careful calculations (without assumptions of type (12)) for the cumulative process:

$$p + A \to \pi^-, K^-, \tilde{p}\ (\theta = 160°) + X ,$$

$$P_p^{in} = 400\,GeV/c \qquad (14)$$

in two variants:

Figure 4 is for the parameter set (8a,b) and Fig. 5, for the parameter set (10).

As it was pointed out in paper/2/ at E^{in} = 400 GeV the set (10) seems to be preferable.

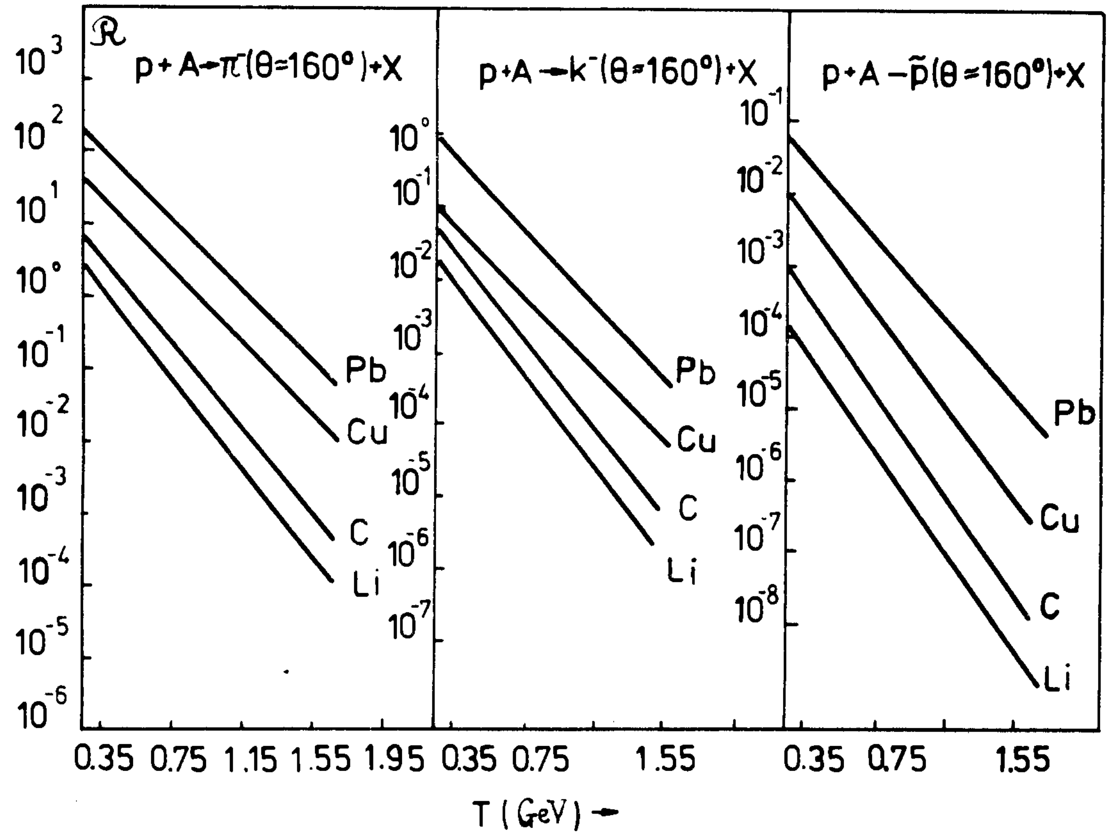

Fig. 4. The qualitative composition of cumulative particles with respect to A at $P^{in} = 400$ GeV/c. The parameter set (10).

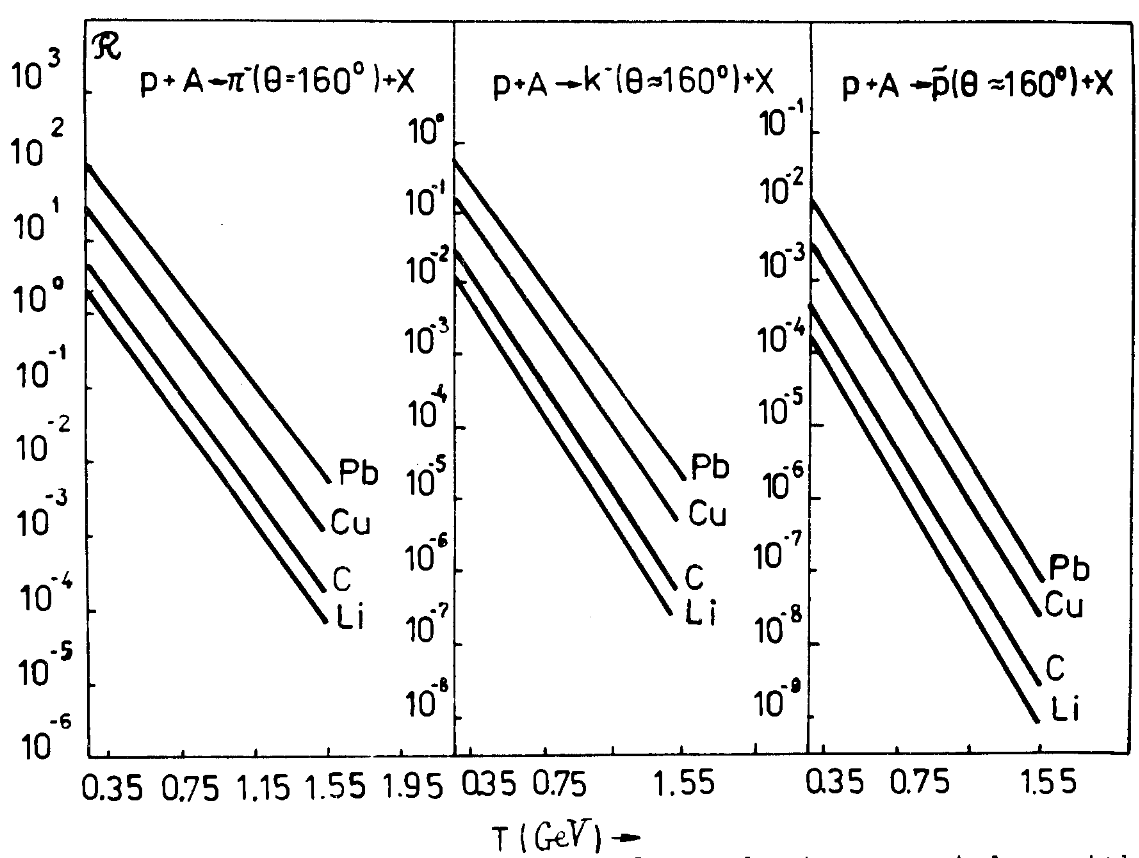

Fig. 5. The qualitative composition of cumulative particles with respect to A at $P^{in} = 400$ GeV/c. The parameter set (8a,b).

Let us argue this choice in more detail. The effective lifetime of the compound-system with respect to cumulative process should not be smaller than the time of its rearrangement before particle emission which in turn should not be smaller than some minimal value. The latter got multiplied by "c" (light velocity) must be of an order of the hadron size. The evaluation made in ref. [2] yields

$$\langle r \rangle \simeq 0.6 \text{ fm} \simeq \text{ the hadron size} \qquad (15)$$

for $\bar{\tau}_0$ obtained from (10) at $P^{in} = 400$ GeV/c. In addition let us make one more remark. The condition (15) implies that the system before its decay approaches the state in which the energy is distributed over the hadron volume and whose decay may be described thermodynamically

The same evaluation for the parameter set (8a,b) will produce for $\langle r \rangle$ the value three times smaller as compared to (15). Hence in this case we would deal with the situation appropriate to gluon and quark hard scattering. (Then perhaps we should reformulate our model in its kinematics and in definition of cross sections since in this case we should describe not the collision of hadron as unique objects but of their constituents).

However, it is known that in the picture of hard scattering the interpretation of the inclusive cross section of large $p_\perp$ -particle production ($p_\perp \leq 6$-7 GeV/c) is not yet guaranteed at $P^{in} = 400$ GeV/c

The above-mentioned arguments show that in this very preliminary study of the problem the parameter set (10) seems to be preferable for process (14) at $P^{in} = 400$ GeV/c.

It stands to reason the decisive factor is the future experiment.

To complete this discussion note that we have obtained also the spectra of π^-- , K^--mesons and $\bar{p}$ antiprotons in process (14) in both variants and at other angles in the backward hemisphere (up to $\theta = 90°$). Here we do not cite these results because it will increase considerably the volume of the paper.

4. CONCLUSION

Let us formulate the main results.

1. It is shown that for $P^{in} \leq 40$ GeV/c (here most experiments have been carried out) the space-time approach [1,2] describes satisfactorily the general regularities of the cumulative process accompanied by the particle production with different masses and other quantum numbers. (In addition to π^-- , π^+- , K^+ -mesons here K° -mesons and Λ° -hyperons have also been studied).

Hence, in this range the picture [1,2] appears to be universal.

2. The questions concerning very high energies are considered. The estimations-predictions are made on the behaviour of the qualitative composition with increasing energy. The comparison of these results with experimental data will provide a useful information on the space-time characteristics of the process occurring under these conditions, the information on the hadron-interaction channel proceeding through the compound system formation. A special interest represents the question concerning the magnitude of the cross section $\sigma_c(E^{in} = 400$ GeV).

This comparison will also reveal the range of applicability of our model in its present phenomenological form.

It may turn out that the comparison will raise new interesting problems, since, in principle, at such high energies there can arise the necessity in model modifications caused by hadron structure details.

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