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INVESTIGATION OF EXCITED NUCLEAR MATTER IN RELATIVISTIC NUCLEUS – NUCLEUS COLLISIONS

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1. INTRODUCTION

The search for possible phase transitions in nuclei and properties of excited nuclear matter are the main subject of investigations in nowadays relativistic nuclear physics. Traditional estimates of temperature and density in different experiments at the energy of incident temperature nuclei $P = 0.8 \div 4 \cdot A$ GeV/c [1] have shown that these quantities grow whith increasing of collision energy. The identical analysis of data on nucleus-nucleus collisions was performed in the experiment using the 2 m propane bubble chamber irradiated in the carbon nucleus beam at $4.2 \cdot A$ GeV/c. The obtained results show that in CC collisions the temperature may reach $130 \div 150$ MeV and the density of nuclear matter can be more than the normal density [2]. The analysis of these values using theoretically calculated phase diagrams pointed out that one can reach such a stage of excited nuclear matter which is transitional between hadron matter and quark-gluon plasma (fig. 1).

The study of main regularities of multiple particle production and properties of nuclear matter in the transitional region is the subject of the paper.

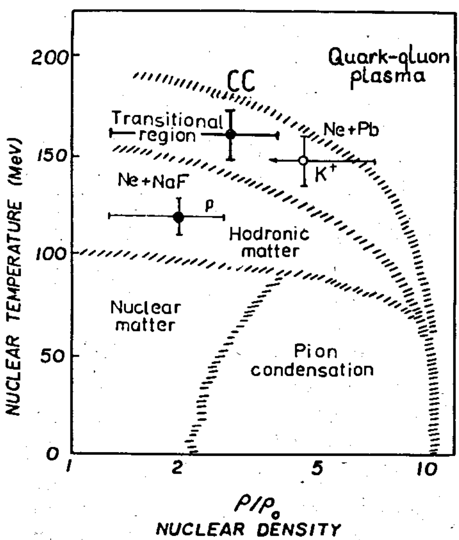

Fig. 1

To describe multiple particle processes we used dimensionless relativistic invariant quantities $b_{ik} = -\left(\frac{P_i}{m_i} - \frac{P_k}{m_k}\right)^2 = -(u_i - u_k)^2$ which are the difference of 4-velocities of two various particles i and k [3]. The applicability of these variables is caused by the following. In nuclear collisions in each individual case it is experimentally impossible to determine the number of interacting nucleons on the incident and target nucleus. That is

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why by analysing Lorentz-noninvariant characteristics of secondary particles in the nucleus-nucleus c.m.s. some kinematical effects can occur which are due to the fact that in each case the c.m.s. does not coincide with the nucleus-nucleus c.m.s.

The use of b_{ik} for the analysis of hadron jet properties production, which is connected with the quark structure of hadrons and nuclei, allows one to simplify the analysis of experimental information and to obtain a set of new interesting regularities.

In relativistic invariant approach the jet is considered as hadron cluster in the 4-velocity space (i.e. a group of particles with small b_{ik}). The centre of cluster V_α (or jet axis) is determined as follows [4]

$$V_\alpha = \sum_i u_i \Big/ \sqrt{\left(\sum_i u_i\right)^2} \; ,$$

V_α is a single 4-vector. The distribution of jet particles on $b_k = -(V_\alpha - u_k^\alpha)^2$ - squared 4-velocity relative to the centre V_α is studied. The performed analysis of hadron jet properties in soft $\pi^- p$, $\pi^- C$, pp, $\bar{p}p$ and hard $\tilde{\nu}N$ collisions shows that properties of 4-dimension invariant jets are similar in soft and hard particle collisions at similar energies in the c.m.s. and do not depend on the type of interaction and its energy within $\sqrt{S} = 6 \div 20$ GeV [5-7]. Hadron jet properties have been studied using relativistic invariant approach in the events with e^+e^--annihilation simulated by the LUND model within the energy interval $W = 6 \div 100$ GeV. In this case it was shown that the average quantity of b_k in one jet remained approxiately constant in the considered energy interval [8]. Thus, hadron jet properties are characterized by asymptotic behaviour.

Generalizing main regularities of particle production connected with quark structure of hadrons and nuclei, such as scale invariance, limiting fragmentation, universality of hadron jet properties, etc., the correlation depletion and automodelity principles have been formulated using lorentz-invariant and dimensionless variables b_{ik} [9]. The principle of automodelity was effectively applied to solve equations in mechanics of continuous media, in theories of heat and shock waves extention and in a set of problems described by nonlinear equations of some variables [10]. Adopting the automodelity solution in mechanics of continuous media the automodelity principle was formulated for multiple particle production. Then correlation depletion and automodelity principles can be written as follows [9]

$$W(b_{\alpha k}, b_{\beta k}, b_{\alpha\beta}, \ldots)\Big|_{b_{\alpha\beta}\to\infty} \to \frac{1}{b_{\alpha\beta}^m} W^\alpha\left(b_{\alpha k}, x_k = \frac{b_{\beta k}}{b_{\alpha\beta}}\right) \cdot W^\beta\left(b_{\beta i}, x_i = \frac{b_{\alpha i}}{b_{\alpha\beta}}\right) \cdot \qquad (1)$$

Here W is invariant cross section or probability distribution, describing multiple particle production in the relative 4-velocity space; α and β are two hadron jets or some other noncorrelated (or weakly correlated) secondary particle systems which are considered as clusters in this space; $b_{\alpha k}$, $b_{\beta k}$, etc., squared relative 4-velocities which can be understood from fig. 2.

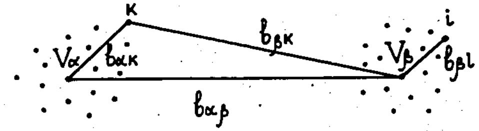

Fig. 2

For the jet production expression (1) means that their properties starting with some values of $b_{\alpha\beta}$ can be described approximately by independent functions, characterized by asymptotic behaviour on two similarity parameters $b_{\alpha k}$ and x_k. The considered functions do not depend on quantities of $b_{\alpha\beta}$, i.e. they obtain automodelity on this variable. Such asymptotic behaviour is called intermediate asymptotics.

Thus, it has been shown that asymptotic properties of hadron jets are a consequence of more general regularities of multiple particle production, namely, the correlation depletion and automodelity principles.

One can expect that a number of intermediate asymptotics, corresponding to different stages of excited nuclear matter, will be observed in nuclear collisions. For example, spectator nucleons, produced under the decay of the excited nucleus, exhibit asymptotic properties already at the energies of the projectile $E \geq 1$ GeV.

In this connection in papers [9,11] it has been suggested that baryon jets (i.e. clusters in the 4-velocity space) with asymptotic properties within some energy intervals as well as those of hadron jets can be produced in the transition region in relativistic nuclear collisions.

That is why we apply for the study of baryon clusters production and their properties in p, d, He, C and π^- collisions with carbon nuclei within an energy interval $P = 4 \cdot A \div 40$ GeV/c.

2. EXPERIMENT AND METHOD OF ANALYSIS

The experimental data on these collisions are obtained with the aid of the 2-m propane bubble chamber irradiated in beams of p, d, He and C particles at the Synchrophasotron (Laboratory of High Energies) and in π^--meson beams at IHEP. The method of experiment and processing of scanning information are given in papers [12,13]. Here we should mention some peculiarities of identification of positive secondary particles. The lower boundary, starting with which one detects protons in the propane chamber, is $P_{lab} = 150$ MeV/c.

By path and ionization protons differ from π^+ mesons up to $P_{lab} \simeq 900$ MeV/c. Positive one-charged particles were considered to be protons in p, d, He and CC collisions and π^+ mesons in π^-C collisions. Admixture of π^+ mesons among positive particles in p, d, He and CC events does not exceed 12%. Deuteron (d) and triton (t) admixture among slow protons according to different estimates is about $10 \div 15\%$. Fast positive charged particles with $Q \geq +2$ differ from one-charged by ionization. The total statistics of events is ~ 41000.

The analysis of inclusive proton distributions in CC collisions [14] and the study of collective properties by sphericity and trust [15] have shown that production of two proton clusters is expected. Their formation is connected with beam and target fragmentation regions. In the events with proton multiplicity $n_p \geq 4$ proton clusters were separated out by minimizing the quantity

$$A_2 = \min\left[-\sum_k (V_\alpha - u_k^\alpha)^2 - \sum_i (V_\beta - u_i^\beta)^2\right], \tag{2}$$

where V_α and V_β are centres of clusters α and β. Spectator ($P_{lab} \leq 250$ MeV/c) and stripping ($P_{lab} \geq 3.0$ GeV/c and $\theta < 4°$) protons were excluded from analysis. All possible combinations of n_p protons were considered to separate out the two groups. It was assumed that there were produced two clusters or a cluster and one positive charged particle, if the "distance" between separated out proton groups $b_{\alpha\beta}$ satisfies the condition

$$b_{\alpha\beta} = -(V_\alpha - V_\beta)^2 \geq 1. \tag{3}$$

If clusters do not satisfy this condition, the event is considered to be undivided. The part of undivided events does not exceed 15%. The average value of b_k for clusters in CC collisions is $\bar{b}_k = 0.32$, and $\bar{b}_{\alpha\beta} = 2.3$, i.e. the average "size" of the cluster ($\bar{b}_k$) in the relative 4-velocity space is substantially smaller, than "distances" ($b_{\alpha\beta}$) between them.

Clusters produced in target fragmentation have been studied only because the identification of positive particles was more hopeful. The method of selection of such clusters is described

in detail in papers [16,17]. Minimum proton multiplicity in clusters is $n_p = 2$. The average multiplicity $\langle n_p \rangle$ in CC events is equal to $\langle n_p \rangle = 3.7$.

3. PROPERTIES OF NUCLEON CLUSTERS

Invariant $F(b_k)$ proton distributions have been analysed to study nucleon claster properties. The function $F(b_k)$ is invariant cross section $E\frac{d\sigma}{d\vec{p}}$ expressed in b_k and integrated on angular variables.

$$F(b_k) = \frac{2}{m^2} \int \frac{1}{\sqrt{b_k + b_k^2/4}} \frac{d\sigma}{db_k d\Omega} d\Omega. \tag{4}$$

Figs. 3 and 4 present normalized functions $F(b_k)$ for clusters in pC, dC, He and CC interactions. Figures show that the given dependences have exponential character in pC and CC collisions.

$$F(b_k) = a_1 \exp(-b_k / \langle b_k \rangle_1). \tag{5}$$

Invariant functions $F(b_k)$ for HeC and CC collisions can be approximated as a sum of two exponential dependences

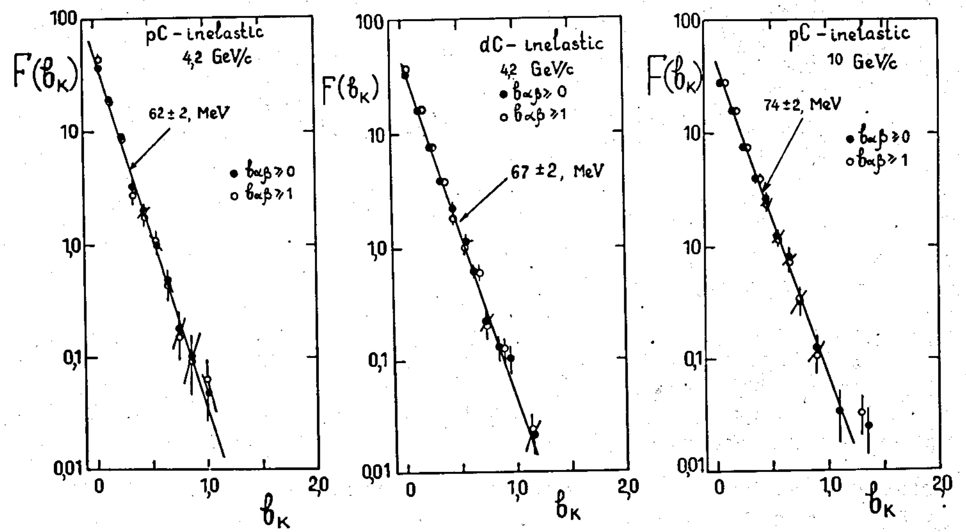

Fig. 3

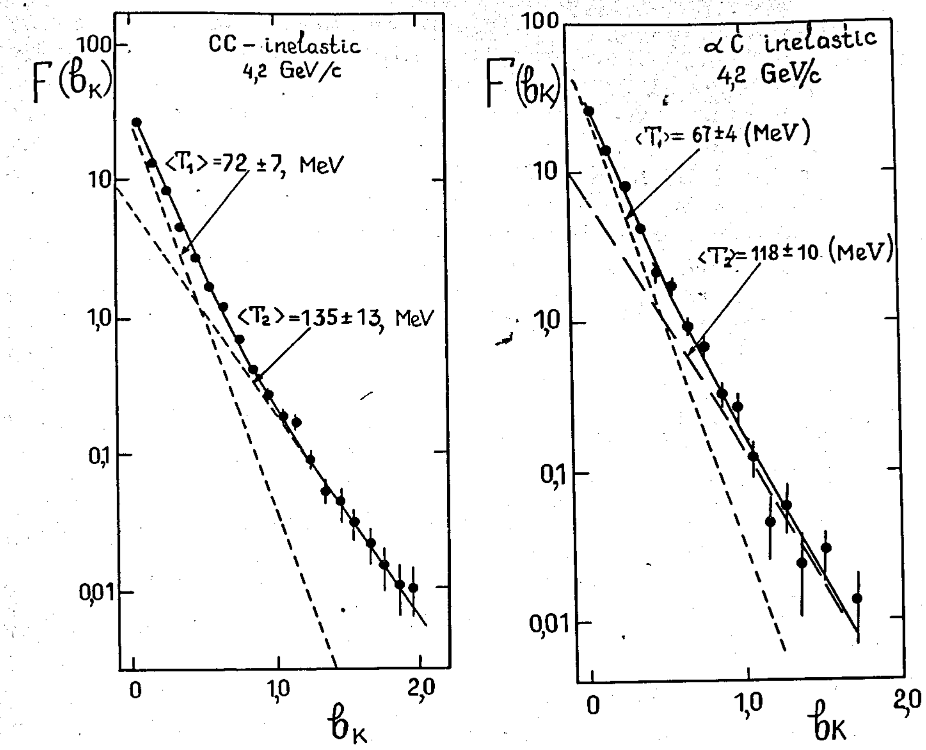

Fig. 4

$$F(b_k) = a_1 \exp(-b_k/\langle b_k\rangle_1) + a_2 \exp(-b_k/\langle b_k\rangle_2). \qquad (6)$$

It is easy to show that the quantity b_k is unambiguously connected with the kinetic energy of particle in the cluster rest frame

$$b_k = \frac{2E_k}{m_k} - 2 = \frac{2T_k}{m_k}, \qquad (7)$$

here E_k and T_k are the total and kinetic energy of protons in the cluster rest frame. Hence, it follows that one can calculate the "temperature" of protons in clusters defining the values of parameters $\langle b_k\rangle_1$ and $\langle b_k\rangle_2$ by approximation. In the present case the slope of invariant cross sections $\frac{1}{P}\frac{d\sigma}{dT}$ in the cluster rest frame was determined as follows

Table 1

Type of interaction	Momentum P, GeV/c	Cluster I $\langle b_k\rangle_1$	$\langle T\rangle_1$, MeV	Cluster II $\langle b_k\rangle_2$	$\langle T\rangle_2$, MeV
pC	4.2	0.133 ± 0.004	62 ± 2	–	–
dC	4.2 · A	0.147 ± 0.002	67 ± 1	–	–
HeC	4.2 · A	0.147 ± 0.008	67 ± 4	0.248 ± 0.022	118±10
CC	4.2 · A	0.154 ± 0.014	72 ± 7	0.288 ± 0.028	135±13
pC	10	0.158 ± 0.005	74 ± 2	–	–

$$\langle b_k\rangle = \frac{2\langle T_k\rangle}{m_k}. \qquad (8)$$

The values of temperature obtained in this manner in different collisions are given in Table 1. From these data one can draw a conclusion that clusters with $\langle T\rangle_1 = 60 \div 70$ MeV are observed in all considered interactions. In addition, in CC collisions clusters with higher temperature $\langle T\rangle_2 = 120 \div 130$ MeV are observed. Systematic errors connected with identification of positive particles are about 10%. The contribution of such clusters is not large and in CC collisions is about (20 ± 6)%. The study of proton properties from identical clusters with the aid of traditional variables has shown that they are produced mainly in the central region on rapidity y and have relatively large transverse momenta $\langle P^2\rangle = 0.51 \pm 0.05$ $(GeV/c)^2$ /17/.

In figs.5 and 6 proton distributions on variables b_k and x_k in the first type clusters, produced in pC, dC, HeC and CC collisions, are compared with analogous data for π^-C interactions at P = 40 GeV/c. One can see that all distributions coincide within experimental errors.

Thus, the properties of nucleon clusters with $\langle T\rangle_1 = 60 \div 70$ MeV in accordance with automodelity principle, depend on neither the type of projectile nor its energy within an interval 4 ÷ 40 GeV/c. Universality of baryon cluster properties points out that we observe asymptotic state of excited nuclear matter in the transition domain of relativistic nuclear collisions.

The obtained data are in agreement with the results of investigation on proton properties in nucleus-nucleus collisions published in papers by S.Nagamiya, V.Manko and other coauthors /18,19/.

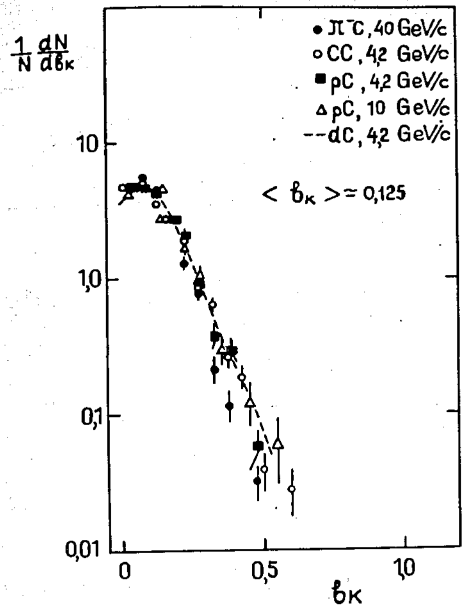

Fig. 5

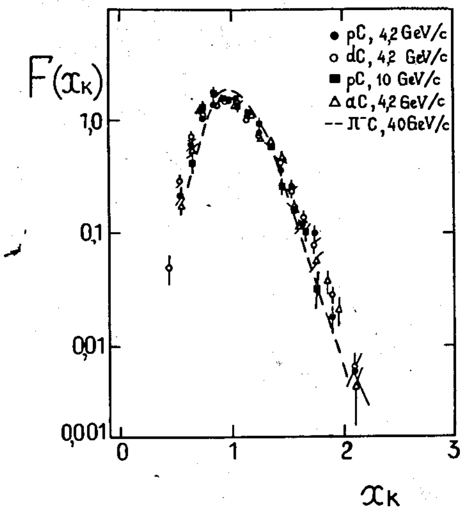

Fig. 6

4. DEPENDENCE OF CLUSTER PROPERTIES ON PROTON MULTIPLICITY

The observation of clusters in CC collisions with $\langle T \rangle_2 = 130$ MeV could mean in nucleus-nucleus collision an occurance of new maximum in their production, connected with multinucleon interactions. The temperature of clusters has been defined depending on their multiplicity n_p to study this problem. Table 2 presents cross sections and temperature of clusters with multiplicity $n_p = 2 - 7$ in pC, dC and CC events. The dependence of $\langle T \rangle$ on multiplicity n_p is shown in fig. 7 as well. From the represented data one can see that the temperature in clusters in all the considered collisions grows with increasing of their multiplicity and reaches 120 MeV at $n_p = 6$ in CC collisions. However, in pC, dC collisions it is systematically lower, than in CC ones at similar values of n_p. The invariant functions $F(b_{IIc})$, describing cluster distributions relative to target nucleus for CC and pC collisions are given in figs.8 and 9. Here $b_{IIc} = -(u_{II} - V)^2$ is the squared 4-velocities with respect to the target. The function $F(b_{IIc})$ represents invariant cross section $E_c \frac{d\sigma}{d\vec{P}_c}$, (where E_c and $\vec{P}_c$ energy and

Table 2

n_p	pC, dC: Number of events	pC, dC: σ, mb	pC, dC: $\langle T \rangle$, MeV	CC: Number of events	CC: σ, mb	CC: $\langle T \rangle$, MeV
2	212	19	49 ± 2	447	47	58 ± 2
3	358	32	64 ± 2	514	55	82 ± 2
4	119	11	77 ± 3	335	36	94 ± 2
5	26	2.3	92 ± 9	204	22	112 ± 3
6	–	–	–	110	12	120 ± 4
7	–	–	–	68	7	–

momentum of the whole cluster) expressed by the dependence on variable b_{IIc} and intergrated on angular variable. The function $F(b_{IIc})$ is written in the analogous manner (4).

The figures show that the function $F(b_{IIc})$ with small proton multiplicity in clusters $n_p = 2 \div 4$ in CC collisions has two slopes, defined by parameters $\langle b_{IIc} \rangle_1$ and $\langle b_{IIc} \rangle_2$. These values can be found by approximation of experimental data by the sum of two exponential functions analogous to (6). Behaviour of the function $F(b_{IIc})$ can be desctibed by exponential dependence identical to type (5) at large multiplicities $n_p = 5$-6. In pC collisions only one slope is observed in the experimental distribution $F(b_{IIc})$.

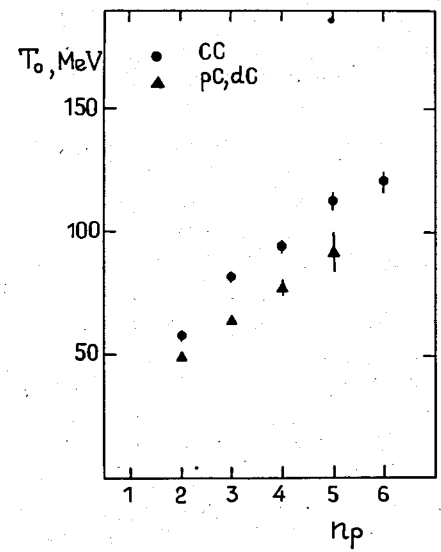

Fig. 7

The values of parameters $\langle b_{IIc} \rangle_1$ and $\langle b_{IIc} \rangle_2$ obtained by approximation of experimental data by the exponential dependences of the type (5) and (6) are given in Table 3. Analysing the obtained data one can make a conclusion that the first slope of $F(b_{IIc})$ is connected with cluster production with $\langle T \rangle_1 = 60 \div 70$ MeV. The contribution of these clusters decreases with

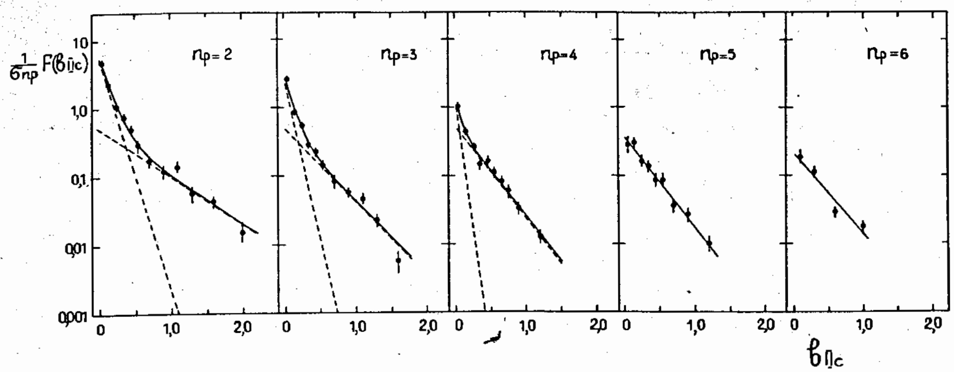

Fig. 8

growing of multiplicity n_p and is not observed at all at $n_p \geq 5$ within experimental errors. The second slope can be due to production of high-temperature clusters $\langle T \rangle_2 = 120 \div 130$ MeV. The contribution of clusters of this type is too little with small multiplicities n_p in CC collisions and is not observed in pC ones within experimental errors. Apparently, the fact the temperature in clusters in CC events on all values of n_p is higher, than in pC and dC ones, can be explained by the presence of high temperature components for all multiplicities.

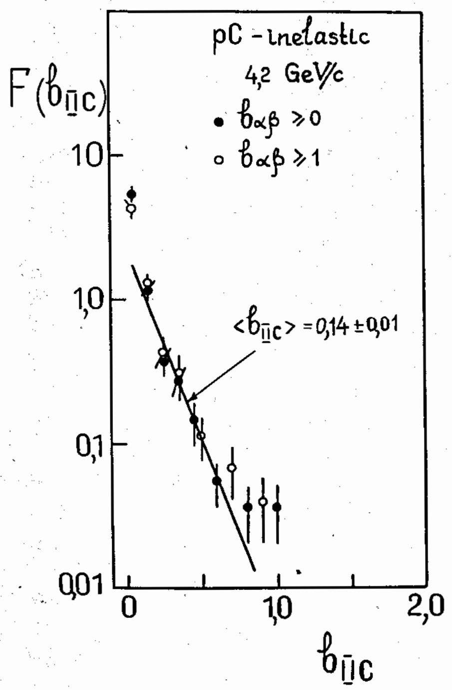

Fig. 9

Thus, the appearance of high temperature clusters in CC collisions is connected with multinucleon interactions. The cross section of clusters with $n_p = 5 \div 7$ is equal to 40 mb, it is ~5% from all inelastic CC collisions. A natural question arises: whether the temperature of such type of clusters will increase more with growing of the number of interacting nucleons or it will obtain asymptotic value. The latter will point out to the existence of another intermediate asympto-

Table 3

n_p	a_1	a_2	$\langle b_{IIc} \rangle_1$	$\langle b_{IIc} \rangle_2$
2	0.92 ± 0.13	0.08 ± 0.03	0.13 ± 0.02	0.63 ± 0.12
3	0.87 ± 0.16	0.13 ± 0.04	0.09 ± 0.02	0.41 ± 0.06
4	0.72 ± 0.36	0.28 ± 0.06	0.06 ± 0.03	0.33 ± 0.03
5	–	1	–	0.33 ± 0.02
6	–	1	–	0.37 ± 0.05

tics in relativistic nuclear collisions. Further experiments could answer this question.

To study the problem on possibility of production of quasi-stationary states of nucleons in multinucleon nucleus-nucleus collisions the effective mass spectra of nucleon clusters depending on multiplicity of protons have been constructed (fig. 10).

As was shown in the analysis experimental distributions based on the statistics obtained could be satisfactorily described by the Breit-Wigner function

at $n_p \geq 5$

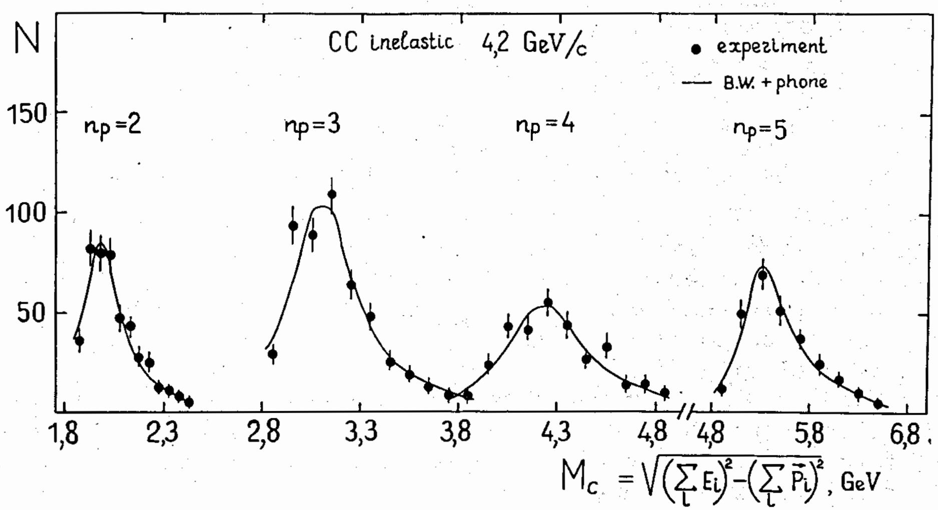

Fig. 10

$$F(M) = \frac{a^2}{(M - M_0)^2 + \Gamma^2/4}, \qquad (9)$$

where M_0 and Γ are seen to be equal with $n_p = 5 - M_0 = 5.24 \pm 0.04$ GeV and $\Gamma = 0.51 \pm 0.07$ GeV; with $n_p = 6 - 7 - M_0 = (1.08 \pm 0.04) + n_p \cdot m_p$, GeV and $\Gamma = 0.74 \pm 0.10$, GeV.

The picture is more complicated with smaller values of $n_p = 2 \div 4$, and it is difficult to interprete in a simple manner.

5. SIZES OF PROTON EMISSION REGION IN BARYON CLUSTERS AND THE DENSITY OF THE NUCLEAR MATTER

The definition of space - time characteristics in the emission region of protons in baryon clusters has been made traditionally by means of analysis of interferent correlations of pairs of identical particles, in this case protons.

The theoretical view of the correlation function, used for the analysis, is given in paper /20/. The effects, connected with quantum statistics of protons, the Coulomb's and strong interactions in their finite state are taken into account in the formulae. Assuming the independence of proton radiation by sources distributed according to the Gaussian law the correlation function can be written as follows

$$R(q, P) = A_c(k^+)[1 + B_0(q, P; r_0, \tau_0) + B_i(q, P; r_0, \tau_0)], \qquad (10)$$

where $q = P_1 - P_2$; $P = P_1 + P_2$ is the difference and sum of 4-momenta; $k^* = \frac{1}{2}\sqrt{-q^2}$ is the momentum of one proton in the c.m.s. of the pair. Theoretical functions have been calculated depending on variable k^*. The theoretical functions have been calculated under different values of parameter r_0 and fixed values of parameters remained: τ_0 (the life time of the source) was assumed to be equal to ~ 1 fm /21,20/ ; $v = 0.4C$ was defined as average velocity of proton pairs. The terms $B_0(q, P; r_0, \tau_0)$, $A_c(k^+)$, $B_i(q, P; r_0, \tau_0)$ describe the effects of quantum statistics, the Coulomb's and strong interaction in the finite state. In formula (10) the nuclear potential is taken into account in the form of rectangular hole /23/.

The effect of interferent correlations in the domain of small values k^* was defined by analysis of the correlation function, constructed in the form of the ratio

$$R(k^*)_{exp} = \frac{\rho(k^*)}{\rho_\phi(k^*)}, \qquad (11)$$

where $\rho(k^*)$ is the measured density of proton pairs in the phase space, $\rho_\phi(k^*)$ the density of proton pairs obtained in the field of correlation absence. Phone distributions are made by mixing together protons from different events in occasional manner. Two-particle correlation functions were analysed for protons at a momentum $P \leq 1$ GeV/c.

The method of finding radius r_0 in the region of proton emission in baryon clusters in CC collisions is seen to be described in paper /24/.

The value of r.m.s. radius $\langle r^2 \rangle^{1/2} = \sqrt{3}\, r_0$ of protons in the cluster rest frame was $\langle r^2 \rangle^{1/2} = 2.5^{+0.8}_{-0.6}$, i.e. approximately equal to the radius of carbon nucleus. And the quantity of $\langle r^2 \rangle^{1/2}$ does not depend on proton momentum in the proton rest frame differing from the data of analysis in the laboratory system. In the latter case we have observed the dependence of the radius in the emission region on proton momentum.

Knowing the sizes of emission region of protons in the cluster one can estimate the density of the nuclear matter in the production processes. The density was estimated in the traditional manner

$$\rho = \langle \nu \rangle / \frac{4}{3}\pi R^3, \qquad (12)$$

where $\langle \nu \rangle$ is the average number of interacting nucleons in CC events in which clusters have been separated out. The value R was defined with account of the expansion of emission region: $R = \langle r^2 \rangle^{1/2} - v \cdot \tau_0$. Here v is the velocity of protons in the rest frame of the cluster. It has been calculated from experimental data and is equal to $v = 0.5$ C. The time was assumed to be ~1 fm as well. The quantity $\langle \nu \rangle$ was determined as the sum of the average number of interacting protons $\langle \nu_p \rangle$ and neutrons $\langle \nu_n \rangle$. It was assumed that $\langle \nu_p \rangle \simeq \langle \nu_n \rangle$

$$\langle \nu \rangle = \langle \nu_p \rangle + \langle \nu_n \rangle \simeq 2\langle \nu_p \rangle = 13.2 \pm 0.1. \qquad (13)$$

Proceeding from these assumptions the density of nuclear matter has been estimated as

$$\rho/\rho_{norm} \simeq 2.7.$$

The quantity of ρ_{norm} for carbon nucleus is equal to 0.168 fm^{-3}. Thus, the density of nuclear matter in the processes of baryon cluster production exceeds 2-3 times the normal density. The obtained estimations on density are mainly applied to the reactions of cluster production with temperature $\langle T\rangle_1 = 60 \div 70$ MeV. The deficiency of statistics does not allow one to obtain analogous estimations for clusters with $\langle T\rangle_2 = 130$ MeV. To compare the latest results of analysis with the data on nucleus-nucleus collisions in experiment N A35 [25] it is of special interest to estimate the density of energy in baryon clusters. The density of energy could be written as

$$\rho_E = \frac{\bar{E}_N \cdot \langle n_N \rangle}{\frac{4}{3}\pi R^3}.$$

Here $\langle n_N\rangle$ is the average multiplicity of nucleons in the cluster, it was about

$$\langle n_N \rangle = \langle n_p \rangle + \langle n_n \rangle \simeq 2\langle n_p \rangle = 7.5\ ,$$

$\bar{E}_N$ is the average energy of nucleons in the rest frame of the cluster. For protons this quantity has been defined from the experimental data according to the formula

$$\bar{E}_p = \bar{T}_p + m_p = \frac{m_p \bar{b}_k}{2} + m = 1.04\ \text{GeV}.$$

In addition, we assume that $\bar{E}_n \simeq \bar{E}_p$. Proceeding from this assumption one obtains the following estimation

$$\rho_E \simeq 0.25\ \text{GeV/fm}^3.$$

6.HADRON JET PROPERTIES IN π^-C INTERACTIONS

As was mentioned above the process of hadron jet production in nuclear collisions is connected with quark degrees of freedom. That is why it is of special interest to compare the temperature and density of nuclear matter in this case with analogous characteristics of processes of baryon cluster production. We hope that such a consistent study of different stages of the excited nuclear matter will be usefull for the solution of the problem on detection of quark-gluon plasma.

Properties of jets in π^-C collisions at $P = 40$ GeV/c have been analysed with the aid of relativistic invariant approach

in relative 4-velocity space. As was shown in previous papers [5,26], in π^-C collisions one can observe the production of predominantly two hadron jets: one of which is due to hadronization of noninteracting quarks from the incident π^- meson; the other, of interacting quarks, diquarks and multiquark configurations from the carbon nucleus.

The separation of two jets was performed by minimizing the function (2) in events with pion multiplicity $n_{\pi^\pm} \geq 4$. These jets were considered to be divided in the relative 4-velocity space, if they satisfy the condition $b_{\alpha\beta} > 10$. A part of undivided events is equal to ~30%. To determine the region of jet production we use variables x_{st} and x_{sp} [27] which characterize a fraction of 4-momentum colliding particles

$$x_{st} = \frac{M_{\alpha(\beta)}}{m_{II}} \frac{(V_{\alpha(\beta)} \cdot u_I)}{(u_I \cdot u_{II})}\ , \qquad (14)$$

and

$$x_{sp} = \frac{M_{\alpha(\beta)}}{m_I} \frac{(V_{\alpha(\beta)} \cdot u_{II})}{(u_I \cdot u_{II})}\ . \qquad (15)$$

Here $M_{\alpha(\beta)}$ is the effective mass of the jets α and β, indices I and II refer to the incident pion or target, correspondingly. We consider that the jet is formed in the π^- meson fragmentation region if $x_{sp} \geq 0.2$ and $x_{st} < 0.2$; and in the target fragmentation region if $x_{st} \geq 0.2$ and $x_{sp} < 0.2$.

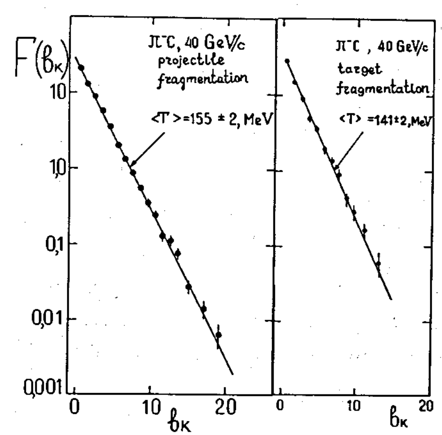

Fig. 11

The functions $F(b_k)$ for pions in both jets are given in fig.11. They are seen to be characterized by exponential behaviour. The value of the temperature determined for the two jets on the basis of analysis of experimental functions $F(b_k)$ is: $\langle T\rangle_p = (155 \pm 2)$ MeV for the beam fragmentation region and $\langle T\rangle_t = (141 \pm 2)$ MeV for the target fragmentation region. Systematic errors in determining $\langle T\rangle$ are about $10 \div 15\%$.

To compare the properties of baryon clusters with the results of the analysis it is advantage-

Table 4

Q	<T> , MeV
0	140 ± 3
+1	139 ± 3
+2	133 ± 4
+3	147 ± 7
+4	123 ± 11
+5	130 ± 27
all	141 ± 2

ous to determine the temperature of jets produced in the carbon nucleus fragmentation region depending on the number of interacting nucleons. Because of momentum limits in identification of positive particles the temperature in jets has been analysed depending on the charge Q of the event. The results of the analysis are presented in Table 4, where one can see that within the experimental errors the temperature in jets does not depend on the charge Q and, hence, on the number of interacting nucleons.

It is interesting to mention that the calculations, performed for e^+e^- annihilation using the LUND model within energy interval $W = 6 \div 100$ GeV, have shown that the multiplicity of jets in events rises with increasing the energy in interaction, but the temperature of one jet remains approximately constant and equal to ~ 150 MeV [8]. Thus, the larger values of temperature cannot be expected in the interactions of hadrons and nucleus proceeding on the quark structure level.

7. SIZES OF REGION OF HADRON JET FORMATION AND DENSITY OF NUCLEAR MATTER

Sizes of the region of hadron jet formation have been determined by studing interferent correlations of identical particles, in this case π^- mesons. The two-particle correlation function in the domain of small relative momenta is defined as

$$R(\vec{q}, q_0) = \frac{\rho(\vec{q}, q_0)}{\rho_\phi(\vec{q}, q_0)}, \qquad (16)$$

where $\rho(\vec{q}, q_0)$ is the density of pairs of identical particles in the phase space, $\rho_\phi(\vec{q}, q_0)$ the density of pairs under the absence of correlation. Here $\vec{q} = (\vec{P}_1 - \vec{P}_2)$, $q_0 = E_1 - E_2$; $\vec{P}_1$, $\vec{P}_2$ and E_1, E_2 are momenta and energy of particles forming pairs. If the space - time distribution of sources is presented as a normal distribution, then the two-particle correlation function can be parametrizes by the following expression[24]

$$R(\vec{q}, q_0; r_0, \tau_0) = A(1 + \lambda e^{-\vec{q}^2 r_0^2 - q_0^2 \tau_0^2}), \qquad (17)$$

where r_0 and τ_0 define space-time characteristics of the process of particle emission; λ phenomenological parameter accounting the "strength" of the effect; A is the normalizing multiplier. One-dimensional distributions $R(\vec{q}, r_0)$ have been analysed by cutting q_0 ($q_0 < 0.2$ GeV) because of lack of statistics on experimental data. Experimental distributions for jets in the region of beam and target fragmentation, presented in fig. 12 were approximated by the formula

$$R(\vec{q}, r_0) = A(1 + \lambda e^{-\vec{q}^2 r_0^2}). \qquad (18)$$

Pairs with nonidentical pions in this case were taken as phone distributions for they do not possess interferent effects, but preserve correlations connected with division of pions into two jets.

The quality of radius r_0 for the jets produced in the region of beam and target fragmentation in the jet rest frame is correspondingly: $r_{0_p} = 0.65 \pm 0.28$ fm and $r_{0_t} = 1.2 \pm 0.5$. The absolute value of r_0 for jets produced in the region of beam fragmentation is identical to the jets produced in e^+e^- annihilation at W = 29 GeV $r_{0\, e^+e^-} =$

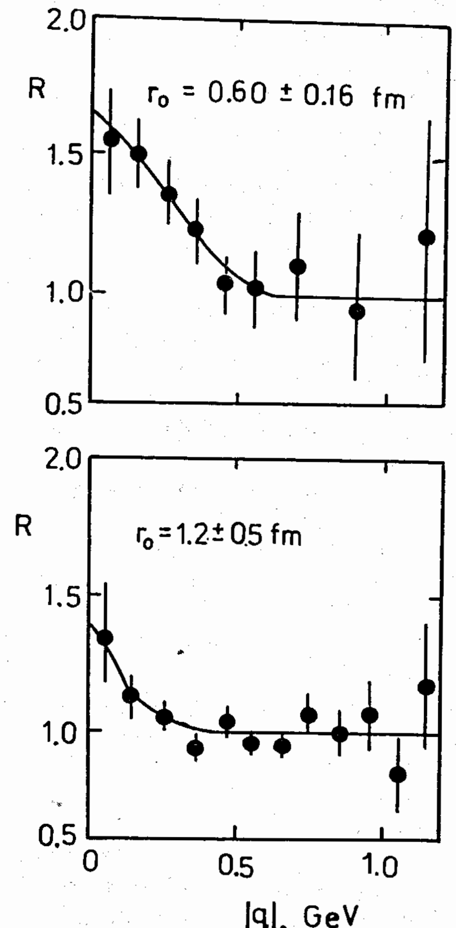

Fig. 12

$= 0.65 \pm 0.04$ [28]. This proves our assumption that jets in the region of beam fragmentation are formed, mainly, by hadronization of noninteracting quarks from the incident pion. The value of r_0 in the region of target fragmentation is more than $r_{0\,e^+e^-}$ which is due to hadronization of multiquark systems.

In this case it is interesting to determine the density of nuclear matter in processes of jet production. The quantity ρ was defined analogous to (12). The average multiplicity of interacting nucleons for π^-C collisions has been calculated by formula (13) where the value $\langle\nu_p\rangle$ is determined from the distribution of events on the charge Q. So $\langle\nu\rangle = 4.7$. The radius of the region of hadron emission in jets has been found with account of its expansion $R = R_0 - v \cdot \tau$, where $R_0 = \sqrt{3}\, r_0$ and $v = 0.9$ c. Under these conditions the density of nuclear matter has been estimated as $\rho/\rho_{norm} \simeq 4$.

Thus, processes of hadron jet production in relativistic nuclear collisions are characterized by higher density of nuclear matter.

The estimation of the energy density of secondary particles has been performed for hadron jets in π^-C collisions. It was calculated by formula

$$\rho_E = \frac{\bar{E}_\pi \langle n_\pi \rangle + \bar{E}_N \langle \nu \rangle}{4/3\, \pi R^3}. \qquad (19)$$

Here $\bar{E}_\pi = 0.35$ GeV is the average energy of pions in the rest frame of jets; $\langle n_\pi \rangle$ the average multiplicity of pions in jets; $\langle\nu\rangle$ the average number of interacting nucleons; $\bar{E}_N = 1.036 \pm 0.002$ GeV the average energy of nucleons in the laboratory system. The estimation of the average value $\langle n_\pi \rangle$ was obtained from the ratio:

$$\langle n_\pi \rangle = \langle n_{\pi^\pm} \rangle + \langle n_{\pi^0} \rangle \simeq \langle n_{\pi^\pm} \rangle + \frac{1}{2} \langle n_{\pi^\pm} \rangle = 6.80 \pm 0.06\,. \qquad (20)$$

The value of the density of the energy at the original moment of expansion of jets was equal to

$$\rho_E \simeq 1.06 \ \text{GeV/fm}^3$$

under these conditions.

The value of $\bar{E}_N$ can be calculated from the assumption that pions in jets and nucleons form common expansing system of secondary particles. Then the average energy of protons in the

rest frame is $\bar{E}_N \simeq \bar{E}_p = 1.15$ GeV and the value of the energy density at the original moment of expansion

$$\rho_E \simeq 1.13 \ \text{GeV/fm}^3.$$

CONCLUSIONS

The following conclusions can be drawn:

1. Production of baryon clusters with $\langle T \rangle_1 \simeq 60 \div 70$ MeV with properties independent on neither the type of projectile nor its energy within an interval of $P = 4 \div 40$ GeV/c is observed in p, d, He, C and π^-C collisions. The obtained result points out that the production of baryon clusters of this type corresponds to the asymptotic state of excited nuclear matter.

2. Estimation of the density of nuclear matter in processes of cluster production has shown that it exceeds the normal nuclear density of carbon. The energy density in baryon clusters is $\rho_E = 0.25$ GeV/fm^3.

3. In multinucleon CC collisions at $P = 4.2 \cdot A$ GeV/c it is observed the production of nucleon clusters with $\langle T \rangle_2 = 130$ MeV, close to the temperature of hadron jets $\langle T \rangle \simeq 150$ MeV produced in processes of quark hadronization.

The dependence of the effective mass spectra of these clusters is satisfactorily described by the function of Breit-Wigher. This points out to the possibility of formation of quasi-stationary states of nucleons in multinucleon nucleus-nucleus collisions.

4. The process of hadron jet production in π^-C collisions at $P = 40$ GeV/c in the carbon nucleus fragmentation region is characterized by the baryon density which is approximately four times larger, than the normal one and with energy density in jets $\rho_E \simeq 1$ GeV/fm^3. These values of the energy density will do for the phase transition in nuclei to quark-gluon plasma, according to theoretical predictions. The results allow to suppose that in relativistic nuclear collisions it is possible local increasing the density of nuclear matter. This leads to the quark deconfinement and then to the hadronization in the form of hadron jets. The temperature of hadron jets is $140 \div 150$ MeV.

Thus the existence of the two regions characterized by asymptotic properties of excited nuclear matter is shown in relativistic nuclear collisions.

REFERENCES

1. Nagamiya S. - International Symposium on Heavy Ion Physics (Heavy Ion '84), Part I, Tikyo, August 24-25, 1984.
2. Grishin V.G. et al. - Yad. Fiz., 1987, b.46, p.768.
3. Baldin A.M. - Nucl. Phys., 1985, A434, p.695c.
4. Baldin A.M., Didenko L.A. - JINR Rapid Comm., No.3-84, Dubna, 1984, p.5.
5. Baldin A.M., Batyunya B.V. et al. - Yad. Fiz., 1986, v.44, p.1209.
6. Baldin A.M., Didenko L.A. et al. - JINR Rapid Comm., No. 1(21)-87, Dubna, 1987, p.17.
7. Didenko L.A., Grishin V.G., Kuznetsov A.A.-JINR,E1-87-829, Dubna, 1987.
8. Grishin V.G., Didenko L.A. et al. - JINR, P1-89-838,Dubna, 1989.
9. Baldin A.M., Baldin A.A. - JINR Rapid Comm-. No. 17-86, Dubna, 1986, p.19.
10. Barenblatt G.I. - Similarity, Automodelity, Intermediate Asymptotics, Leningrad, Gidrometeoizdat, 1982.
11. Baldin A.M. et al. - JINR Rapid Commun., No. 2(22)-87, Dubna, 1987, p.4.
12. Akhababian N. et al. - JINR, 1-12114, Dubna, 1979; Angelov N.S. et al. - JINR, 1-12424, Dubna, 1989.
13. BBCDSSTTU-BW Collaboration - Phys. Lett., 1972, v.39B, p.371.
14. Armutlijski D. et al. - Yad. Fiz., 1987, v.45, p.1047.
15. Agakishiev H.N. et al. - Yad. Fiz., 1983, v.37, p.1495.
16. Armutlijski D. et al. - JINR Rapid Comm., No. 4(24)-87, Dubna, 1987, p.5
17. Baldin A.M. et al. - Yad. Fiz., 1989, v.49, p.1034.
18. Manko V.I., Nagamiya S. - Nucl. Phys., 1982, A384, p.475.
19. Adyasevich B. et al. - Phys. Lett., 1984, v.142B, p.245.
20. Lednicky R., Lyuboshitz V.L. - Yad. Fiz., 1981, v.35, p.1386.
21. Angelov N. et al. - Yad. Fiz., 1977, v.26, p.796.
22. Grishin V.G. et al. - JINR, P1-86-585, Dubna, 1986.
23. Gmitro G. et al. - JINR, P2-86-252, Dubna, 1986.
24. Grishin V.G. et al. - JINR, P1.89.639, Dubna, 1989.
25. N A35 Collaboration - LBL-27926, Berkeley, October, 1989.
26. Baldin A.M. et al. - Z. Phys. C, 1987, 33, p.363.
27. Baldin A.M. et al. - Yad. Fiz., 1988, v.48, p.995.
28. Aihara H. et al. - Phys. Rev. D, 1985, 31, p.996; Althoff et al. - Z. Phys. C, 1986, 30, p.335; Juricic I. et al. - Phys. Rev. D, 1989, 39, p.1.

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