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ON THE EXISTENCE OF THE FIRST INTERMEDIATE ASYMPTOTICS IN RELATIVISTIC NUCLEAR COLLISIONS

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The multiple production of protons in relativistic nuclear collisions in the region of the limiting fragmentation of the carbon nucleus is studied. An approach in which the cross section is considered as a function of the positive relativistic invariant quantities $b_{ik} = -(u_i - u_k)^2$, where $u_i = P_i/m_i$ are particle four-velocities, is used. It is shown that in the range $0.01 < b_{ik} < 1$ a universal behaviour of the cross sections and the clasterization of the b_{ik} distributions, similar to the production of jets in the domain $b_{ik} >> 1$, are observed. This fact enables us to suggest the notion of a first intermediate asymptotics. The asymptotic behaviour of the cross section at large b_{ik} which was established earlier can naturally be called the second asymptotics. The measurement of the characteristics possessing automodelity properties in the region of the first asymptotics makes it possible to study the general properties of a strongly excited nucleon matter and the same meaurement in the region of the second asymptotics enables us to study quark-gluon plasma.

The investigation has been performed at the Laboratory of High Energies, JINR.

О существовании первой промежуточной асимптотики в релятивистских ядерных столкновениях

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Изучается множественное образование протонов в релятивистских ядерных столкновениях в области предельной фрагментации ядра углерода. Используется подход, в котором сечение рассматривается как функция положительных релятивистски-инвариантных величин $b_{ik} = -(u_i - u_k)^2$, где $u_i = P_i/m_i$ – четырехмерные скорости частиц. Показано, что в области $0,01 < b_{ik} < 1$ наблюдается универсальное поведение сечений и кластеризация распределений по b_{ik}, аналогичная образованию струй в области $b_{ik} >> 1$, что позволяет ввести понятие первой промежуточной асимптотики. Установленное ранее асимптотическое поведение сечений при больших b_{ik} естественно назвать второй асимптотикой. Измерение

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характеристик, обладающих автомодельными свойствами, в области первой асимптотики позволяет изучать общие свойства сильновозбужденной нуклонной материи, а в области второй асимптотики — изучать кварк-глюонную плазму.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

The present paper is devoted to the study of the proton production in relativistic nuclear collisions. Instead of the ordinary inclusive approach [1,2], a new approach [3] is used in which all the available experimental information is employed. According to this approach, in relativistic nuclear collisions

$$I + II \to 1 + 2 + 3 + \ldots \qquad (1)$$

the colliding particles I and II (one of them or both can be nuclei) and the produced ones 1,2,3,... are considered in the space of the four-velocities $u_i = P_i/m_i$ $(i = I, II, 1, 2, 3, \ldots)$. The probability distributions W (cross sections) are assumed to depend one the positive relativistic invariant quantities

$$b_{ik} = -(u_i - u_k)^2 = 2(u_i u_k) - 1, \qquad (2)$$

having the sense of the relative distances in the four-velocity space. Unlike the commonly used noninvariant variables (longitudinal rapidities, transveral momenta, "sphericity" and so on), the quantities (2) make it possible to formulate a series of laws of a general nature. As is shown in [3,7], at $b_{ik} \gg 1$ asymptotic regimes set in, which are characterized by a descrease of the probability distribution $W(b_{I\,II}, b_{Ii}, b_{IIk}, \ldots)$ with increasing b_{ik} and by a factorization. This law is analogous to the correlation depletion principle in statistical mechanics. The correlation depletion principle enabled us to give a new relativistic invariant definition of the jets as universal objects in multiple production processes and to formulate the universal properties of the asymptotic regimes describing, in particular, the cumulative effect. The asymptotic regimes and the validity of the correlation depletion principle for the distributions W (cross sections) follow from the existence of the characteristic correlation length, $b_2 \sim 1$, in the relative velocity space. The asymptotic regimes set in at $b_{ik} > b_2$, and by analogy with the mechanics of continuous media they may be considered as a manifestation of the automodelity of the W distributions. The automodelity of the solutions of the mechanics of continuous media [4] means a descrease of the number of the arguments of the function in question at the expense of the importance of only selected combinations of independent variables.

The concept of the automodelity was first applied to multiple production processes by Matveev, Muradyan and Tavkhelidze [5]. They proceeded from the dimensionality theory and the requirement of approximate invariance in scaling transformations

$$P_i \to \lambda P_i \ .$$

In the relative velocity space one deals with the dimensionless quantities b_{ik} and proceeds not from the dimensionality considerations but from the condition of the existence of an asymptotic limit of the functions W when some b_{ik}'s tend to infinity. By infinity we should imply a "physical infinity", i.e., a quantity which makes it possible to expand the function W in a power series of $1/b_{ik}$.

Thereby the expansion coefficients turn out to possess automodelity properties with respect to this variable.

The formulation of automodelity in this sense and the application of the correlation depletion principle enables one to propose a general parametrization of the multiple particle production cross sections (see [6], (eq.) (8)). The scaling invariance of the cross sections follows from this parametrization as a particular case. Scale invariance is valid only for the dependences of the cross sections of reaction (1) for which of importance are not the very quantities (2), but only their relationships. The quantities b_{ik} appear to be scale noninvariant. Scale noninvariant are, e.g., the universal jet parameters. At the same time the jet properties are a direct consequence of automodelity.

As was noted [3,6], in addition to the correlation length $b_2 \sim 1$ characterizing the scale of quark phenomena, a correlation length $b_1 \sim 0.01$ should exist which characterizes the scale of nucleonic (nuclear) phenomena. The automodelity character of the asymptotics of the W distributions for $b_{ik}/b_1 \gg 1$ follows from the pole approximation [3] and the smallness of the binding energy per nucleon in the nucleus:

$$W \Big|_{\frac{b_{\alpha II}}{0.01} \gg 1} \to \frac{1}{(b_{\alpha II})^2} W_1 \, ,$$

where W_1 is practically independent of $b_{\alpha II}$ (automodelity with respect to this variable). It should be noted, however, that the pole approximation still needs a detailed experimental check. The validity of this approximation for $b_{ik} \gg 0.01$ should also be studied.

Thus, an experimental check of the existence of universal asymptotics in the intermediate domain of nuclear collisions, $0.01 < b_{ik} < 1.00$, is urgent. It is important to note that the measurement of the automodelity characteristics in this domain means the study of the general properties of a strongly excited nuclear matter. As was often stressed, the first intermediate asymptotics $b_{ik} \gg b_1$ is due to quite other laws than the second one $b_{ik} \gg b_2$. The first asymptotics corresponds to quasi-free nucleons whereas the second one to quasi-free quarks. In order to verify these ideas, the vicinity of the point u_{II} was investigated in the four-velocity space, i.e., all the protons within the range

$$0.03 < b_{IIk} = (u_{II} - u_k)^2 < 0.63. \tag{3}$$

The ^{12}C nucleus was taken as particle II in all the investigated reactions. As particle I we used: a) 4 GeV/c negative pions ($b_{I\,II} = 55.2$), b) neutrons, having almost Gaussian momentum distribution with an average value of 7.04 GeV/c ($b_{I\,II} = 13.1$) and a standard deviation of 2.84 GeV/c, c) 10 GeV/c protons ($b_{I\,II} = 19.4$), and d) 50.4 GeV/c ^{12}C nuclei ($b_{I\,II} = 1.2$).

The data were obtained with the aid of a 55 cm (a,b) and a 2 m (c,d) propane bubble chambers of the Laboratory of High Energies.

In all the considered cases the distance between the points u_I and u_{II} is larger than the correlation lengths b_1 and b_2, and, according to the correlation depletion principle, the function W in the vicinity of the point u_{II} (inequality (4)) must not depend on the properties of particle I and $b_{I\,II}$. Figure 2 shows the validity of this statement.

Region (3) is divided into two parts:

$$0.03 < b_{IIk} < 0.1, \tag{4}$$

where of greate importance is closeness of the point u_{II} (the nucleus), and

$$0.1 < b_{IIk} < 0.63, \tag{5}$$

where of importance is the clusterization of protons of the type of the jets. It would be very interesting to discover such a clusterization. In just the same manner as in the study of the jets /7/ we define the four-vector:

$$V_a = \frac{\Sigma u_i}{\sqrt{(\Sigma u_i)^2}}.$$

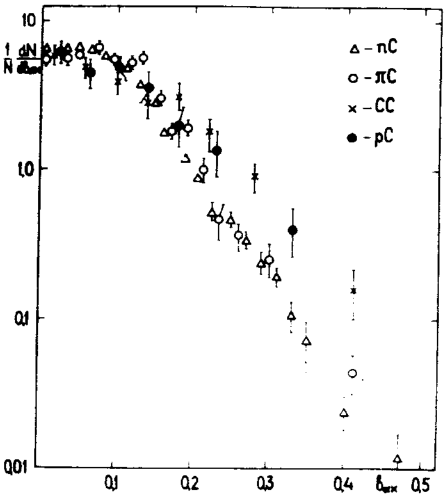

Fig.1. b_{1k} *distribution of the protons from the region (5).*

The summation is performed over the protons either from the region (4) or the region (5).

The $b_{\alpha k} = -(V_\alpha - u_k)^2$ distribution of the protons from the region (5) is shown in Fig.1, and from the region (4) in Fig.2. The average value $\langle b_{\alpha k} \rangle$ for the protons from the region (5) is much larger than the average value $\langle b^c_{\alpha k} \rangle$ for the protons from the region (4). This shows that the mechanisms of the proton production in the regions (4) and (5) are quite different. The $b_{\alpha II} = -(V_\alpha - u_{II})^2$ distributions are shown in Fig.3 and 4, where u_{II} is the four-velocity of the target nucleus for the regions (5) and (4), respectively. The distance from the centre of the cluster V_α to the point u_{II} (nucleus) is characterized by the variable $b_{\alpha II}$. To these distributions there correspond the average values $\langle b_{\alpha II} \rangle$ and $\langle b^c_{\alpha II} \rangle$ shown in the Table. The average distances $\langle b_{\alpha k} \rangle$ and $\langle b^c_{\alpha k} \rangle$ between the protons and the cluster centre in the velocity space are shown for comparison in the same table.

The fact that the $\langle b_{\alpha k} \rangle$ and $\langle b_{\alpha II} \rangle$ values are close to each other shows that the proton clusters (nuclear fireballes) are not so strongly pronounced as the jets. In this connection it is interesting to consider other values which are able to characterize the particle clusterization. The average distances $b_{\alpha k} = -(V_\alpha - u_k)^2$ are shown in Fig. 5,6,7 to be a function

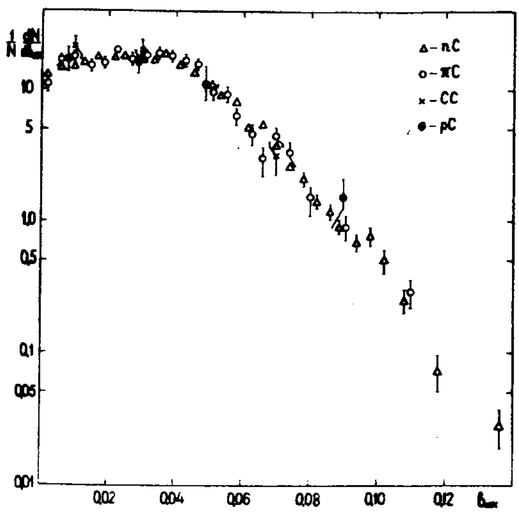

Fig.2. $b_{\alpha k}$ *distribution of the protons from the region (4).*

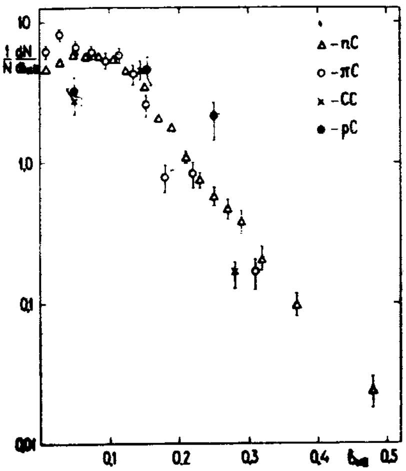

Fig.3. $b_{\alpha II}$ *distribution for protons from the region (5).*

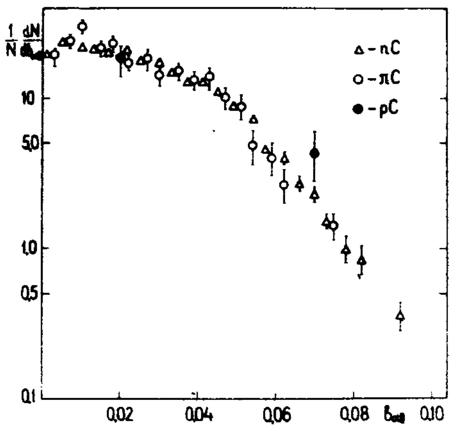

Fig.4. $b_{\alpha II}$ *distribution for protons from the region (4).*

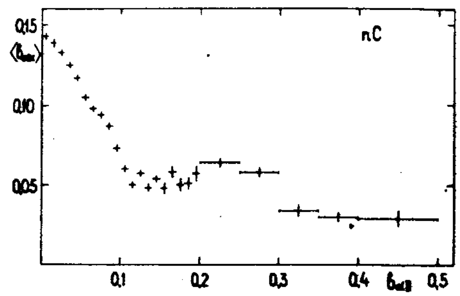

Fig.5. $\langle b_{\alpha k}\rangle$ *dependence on* $b_{\alpha II}$ *for protons from the* nC *collisions.*

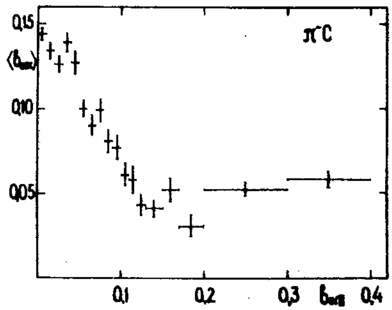

Fig.6. $\langle b_{\alpha k}\rangle$ *dependence on* $b_{\alpha II}$ *for protons from the* π^{-}C *collisions.*

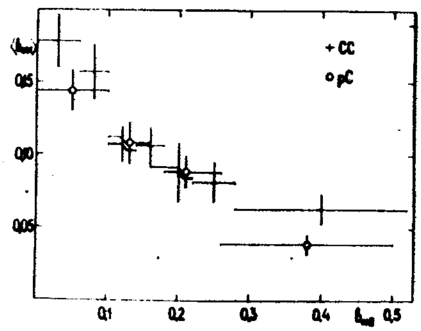

Fig.7. $\langle b_{\alpha k}\rangle$ *dependence on* $b_{\alpha II}$ *for protons from the* CC *and* pC *collisions.*

Table

Average values $b_{\alpha k}$ *and* $b_{\alpha II}$ *for the protons from the regions (4) and (5)*

Type of collision	P_{lab} GeV/c	Statistics	$0.1 > b_{IIk} > 0.03$		$0.63 > b_{IIk} > 0.1$	
			$<b^c_{\alpha k}>$	$<b^c_{\alpha II}>$	$<b_{\alpha k}>$	$<b_{\alpha k}>$
nC	7	11940	0.033 ± 0.001	0.026 ± 0.001	0.087 ± 0.001	0.101 ± 0.001
π^-C	4	1870	0.032 ± 0.001	0.025 ± 0.001	0.094 ± 0.002	0.082 ± 0.003
CC	4.2	114	0.027 ± 0.003	0.037 ± 0.004	0.116 ± 0.006	0.151 ± 0.009
pC	10	103	0.031 ± 0.003	0.031 ± 0.004	0.107 ± 0.007	0.135 ± 0.010

of $b_{\alpha II} = -(V_\alpha - u_{II})^2$ for the protons from the region (5). The average $b_{\alpha k}$ value is seen to decrease with increasing $b_{\alpha II}$ and $<b_{\alpha k}> \approx$ ≈ 0.05 at $b_{\alpha II} > 0.15$ which is close to the value of $<b^c_{\alpha k}>$ for slow protons. It is important to note that the distance between the points V_α and u_{II} is much larger than the average distances inside each of the clusters. So, we have got the main result of this work: the intermediate asymptotics of relativistic nuclear collisions in the region $0.01 < b_{Ik} < 1.00$ does exist and the clusterization is observed.

Further investigations are required. A direct proof of the correlation depletion principle in the region of the first intermediate asymptotics, a detailed study of the universal properties of the cross sections and the verification of the universality of the correlation length in this region are of particular importance.

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