объединенный
институт
ядерных
исследований
дубна

E1-83-334

A.A.Kuznetsov

EXPERIMENTS IN THE FIELD OF RELATIVISTIC NUCLEAR PHYSICS AT THE DUBNA SYNCHROPHASOTRON

Submitted to "VI International Conference
High Energy Nuclear Physics, 6-11 June 1983,
Balatonfüred, Hungary.

1983

1. Introduction

Relativistic nuclear physics is a new scientific field arising at JINR in the beginning of the seventies with the acceleration of deuterons to the highest energies of the synchrophasotron[1] at the High Energy Laboratory (HEL) and when the corresponding program of experimental research had been developed in general outline [2].

During the ensuing years the fulfilment of new operating conditions at the synchrophasotron and the construction of a highly effective (above 90%) slow extraction beam system in a new experimental hall allowed us to accelerate still heavier nuclei to neon inclusive and to obtain relativistic nuclear beams, the intensity of which is much larger than that of secondary particle beams.

At present the synchrophasotron is the leading accelerator of light nuclei over an energy range up to ≈ 5 GeV/nucleon and the only accelerator that possesses a nuclear energy of ~ 3.5 GeV per nucleon, which is threshold for the region of limiting nuclear fragmentation and in which new properties of nuclear matter begin to manifest themselves.

Beams of nuclei with energies up to 5 GeV/nucleon have not yet been obtained at other accelerator centres. At CERN short runs were made with colliding beams of α-particles for a c.m.s. energy of 126 GeV. In addition to JINR, beams of relativistic nuclei were obtained at Bevalac, Berkeley(USA) and at Saturne, Saclay(France). However, the energy per nucleon at Berkeley is twice as low as that at Dubna, and the energy at Saclay that must be achieved in the nearest future will be two times lower than at Berkeley and four times lower than at Dubna. The implementation of the projects of more powerful nuclear accelerators in Japan, USA and FRG is expected in 1987-1990.

Currently the types and intensities of nuclei (protons - 10 GeV, nuclei - 4.2 GeV/nucleon) accelerated at the synchrophasotron are the following:

Type of Nuclei	Intensity per Pulse
P	$4 \cdot 10^{12}$
d	$1 \cdot 10^{12}$
↑d	$6 \cdot 10^{8}$
$_3He^{2+}$	$5 \cdot 10^{9}$
$_4He^{2+}$	$5 \cdot 10^{10}$
C^{6+}	$8 \cdot 10^{7}$
O^{8+}	$4 \cdot 10^{5}$
Ne^{10+}	10^{4}

The total running time of the accelerator is 4000 hours a year, 85% of which is used to implement the program of experimental research and 15% to study and improve operating conditions of the synchrophasotron and its beams. Breakdowns of the accelerator due to faults do not exceed 7% of the scheduled time.

Thus the current state of the synchrophasotron among nuclear accelerators of the world and its operating conditions enable physicists from JINR member-coumtries to carry out promising experiments of to-day. In particular, further development of the synchrophasotron as an accelerator of relativistic and polarized nuclei allows us to study not only the behaviour of nuclear matter at small internuclear distances under extreme conditions, but also to create completely new states of hadron matter-quark plasma.

Further development of the synchrophasotron and the simultaneous and effective operation of its beams enable us to check in detail the conclusions of quantum chromodynamics and to begin systematic studies of the dynamic characteristics of interference in strong and weak interactions.

The importance of studies in the field of relativistic nuclear physics is obvious. Using the available experimental results, one can see that nuclear collisions at high energy are the unique source of information on a space-time picture of hadron production and their internal structure[3]. This primarily concerns studies of nuclear reactions, in which a momentum, which is much larger than the Fermi momentum of nucleons of the nucleus, is transferred to atomic nuclei. The study of the processes has led to the discovery of previously unknown regularities and of the character of manifestation of multiquark degrees of freedom in nuclei. For example, as shown, already at momentum transfer $Q \sim 1$ GeV/c the quark degrees of freedom begin to play an important role in nuclear processes, hadrons of the nucleus cannot be regarded as elementary and their quark structure should be taken into account. Consequently, studies in the field of relativistic nuclear physics are directly related to the problem of high energy and elementary particle physics being solved at the largest accelerators of the world.

Although relativistic nuclear physics exists over a relatively short period of time, a great deal of information has been obtained by different groups of physicists from JINR member-countries in the following important fields of strong interaction physics: scale invariance, limiting fragmentation, quark-parton models and so on. These results have been confirmed at other scientific centres and have been generally recognized.

Below we discuss some experimental results that have been recently obtained at the synchrophasotron. Results of earlier studies can be found elsewhere[4]).

2. Experimental test of consequences of the hypothesis of cumulative effect

The hypothesis of the cumulative nuclear effect was first advanced by A.M.Baldin in 1971[5]). According to this hypothesis, in interactions of elementary particles with nuclei there occur particles in the kinematical region forbidden for interactions with nucleons of the nucleus at rest. In this case properties of cumulative particles should be determined not by geometric characteristics of colliding objects but by local features of hadron matter, i.e. they must satisfy the principles of local interaction and scale invariance.

Secondary pions, the energy of which is much higher than the kinematical limit of NN collisions, were detected already in first experiments carried out by V.S.Stavinsky's group [6]) at the synchrophasotron with a beam of relativistic deuterons. In particular, such important properties of the cumulative effect were found as scale invariance of inclusive spectra of pions and enhanced A-dependence of inclusive production cross sections of hadron in cumulative processes [7]) . A year later the latter observation was confirmed in proton-nuclear experiments for large transverse momentum by J.Cronin [8]).

During the ensuing years some other consequences of the hypothesis of the cumulative effect have been confirmed experimentally. In the experiments of V.S.Stavinsky's group it has been shown that the dependence of particle production cross sections on cumulative number is universal and the dependence on the flavour of produced particles is extremely weak[9]). A series of experiments, primarily experiments carried out by G.A.Leksin's group at the ITEP accelerator [10]) allows one to measure the polarization of cumulative Λ^0-hyperons, which has been found to be very large, and to ascertain a strong correlation in the production of cumulative Λ^0- and ΛK^0-pairs and no correlation for cumulative $K_1^0 K_1^0$-pairs [11]).

The main regularities resulting from the hypothesis of the cumulative effect have been studied rather completely. The processes of cumulative particle production have been investigated over a broad range of energies and for nuclear interactions of different types [12]). These results have made it possible not only to test experimentally the most important consequences of the hypothesis of the cumulative effect and to confirm its existence, but also to ascertain the universal character of its main properties for nuclear processes with large momentum-energy transfers in the region of relativistic energies (region of limiting nuclear fragmentation).

It is difficult to interpret theoretically the above regularities of the cumulative effect without using quantum chromodynamics and quark-parton models [13]). In fact, as already mentioned, in interactions of particles and nuclei with nuclei for large momentum transfers ($Q \gtrsim 1$GeV/c) the quark degrees of freedom play an important role, and the quark nature of nuclear matter should be allowed for. Hence, the study of nuclear interactions for high energy is directly related to information on the quark structure of nuclei and, in particular, on the manifestation of multiquark states in nuclei and nuclear processes. In this connection the experimental test of the consequences and the ascertainment of the regularities of the cumulative effect are the most specific example of such a type of research.

2.1. Properties of invariant inclusive cross sections of cumulative particles

To describe nuclear reactions in the region of relativistic energies, we use relativistic-invariant cross sections for inclusive reactions of the type

$$I + II \rightarrow 1 + X, \quad I + II \rightarrow 1 + 2 + X \quad \text{and so on}$$

measured in experiments. Cross sections

$$E\frac{d\sigma}{d\bar{p}}, \quad E_1E_2\frac{d^2\sigma}{d^2\bar{p}}$$

and so on corresponding to these types of reactions are the functions of variables, A_I and A_{II} the atomic masses of colliding objects, P_I and P_{II} the four-dimensional vectors of their momenta and (P_4P_I), (P_4P_{II}) the products of the energy-momentum four-vectors which determine angular and energy distributions of secondary particles measured in the relativistic-invariant form.

Introduce two new variables [14]

$$\varepsilon = (p_I\, p_{II})/m_I m_{II} = (p_I^o\, p_{II}^o)/m_o^2,$$

the specific invariant energy of collision, and

$$y_i = 1/2 \ln[(E_i + p_{iz})/(E_i - p_{iz})]$$

longitudinal rapidities. Here $P_I = A_I P_I^o$ and $P_{II} = A_{II} P_{II}^o$ are the four-dimensional vectors of the momenta of colliding nuclei A_I and A_{II} with atomic mass m_o, energy E_i and momentum projection P_{iz} on the reaction axis. In the rest system of nucleus I

$$\varepsilon = E_{II}/A_{II}m_o$$

and in the rest system of nucleus II

$$\varepsilon = E_I/A_I m_o$$

Besides, the products of the energy-momentum four-vectors can be expressed as follows:

$$(p_I\, p_{II}) = m_I m_{II}\, ch(y_I - y_{II}) \quad \text{and} \quad (p_I\, p_i) = m\sqrt{m_i^2 + p_{i\perp}^2}\; ch(y_i - y_I)$$

From experiments on multiple particle production in hadron collisions it is known that the difference of the rapidities is $\Delta y \gtrsim 2$. Then

$$\varepsilon = \frac{(p_I\, p_{II})}{m_I m_{II}} \approx ch\, 2 \approx 3\,7 \quad \text{when} \quad (p_I\, p_{II}) \approx m_I m_{II}\, ch\, \Delta y$$

Consequently, for an energy of relativistic nuclei $\gtrsim 3.5$ GeV/c/nucleon the ε-dependence of invariant cross sections of nuclear reactions is insignificant, and the limiting nuclear fragmentation takes place.

The existence of the region of limiting nuclear fragmentation has been determined in experiments performed by V.S.Stavinsky's group [9]. These results have been confirmed more clearly by the groups of G.N.Leksin [15], K.SH.Eginian [16] and L.S.Shroeder [17] who have studied cumulative processes in another type of nuclear reactions and for other energies.

In the region of limiting nuclear fragmentation the invariant cross sections of nuclear reactions are weakly dependent not only on ε, but also on other variables. As found in the first experiments of V.S.Stavinsky's group, the cross sections over this range of energies strongly depend only on the ratio of scalars

$$\frac{(P_i\, P_{II})}{(P_I\, P_{II})} = \frac{\sqrt{m_i^2 + p_{iz}^2}}{m_I} \exp(y_i \quad y_{II}) \ ,$$

i.e. the principle of scale invariance is valid.

Using the definition of cumulative effect and taking the foregoing into account, one can determine the limit of the region of cumulative processes. The limit of the region of the cumulative effect is $\varepsilon > 3.7$ and

$$\beta^o = \exp(y_i - y_I)\frac{\sqrt{m_i^2 + p_{iz}^2}}{m_o} > 1 .$$

Here $m_o = 0.931$ GeV and β^o is the kinematical variable which determines the order of cumulativity; $m\beta^o$ is the minimum target mass.

Main experimental data on the cumulative effect have been obtained under these conditions. As already mentioned, the most important of them have been first obtained by V.S.Stavinsky's group. This group has performed the most complete experimental test of the consequences of the hypothesis of the cumulative effect and has made systematic studies of its regularities for large values of cumulative number β^o.

The characteristic properties of collisions of particles and nuclei with nuclei originates from the idea of local interaction at large momentum transfers and from the fact that a point-like object receiving a momentum larger than that of the whole nucleon belongs to the group of nucleons of the nucleus. This means that, in studying processes of this type, the notion of nucleon inside the nucleus as a good quasi-particle loses its sense, and its quark structure must be allowed for. In other words, specific multiquark interactions are investigated which are directly related to the collectivity of quarks of the nucleus. This naturally allows one to use quark-parton structure functions of nuclei $G(\beta^o, P)$ as a main property of nuclear processes at relativistic energy by analogy with hard interactions of hadrons. For relativistic nuclear collisions the distributions of quarks in the nucleus and the probability that the constituent (quark) carries the momentum of a group of nucleons are determined by the function $G(\beta^o, P_\perp^2)$ in the region $\beta^o > 1$.

For cumulative processes (the region where $\varepsilon > 3.7$ and $\beta^o \geq 1$) the inclusive cross section normalized to the atomic weight of the nucleus is well described by the expression [18]

$$\frac{E\,d\sigma}{A\,d\bar{p}} = \beta^o \frac{d^2\sigma}{d\beta^o dp_\perp^2} \approx G(\beta^o, p_\perp^2) \quad .$$

An explicit form of the $P_\perp^2$-dependence has been measured [19] in cumulative reactions of different types and for a variety of energies. These data are well approximated by the following expression

$$\phi(p_\perp^2) = 0.9 \exp(-2.7\, p_\perp^2) + 0.1 \quad .$$

If the cross section measured is normalized to the function $\phi(P_\perp^2)$, one can obtain the cross section depending only on β^o, i.e. the structure function must take the following form: $G(\beta^o, 0)$.

The validity of this statement has been tested by the group of V.S.Stavinsky [18] and in experiments at the Fermilab accelerator for higher energy [20]. Results of the experiments are presented in fig. 1a,b, respectively. Here the invariant production cross sec-

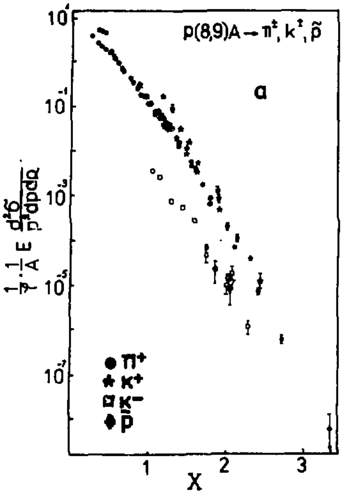

Fig. 1a

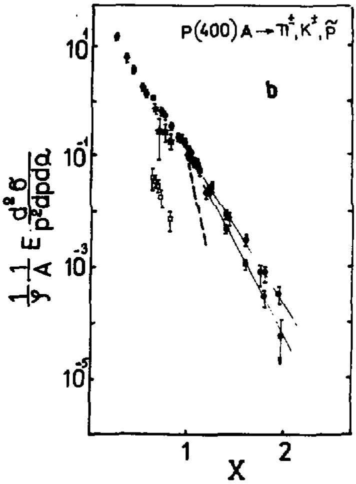

Fig. 1b

tions of different cumulative particles are dependent on variable X introduced by V.S.Stavinsky 21). The variable X is a generalized scale variable determining the effective cumulative number. This variable differs from the Bjorken variable x. The relation between them is found for deep inelastic scattering of leptons as follows 18):

$$\frac{X}{A_{II}} \approx -\frac{1/2\,(p_I - p_i)}{(p_I\, p_{II}) - (p_{II}\, p_i)} = x \quad .$$

The cumulative region takes place when X>1. From the figures one can draw the following conclusions: a) the X-dependence of inclusive production cross sections of cumulative particles is described by a unique exponential function G(X) in interactions with a large set of nuclei and for different energies although the G(X) function for K^- and p markedly differs from that for π^+ and K^+ in absolute value; b) parametrization of this dependence by the form $G(X) \sim \exp[-X/\langle X \rangle]$ leads to a universal value of

$$\langle X \rangle \approx \frac{d}{dX}\left(\ln E \frac{d\sigma}{d\bar{p}}\right) \quad , \qquad \langle X \rangle \approx 0.14$$

The latter can be seen in fig. 2, where $\langle X \rangle$ has been measured in different experiments with different nuclei for different energies and values of X.

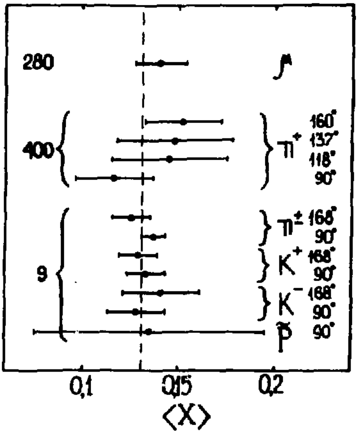

Fig. 2

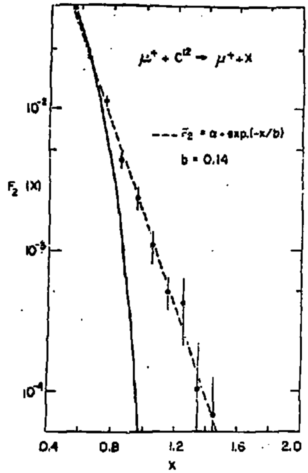

Fig. 3

These results are extremely important for understanding the nature of the cumulative effect. They point directly to the quark mechanism of cumulative processes. Indeed, the behaviour of the inclusive cross sections for cumulative meson production (i.e. the equality of the cross sections for π^+ and K^+ and a marked difference from the cross sections for K^- and K^+) can be interpreted as a result of pickup from the symmetric quark sea of corresponding quarks by the valence quarks of the colliding objects. Then, e.g., the equality of the cross sections for K^+ and π^+ should be a result of pickup from the sea of $\bar{d}$ and $\bar{s}$ quarks by knocked out valence u quarks. The production of K^- in this way will be strongly suppressed.

The above results, obtained in the study of the cumulative effect, have allowed A.M.Baldin to make concrete predictions concerning the absolute value and X-dependence of deep inelastic scattering cross sections for muons on nuclei [19].

This prediction was tested experimentally in a joint JINR-CERN experiment. The group of NA-4 studied the inelastic scattering of negative muons on carbon nuclei for an energy of 280 GeV and a momentum transfer of $Q \approx 100$ GeV/c [22]. The structure functions of carbon nuclei F_2 (X) and their dependence on variable $X = Q^2/2M(E_0 - E)$ were measured in the region $X > 1$. Results of the experiment are shown in fig.3. The figure also presents results calculated by some theoretical models: — the Fermi-step model for a Fermi momentum of 0.22 GeV/c. As predicted, the structure function of nuclei had an exponential X-dependence, and the parameter $\langle X \rangle$ was found, within the experimental errors, to be 0.14 ±0.01, i.e. it is equal to universal parameter .

Thus, the results on deep inelastic scattering of leptons com-

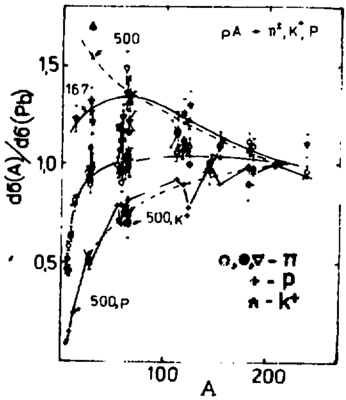

Fig. 4a

pletely confirm the quark nature of the cumulative effect, the universal character and validity of introducing the quark-parton structure functions of nuclei as main properties of nuclear processes at large momentum transfers in the relativistic region of energies. In addition, these results argue against the opinion still existing that the cumulative effect is the process related to the Fermi motion of nucleons in the nucleus.

2.2. Enhanced A-dependence

Another important property of the cumulative effect originating from the principle of local interaction was found as enhanced (as compared to A) dependence of production cross sections of cumulative particles on the atomic weight of the nucleus, i.e. a dependence of the type

$$E\frac{d\sigma}{d\bar{p}} \sim A^{n} \quad ,$$

where n = 1.0. In this case the power index n must depend on X and $P_{\perp}$.

The enhanced A-dependence of the cross sections for particle production, which is significantly different from a simple $A^{2/3}$ behaviour, has been first studied by V.S.Stavinsky's group [6,7] in nuclear interactions with large momentum transfers. A similar effect has been also observed by the group of J.Cronin [8].

Futher on the effect of enhanced A-dependence was studied by the group of V.S.Stavinsky in more detail [18]. This group obtained experimental results for a broad range of nuclei (more than 20) and different types of produced particles.

A summary of the results is presented in fig.4a,b. One can see that a) the A-behaviour of the cross sections strongly depends on the flavour of produced particles, namely, at first the cross sections for pions sharply increase with increasing A and then, from $A \approx 20$, remain approximately constant; for kaons and protons the production cross sections, normalized to A, increase as A increases and the transition to the A-dependence appears to set in only for $A \approx 100$. b) The A-dependence of the cross sections is determined neither by the momentum of produced particles nor by their emission angle, but by the value of cumulative number X. In fact, as already mentioned, the inclusive cross sections of cumulative particle production are well approximated by the expression

$$1/\emptyset E\frac{d6}{dp} \approx G(X) \qquad .$$

In this case the quark-parton structure function G(X) is of the form

$$G(X) \approx A^{n} \exp\left(-\frac{X}{\langle X \rangle}\right) \qquad \text{where } n = 2/3 + X/3.$$

Consequently, as expected, with increasing X the cross section of cumulative particle production as a function of A is more markedly different from the simple $A^{2/3}$ behaviour. Figure 5 presents experimental data of V.S.Stavinsky's group on the X-dependence of the power index n in $\sim A^{n}$

(in the experiment $n = \dfrac{\ln[f(A_{Pb})/f(A_{Al})]}{\ln[A_{Pb}/A_{Al}]}$).

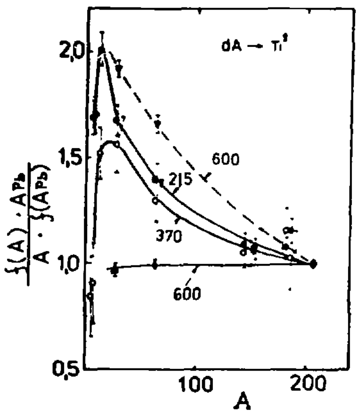

Fig. 4b

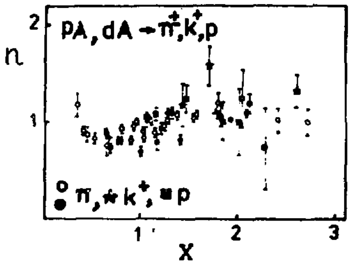

Fig. 5

As seen, n increases from 2/3 to 1 when X varies between 0.4 and 1, and for X>1, within the errors, the value of n does not change and its values are grouped around 1, i.e. in this case the enhanced A-dependence takes place.

A similar character of the A-dependence of the inclusive cross sections for nuclear reactions with large momentum transfers is also observed in pion-nucleus [15], gamma-nucleus [16] and (for other energies) proton-nucleus [17] interactions. In fig.6 are presented results of the recent paper. The power index of the A-dependence is shown as a function of variable K which coincides with the value of β^0 with a good precision. From the figure one can see that the enhanced A-dependence takes place for $K \geqslant 1.0$ when the energy of collision is above 3.5 GeV/nucleon. The results of V.S.Stavimsky's group are well confirmed by these data.

To date the character of the A-dependence of the inclusive cross sections for nuclear reactions of different types has been studied in a series of experiments [24]. For example, in experiments [25] it has been found that the invariant production cross sections of hadrons with large transverse ($P_\perp$) moments in pA interactions can be parametrized by exponential A dependence

$$E\frac{d^3\sigma}{d^3p} \sim A^{\alpha(P_\perp)} ,$$

where $\alpha(P_\perp)$ is an increasing function of transverse momentum independent of A which is > 1 for large $P_\perp$ (the so-called "anomalous nuclear deviation").

An anomalous character of the A-dependence is also observed in nucleus-nucleus interactions for a momentum interval of 1 ÷ 4 GeV/c/nucleon [27] and in $\alpha\alpha$-collisions for ISR energies [26]. A description of different mechanisms advanced to discuss the effect of anomalous increasing the cross sections of particles with large P on nuclei and a more detailed list of references devoted to this subject can be found in papers [32].

In this review we discuss the experimental data obtained recently at the Dubna synchrophasotron, in which the anomalous A-dependence has been studied for the production of particles and nuclear fragments in proton-nucleus and nucleus-nucleus interactions. Note that for nucleus-nucleus collisions it is natural to assume generalization of the parametrization by the exponential A-dependence used to describe proton-nucleus interactions. In particular, if we have a reaction of the type A+B→h(f) + X, where A and B are the atomic weights of projectile and target-nucleus, h and f the registered hadron or fragment, by analogy to pA interactions we assume

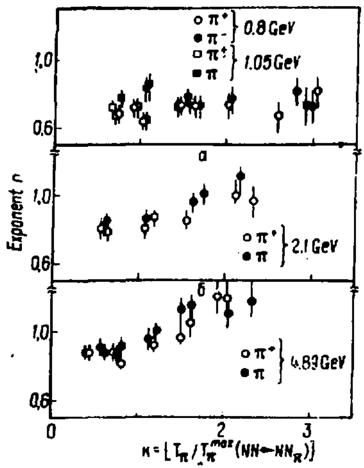

Fig. 6

$$E\frac{d^3\sigma}{d^3p} \sim (A \cdot B)^{\alpha(p_\perp)} .$$

Generally speaking, such parametrization is undoubtedly approximate and valid only for high enough energies. A series of factors related to the nucleon structure of colliding nuclei should be taken into account to describe experimental data in general terms 22). However, as will be shown below, experimental results are rather well described by the above parametrization.

The behaviour of the invariant cross sections of negative pions and protons has been investigated versus the atomic number of projectile (A_i) for p, d, 4He and ^{12}C interactions with Ta at 4.2 GeV/c/nucleon by the group of the 2m propane bubble chamber 28). Experimental results are presented in fig.7. The $\alpha(P_\perp)$ dependence is shown for the case of π^- production. As seen from the figure, within the errors $\alpha(P_\perp) \approx 1.0$ if $P \leq 0.8$ GeV/c.

The A-dependence of the cross sections for protons is given in fig.8. The parameter $\alpha(P_\perp)$ has the following values obtained from this distribution: 1.07 ± 0.02 for $P_\perp^2$ from 0.5 to 1.0(GeV/c)^2 and 1.17 ± 0.03 for $P_\perp^2 > 1.0$(GeV/c)^2.

Figure 9 shows the dependence of $\alpha(X_\perp)$ for π^--mesons in nucleus-nucleus and proton-nucleus interactions. Here $X_\perp = P_\perp/P_{max}$, where P_{max} is the maximum momentum in the c.m.s. of nucleon-nucleon collisions for corresponding energy and

$$R_i = \left(E\frac{d^3\sigma}{d^3p}\right)_{A_iTa} / \left(E\frac{d^3\sigma}{d^3p}\right)_{pTa}$$

is the ratio of the differential cross sections for π^--meson production. One can see that the data obtained by the group of the 2m propane bubble chamber are in good agreement with results for pA interactions at 400 GeV and differ from data at 70 GeV/c 29). One can understand such a difference if to keep in mind that the 70 and 400 GeV/c data have been obtained for particles emitted at angles close to 90° in the nucleon-nucleon c.m.s., and the nucleus-nucleus data refer to inclusive particle production.

Some new and interesting information on the A-dependence of the cross sections not only of particles but also of nuclear fragments has been obtained in experiments carried out at the synchrophasotron for proton-nucleus and nucleus-nucleus interactions. Figure 10 presents data on the behaviour of the power index of the A-dependence of the cross sections for different fragments (it is denoted by N) versus $P_\perp$ in pA interactions . One can see that

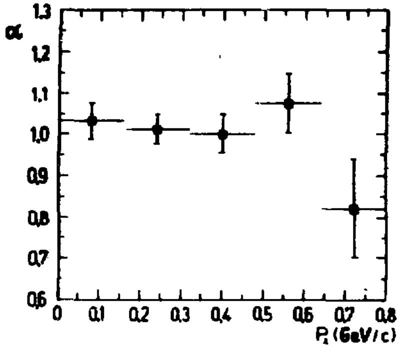

Fig. 7

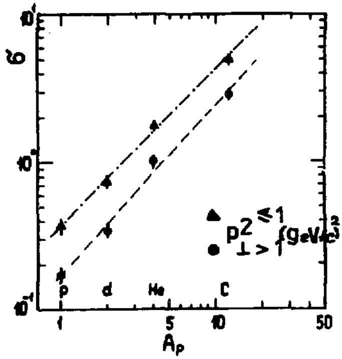

Fig. 8

with increasing the transverse momentum of produced fragments the index of exponential A-dependence achieves 1.0 much faster than for hadrons, and it is larger than 1 at $P_\perp \gtrsim 0.5$ GeV/c.

A similar character of the A-dependence of the cross sections for fragments is also observed for nucleus-nucleus interactions. Results of measurements made by the group of the 2m HEL streamer chamber [31] show that in interactions of 4.2 GeV/nucleon α-particles with Li, C, Al and Cu nuclei the value of $\alpha(P_\perp)$ is ~ 0.3 for all fragmenting channels, and it becomes equal to 1.01 ± 0.06 for events with small impact parameter ("central" collisions).

Thus, all available data obtained in experiments at different energies in different types of interactions for different kinds of produced particles, jets and fragments directly point to the existence of the A-dependence of production cross sections for particles and fragments in nuclear reactions with large momentum transfers and transverse momenta which is different from $A^{2/3}$. As a rule, in most papers experimental data are approximated by the expression $E(d\sigma/d\bar{p}) \sim A^{\alpha}$, where the power index α is larger than unity. This effect is called "anomalous nuclear deviation" [24]. Yet such a form of approximation is insufficiently valid.

In fact, the results obtained by the group of V.S.Stavinsky show that the above approximation is good only for the case when the cross sections are measured for a small number of nuclei (in most of the papers being discussed the number of nuclei used in measurements is $\leqslant 4$). If a large set of nuclei (much larger than four) is used in experiments as has been done by V.S.Stavinsky's group, the so-called "anomalous" A-dependence (i.e. $E(d\sigma/d\bar{p}) \sim A^{\alpha}$ where $\alpha > 1.0$) is the reflection of the transition from the $A^{2/3}$ type dependence to the $A^{1.0}$ type dependence. Indeed, the A-dependence of the cross sections should have a universal behaviour, $E(d\sigma/d\bar{p}) \sim A^{1.0}$, for all relativistic nuclear collisions with large momentum transfers or transverse momenta. This effect is referred to as enhanced A-dependence.

From the analysis of experimental data performed by A.Melis-

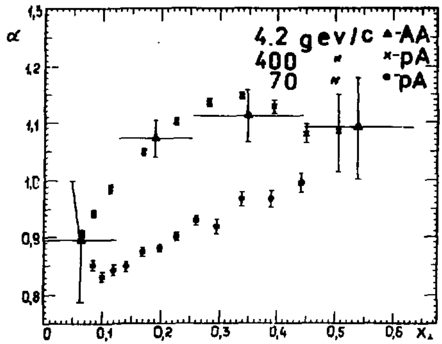

Fig. 9

sinos[24]) it follows that the conclusions on the anomalous A^{α} -dependence of the cross sections for particles in nuclear processes at high energy, where $\alpha > 1.0$, are not universally valid. As mentioned above, there are many theoretical approaches which claim to describe the effect of enhanced increase of the production cross sections for hadrons in nuclear reactions with large transverse momenta or momenta transfers (see, e.g.,[27])). However, this effect is not yet explained satisfactorily.

For example. the character of the enhanced $A^{1.0}$-dependence of the cross sections for hadrons in hadron-nucleus interactions is explained using the hypothesis of hard (predominantly single) quark-parton collisions [32]). It was made an attempt [33]) to describe the measured inclusive spectra of mesons with transverse momenta to 6 GeV/c by the model in which soft multiple and hard quark collisions inside the nucleus are taken into account. As can be seen from fig. 11, the results of theoretical calculation qualitatively agree with the experimental data [8,34]) if quark confinement is allowed for in the model.

Thus, although there are some positive results of a theoretical description of the effect of the enhanced A-dependence of particle production in nuclear reactions for relativistic energies, a detailed mechanism of this effect is not clear as yet. However, using available experimental data, primarily from the study of the cumulative effect, one can confirm that the enhanced A-dependence is quark in nature and is the result of reflection of the presence of multiquark fluctuations inside the nucleus.

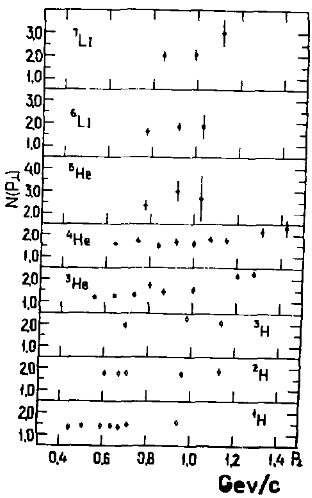

Fig. 10

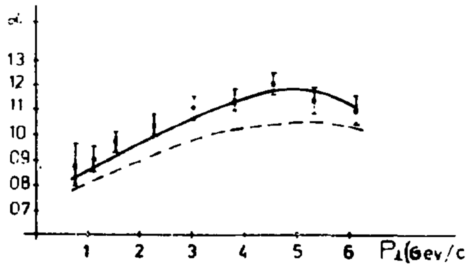

Fig. 11

2.3 Cumulative effect in multiple production processes

The above results of the experimental test of the hypothesis of cumulative effect have been obtained in the studies of inclusive reactions.

An attempt to study cumulative processes in other than inclusive experiments has been made by the group of V.B.Lyubimov [35] in the analysis of pictures from the 2m propane bubble chamber exposed to negative 40 GeV/c pions. The technique allowed the characteristics of "accompanying" particles to be investigated along with cumulative particles. In particular, the experiment made it possible to determine more valid selection criteria for cumulative reactions, to discover correlation effects between "meson" and "proton" cumulative processes and to obtain important information on their cross sections and the properties of accompanying particles. Such experimental conditions allowed more abundant information to be obtained on the dynamics of cumulative processes as compared to inclusive experiments.

The experimental results involved approximately 19000 inelastic $\pi^- C$ interactions. In the analysis, the characteristics of secondary charged particles were studied in detail versus the cumulative variable β° which defines the degree of cumulativity of pions or protons. With this aim the cumulative number of these particles was chosen in each event, i.e.

$$\beta^\circ = \max\{\beta^\circ_i\} ,$$

where

$$\beta^\circ_i = (E_i - P_{iz})/m$$

determines the minimum target mass (the order of cumulativity) which is required for the production of a hadron with energy E_i and momentum projection P_{iz} on the reaction axis.

The following characteristics of secondary particles were studied: average multiplicity, average momentum and emission angle in the laboratory system, average rapidities, etc. These characteristics were studied for secondary π -mesons with a

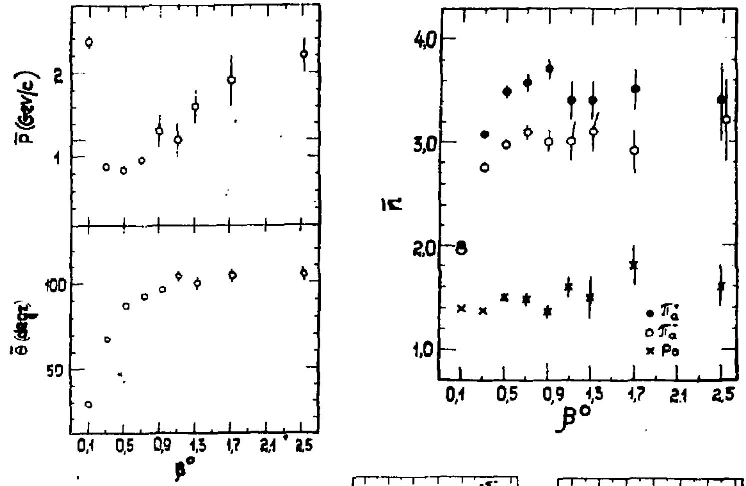

Fig. 12 a

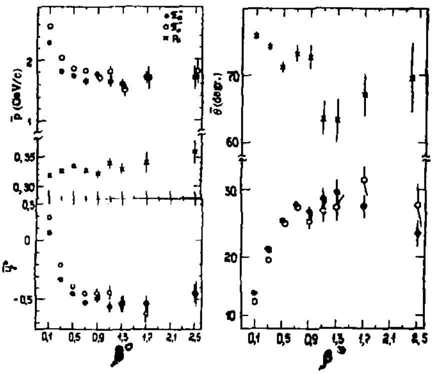

Fig. 12 b

maximum value of β° in a given event (π_c-meson) as well as for all other π-mesons (π_a-meson) accompanying the π_c-meson. The behaviour of the above properties versus β° allowed two groups of events to be separated which are distinctly different from one another. Results of the experiment are presented in fig. 12a, b. One can see that the properties for π_c- and π_a-pions versus β° change at $\beta^\circ \approx 0.6$ and for protons at $\beta^\circ \approx 1,2$. Group I is characterized by $\beta^\circ \leq 0.6$ for pions and $\beta^\circ \leq 1.2$ for protons. For these events the characteristics under study change with β° to the boundary values of β°. Group II has $\beta^\circ > 0.6$ for pions and $\beta^\circ > 1.2$ for protons. For these events all the studied characteristics (except $\bar{P}$ for π_c-mesons which increases with increasing β°) for π_c- and π_a-mesons and protons do not change with β°. Such a character of the dependence of the properties of secondary particles directly points to the existence of two independent and different in their nature sources of pion and pro-

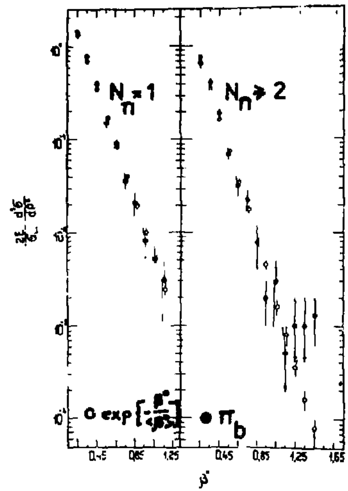

Fig. 13

ton production in hadron-nucleus interactions at high energy. One of them (i.e. events of group II with $\beta^\circ > 0.6$ for pions and $\beta^\circ > 1.2$ for protons) has the general nature expected of cumulative pion and proton production. The analysis of the events from group II shows that the processes, which lead to cumulative pion production, are independent of the processes of cumulative proton production. Only ~ 12% of cumulative protons are accompanied by the emission of cumulative pions, and this fraction does not depend on the degree of cumulativity of protons.

The estimate of the cross sections for cumulative pion and proton production gives the same value of ~ 11mb.

The experimental conditions made it possible to measure the inclusive production cross sections of pions and protons emitted into the backward hemisphere in the laboratory system versus $p_\perp^2$ and β°. In so doing, the cross sections are factorized as:

$$E\frac{d\sigma}{d\bar{p}} \sim exp(-p_\perp^2/\langle p_\perp^2\rangle) exp(-\beta^\circ/\langle\beta^\circ\rangle)$$

Results of the experiment are shown in fig. 13. One can see that a) the behaviour of the production cross sections for cumulative pions ($N_\pi = 1$) and for cumulative pion "jets" ($N_\pi \geq 2$) is parametrized by the same dependence exp $(-\beta^\circ/\langle\beta^\circ\rangle)$, where the values of $\langle\beta^\circ\rangle$ are 0.130±0.005 and 0.143±0.004, respectively. A similar behaviour of the inclusive cross sections for cumulative particles and a group of particles versus β° agrees with the hypothesis of soft quark hadronization and serves as an additional argument in favour of using quark-parton structure functions of nuclei as the main characteristics of ralativistic nuclear collisions; b) the dependence of the cross sections on $P_\perp^2$ strongly differs for different values of β°. If the experimental data are approximated by $exp(-P_\perp^2/\langle P_\perp^2\rangle)$, the following values can be obtained for $P_\perp^2$: 0.034±0.002(GeV/c)^2 for $0 < \beta^\circ < 0.5$ and 0.13±0.02 (GeV/c)^2 for $0.5 < \beta^\circ < 2$. These results serve a good argument in favour of the validity of selection of the cumulative region.

The character of the dependence of the inclusive production cross sections for cumulative protons on β° is similar to that observed for pions. However, the value of β° for protons is somewhat larger, and it increases with increasing the multiplicity of accompanying particles. A similar behaviour of the cross sections for cumulative particles in hadron-nucleus interactions at a large variety of energies (in this experiment ε =286) is one more evidence for the existence of the limiting fragmentation region of nuclei.

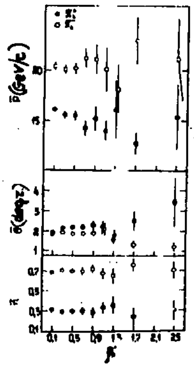

Fig. 14

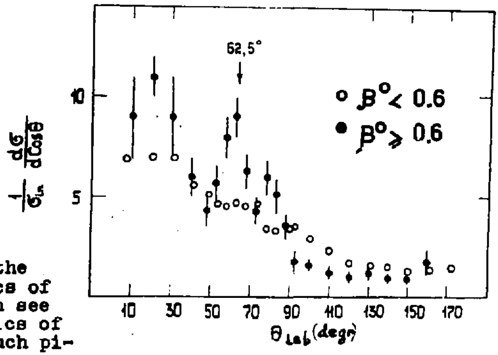

Fig. 15

Figure 14 shows the average characteristics of leading pions. One can see that the characteristics of leading pions, i.e. such pions which have a maximum momentum for a given event and $x = P^*/P_{max} > 0.2$ in the πN c.m.s., are independent of β^o. This fact can be explained by the mechanism in which leading pions are produced from spectator quarks that pass through the nucleus without interaction, whereas cumulative particles are produced in hard collisions with another quark of the incident pion.

Figure 15 presents the angular distributions of protons for all groups of events: protons with $\beta^o < 0.6$ and protons with $\beta^o \geq 0.6$. For the events, in which protons have $\beta^o \geq 0.6$, one can observe an enhancement at $\cos\theta = 0.5$ although the momentum distributions of these protons have no distinct anomalies. This may be due to the motion in nuclear matter of a colour charge of that quark which did not take part in hard collision inherent in cumulative processes. The enhancement found in the angular distributions of protons from the events with $\beta^o \geq 0.6$ was also observed in the events with the total disintegration of the nucleus [36].

Thus the regularities of cumulative particle production, determined in this experiment providing the maximum number of accompanying particles were detected, well confirm the conclusions drawn from the study of purely inclusive reactions, give new important information on cumulative processes and make an emphasis on the validity that these processes correspond to the quark-parton picture of hard collisions.

2.4. Jet behaviour of hadrons in cumulative nuclear collisions

Numerous studies of jet hadron production in different processes, such as e^+e^-, γp and hadron-hadron collisions, have shown that in these interactions the jets of secondary particles have a variety of universal properties [37]. For example, one of the important and global properties of hadrons is their jetness which can be determined by "sphericity"

$$S = 3/2\min(\sum_i P_{\perp i}^2 / \sum_i \vec{P}_i^2), \quad \text{where } \vec{P}_i \text{ are}$$

the momenta of secondary charged particles in the c.m.s. of colliding objects and $P_{\perp i}$ are the transverse momenta of particles with respect to the jet axis, for which the sum $\sum P_{\perp i}^2$ has a minimum value [38]. The value of S is equal to 1 for events with a large number of secondary particles distributed isotropically in phase space and S ≪ 1 if two narrowly collimated groups of particles emitted to the opposite sides relative to the direction of primary particle (or beam particle) are produced in the interaction.

Figure 16 illustrates average values of the sphericity versus energy in the c.m.s. of colliding particles for different types of interaction. One can see that the jet characteristics of hadrons are practically similar in these interactions for corresponding c.m.s. energies. This and other facts indicate that a single mechanism of quark/gluon hadronization is realized to the jet of secondary particles in different, at first glance, processes.

Below we discuss the data on the jet characteristics of multinucleon π^-C interactions of the cumulative type for a momentum of 40 GeV/c obtained by the group of the 2m propane bubble chamber. The jet characteristics of hadron-nucleus interactions have been scarcely investigated [39]. Nevertheless, they are of interest to solve different problems associated with nuclear interactions [40].

The method of event selection and experimental data analysis are described in detail in [41]. For comparison with data on e^+e^- annihilation, the events were selected, in which the multiplicity

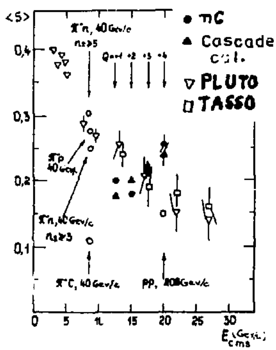

Fig. 16

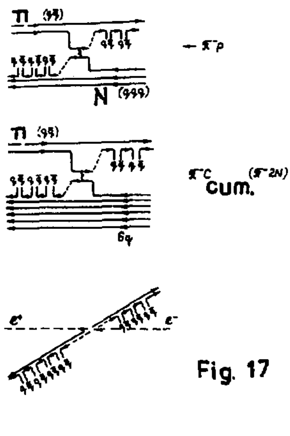

Fig. 17

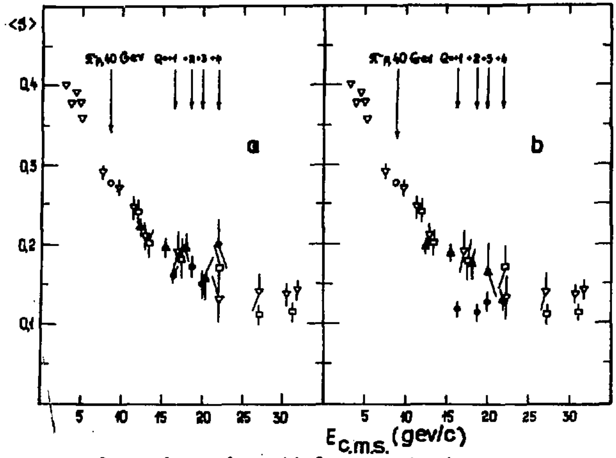

Fig.18a,b

of secondary charged particles was ≥ 4.

A possible mechanism of jet particle production in hadron-nucleus processes is shown in fig. 17. In the figure are presented the corresponding diagrams for e^+e^- and π^-p interactions. Figure 18a,b depicts the value of $< S >$ for the jets of secondary charged particles versus energy in the c.m.s. of colliding objects for e^+e^-(∇ , $\square$), π^-p(O) and π^-C(● , ▲) interactions. The value of $< S >$ is presented for the jets emitted to the forward (fig. 18a) and backward (fig. 18b) hemispheres in the case of e^+e^- and π^-p interactions and the jets having extra cumulative particles (●) or without them (▲) for π^-C interactions. From the figure one can see the following:

- The values of $< S >$ for the jets from π^-C interactions, emitted in the direction of primary pion and having cumulative /noncumulative particles, do not differ from one another and agree with the e^+e^- and π^-p data for equal c.m.s. energies.
- The value of $< S >$ for the jets from π^-C interactions, emitted backwards and having cumulative particles, is much smaller than for the jets free of cumulative particles and differs from similar e^+e^- data.
- The value of $< S >$ for the jets from π^-C interactions, having cumulative particles, is practically invariable as the number of interacting nucleons of the carbon nucleus increases.

Figure 19a,b presents the value of $< S >$ versus the energy in the c.m.s. of colliding objects for the jets of secondary charged particles emitted in the direction of primary pion (fig. 19a) and against it (fig. 19b). In this case in the cumulative and noncumulative jets all charged particles, emitted backwards in the collision c.m.s., had $\beta^\circ \geq 1.5$ and $\beta^\circ \leq 1.5$, respectively (the value of β° was measured in section 2.3). As is seen from the figure,

- The value of $< S >$ for the cumulative and noncumulative jets from π^-C interactions, emitted in the direction of primary pion, well agrees with similar e^+e^- and π^-p data for equal energy in the c.m.s..
- The value of $< S >$ for the noncumulative jets from π^-C interactions, emitted to the backward hemisphere, does not coincide with the e^+e^- and π^-p data.

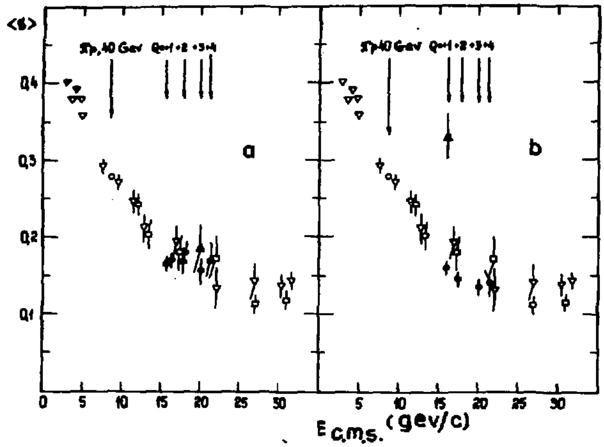

Fig. 19a,b

In addition to the study of general properties of the hadron jets from π^-C interactions, specific characteristics of particles of a definite type belonging to different kinds of jets have been investigated in this comparative analysis. In particular, e.g., the following properties of hadrons in the jets were studied (and compared to the e^+e^- data): average multiplicity of particles, their longitudinal and transverse variables ($P_\perp$, $X_\parallel$) relative to the jet axis, their rapidities and so on.

These results are not presented because of a small volume of this report. However, the main conclusions on all the data on the jet behaviour of hadrons in π^-C interactions can be briefly formulated as follows;

- In cumulative π^-C interactions for a momentum of 40 GeV/c, when the number of colliding nucleons is ≤ 5, one can observe the production of the jets of secondary charged hadrons emitted in the direction of primary pion and against it in the collision c.m.s. The value of $\langle S \rangle$ for both jets coincides with the e^+e^- and π^-p data for equal energies in the c.m.s.
- The jets involving cumulative hadrons are much narrower that those in e^+e^- and π^-p interactions.
- The multiplicity of charged hadrons in cumulative π^-C interactions is coincident with a similar value for e^+e^- interactions for equal energies in the c.m.s. It is much smaller for noncumulative π^-C interactions.
- The distribution of pions in cumulative π^-C interactions over the longitudinal and transverse momentum variables relative to the jet axis agrees with a similar distribution of these variables for pions in e^+e^- collisions. The distribution of protons in cumulative jets over similar variables significantly differs from that of pions.
- The probability of hadron jet production in the fragmentation nuclear region for cumulative π^-C interactions is much larger than the probability of the production of one charged hadron for π^-p interactions at the same energy of incident pion.

2.5. Cumulative effect and quark-parton structure functions of nuclei

The results of an experimental test of the hypothesis of cumulative effect made it possible to ascertain rather rigorously that in nuclear reactions with large momentum transfers hadrons cannot be considered as elementary particles. One should take into account their quark structure, i.e. specific multiquark interactions which are due to the collectivity of quarks or irreducable of quark-parton structure functions of nuclei to one-nucleon. In particular, the experimental data on limiting nuclear fragmentation obtained by the group of V.S.Stavinsky allowed one to introduce the concept of quark-parton structure functions of nuclei as main characteristics of relativistic nuclear collisions with large momentum transfers and to predict the universality of their properties for deep inelastic scattering of leptons on nuclei.

Using the property of relatively weak coupling of quarks inside hadrons, the quark-parton model, which is an analog of impulse approximation in nuclear physics, allows the cross section of hard collisions of hadrons to be expressed as the product of the noncoherent scattering cross sections of particles on all constituents σ_o^b of hadron B and the probability $G_{B/b}(x, Q^2)$ to observe constituent b inside hadron B, i.e.

$$\sigma_B(x,Q^2) \approx \sum_b \sigma_o^b \, G_{B/b}(x,Q^2)$$

with $G_{B/b}(x, Q^2)$ the quark-perton structure function of hadron B, $Q^2 = -q^2$ the square of the four-momentum transferred and $x = Q^2/(2Pq)$ the fraction of momentum P of hadron B carried by constituent b. The cross section $\sigma_o^b = A^b / Q^4$ depends only on Q^2 and describes the interaction of point-like charges in the lepton case. This enables the characteristics of quark-parton structure functions of nuclei to be measured directly in studies of deep inelastic scattering of leptons on nuclei.

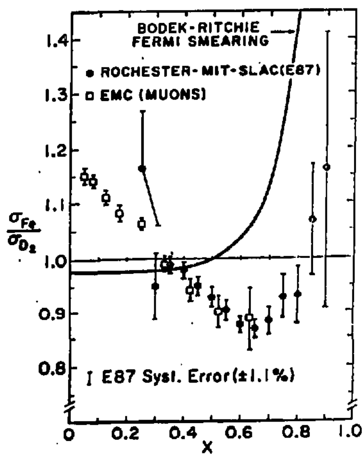

Fig. 20

As noted, this fact was first tested in the joint JINR-CERN NA-4 experiment [23], in which the deep inelastic scattering of negative muons on carbon nuclei was stidied for an energy of 280GeV. The measured characteristics of quark-parton structure functions of carbon nuclei were found to be the same as in the experiments on limiting nuclear fragmentation.

These conclusions have been recently confirmed by experimental results obtained at CERN and SLAC. In these experiments the deep inelastic scattering of muons (CERN) and electrons on Fe and D nuclei were studied.

Studying the X-dependence of the ratio of the structure functions of Fe and D nuclei obtained from the measurements of the deep inelastic scattering of muons, the CERN group 42) has shown that there is a strong difference in the characteristics of these functions for iron and deuterium in the region $x \lesssim 0.7$. The SLAC group 43) has confirmed this effect analyzing the data on deep inelastic scattering of electrons on the same nuclei.

These experimental data are presented in fig.20. In the figure are also shown results calculated for the effect of Fermi motion (solid line) assuming that this effect dominates. The experimental data of both groups are in good agreement. Besides, the observed character of the ratio of the structure functions of Fe and D nuclei versus x cannot be explained by the known nuclear mechanisms 44). "The data show that the momentum distribution of quarks inside the nucleon becomes disturbed due to the presence of other nucleons", write the authors of paper 43). Consequently, quark-parton models must be used for experimental data interpretation.

In other words, the experimental results 42,43) directly point to the quark nature of the observed effect and completely confirm the conclusions drawn previously from the experiments on the cumulative effect at the synchrophasotron.

In fact, if the data of V.S.Stavinsky's group 7,9) discussed above are presented as the variables of fig.20, one can see (fig. 21) that the CERN and SLAC results are in good agreement with the Dubna data in the overlapped region of x values. In addition, the Dubna data give new information on the properties of structure functions of nuclei for the region of large values of x (not yet studied in lepton-nucleus processes) as well as on the property of structure functions of nuclei different from 42,43).

3. Search for multiquark states in nuclei

The question of the existence of multiquark states in nuclei has been intensively discussed in a series of theoretical papers 45). The study of multiquark states, when quarks belonging to the group of nucleons are mixed, can give valuable information on the nature of asymptotic freedom and quark confinement. Consequently, the question of the existence of multiquark states is to date one of the important problems of quark physics.

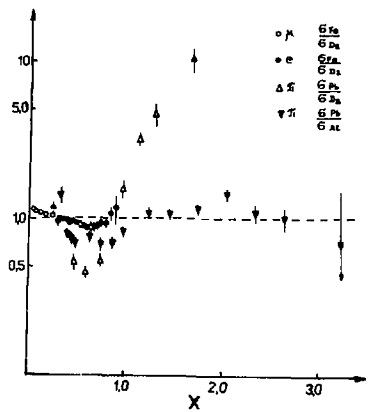

Fig. 21

The observation of multiquark states should be expected in processes involving relativistic nuclei. For example, the above data on the study of cumulative effect allowed us to broaden ideas of the quark nature of nuclear matter and, in particular, of the manifestation of multiquark states in nuclear reactions with large momentum transfers for relativistic energies.

The search for a possible manifestation of multiquark degrees of freedom in nuclei has been performed by the groups of M.G.Meshcheryakov 46) and

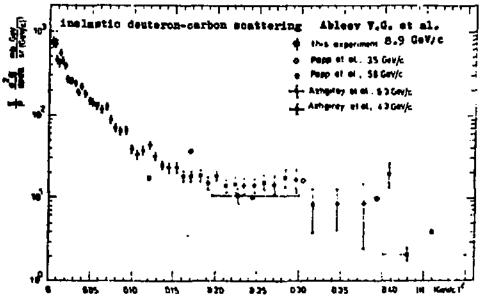

Fig. 22

L.N.Strunov [47]) in studies of inelastic scattering processes of deuterons on different nuclei in reactions of the type

$$d + A' \rightarrow A + X, \text{ where } A = p,\ d,\ C,\ CH_2, \ldots \text{ and } A' = p,\ d.$$

In the experiment of M.G.Meshcheryakov's group deuterons having momenta of 4.3 and 6.3GeV/c were scattered by target nuclei at an angle of 103 mrad so that the four-momentum transfer squared /t/ was $\geqslant 0.41 (GeV/c)^2$. In the experiment of L.N.Strunov's group the primary momentum of deuterons was 8.9GeV/c and protons were emitted at an angle of $< 0.4°$ so that the value of /t/ reached $\leqslant 0.4$ $(GeV/c)^2$.

The data on the inelastic scattering cross sections of deuterons versus /t/ obtained in these experiments are shown in fig.22. In the same figure are presented the data of paper [48]), in which the cross sections were measured for deuteron momenta of 3.5 and 5.8GeV/c and a deuteron detection angle of 43.6 mrad. As seen from the figure, the data presented show that the behaviour of the cros sections versus /t/ is complicated in character: it slowly changes with increasing /t/ from $/t/ \approx 0.2 (GeV/c)^2$. An analysis of the deuteron spectra in the region $/t/ \geqslant 0.2 (GeV/c)^2$ shows [46]) that there is a structure characteristic of excitation processes of nucleon resonances. This fact means that the incident deuteron, to a large extent, loses a significant fraction of its momentum and does not "disintegrate" into individual nucleons. The mechanism of this process can be explained assuming that the deuteron has a quark structure and the multiple scattering of quarks of the incident deuteron on quarks of the target-nucleus makes a major contribution to the reaction cross section. Based on this point of view, the authors of paper [49]) satisfactorily reproduced the basic regularities of inelastic reactions $p + P \rightarrow p + X$ and $d + P \rightarrow d + X$. In particular, in order to describe the above results obtained by the group of M.G.Meshcheryakov, it was necessary to introduce the "hybrid" wave function of deuterons containing the contribution of a six-quark state. As is seen from fig. 23 (solid line), the best agreement with experiment is reached if one assumes that in the reaction $d + p \rightarrow d + X$ the dominating contribution belongs to excitation processes of nucleon resonances and to $\sim 5\%$ of six-quark admixture in the wave function of the incident

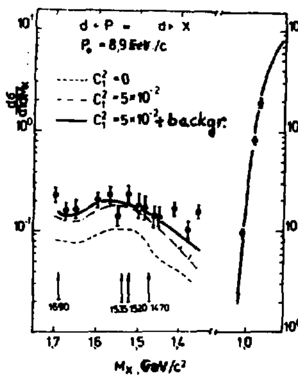

Fig. 23

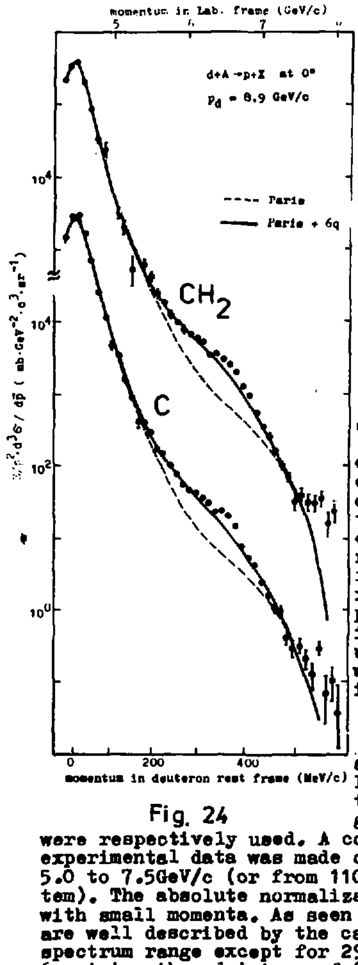

Fig. 24

deuteron.

The use of the hybrid wave function of deuterons allows one to interpret experimental data obtained by the group of L.N.Strunov [47]. The spectrum of protons, produced in the reaction $d + A \to p + X$ and identified by means of Cerenkov threshold counters, was measured in this experiment. The measured invariant cross sections of the yield of protons for C and CH_2 targets are shown in fig.24. Results of calculations made using the hybrid model, in which the wave function of relativistic deuteron is of the form

$$\Psi_d = \Psi_{np} + \Psi_{6q} ,$$

are given in the same figure. To calculate the wave functions Ψ_{np} and Ψ_{6q}, the Paris potential (PARIS in the figure) and the oscillator quark model were respectively used. A comparison of the calculated results and experimental data was made over the range of proton momenta from 5.0 to 7.5GeV/c (or from 110 to 500 MeV/c in the deuteron rest system). The absolute normalization was made to the spectrum region with small momenta. As seen from the figure, the experimental data are well described by the calculated results over all the momentum spectrum range except for 290-390 MeV/c. The root-mean-square of 6q-state, the admixture of 6q-state in the deuteron and the relative phase of np- and 6q-components in the wave functions of the deuteron fitted in the experiment are presented in Table II.

From the table one can see that the contribution of 6q-state in the deuteron is practically the same and equals ≈ 10% despite different isospin target states.

The existence of the 6q-component of the deuteron has been recently supported by the SLAC group [51]. This group made an analysis of all previous data and results from paper [52] to obtain in-

Table II

Type of target	Probability of 6q-admixture	r (6q) fm	Phase of np- and 6q-components	χ^2/degree of freedom
C	2·(5.4 ± 0.6)%	0.99 ± 0.04	(95 ± 7)°	1.6
CH_2	2·(4.3 ± 0.4)%	0.95 ± 0.05	(82 ± 6)°	1.9

formation on the character of the momentum spectrum of nucleons in the deuteron at deuteron electrodisintegration (the energy of electrons was from 6 to 20 GeV and Q^2 from 8 to 10(GeV/c^2). Results of the analysis are given in fig.25a. The momentum distribution of nucleons in the deuteron is presented as the square of the wave function $|\psi(K^2)|^2$ versus variable K which is called the nucleon momentum of spectator P^*. The data of L.N.Strunov's group in the same variables are shown in fig.25b. As seen from the figures, the SLAC data are in good agreement with the results of L.N.Strunov's group and confirm their conclusion on the existence of 6q--state in the deuteron.

As noted above, in the comparative analysis of the data obtained by L.N.Strunov's group and the calculated results using the hybrid model, an enhancement is observed over the range of proton momenta $290 \leq P^* \leq 390$MeV/c which is not described by the hybrid model. This enhancement can be due either to the process described by a triangular diagram with nucleon isobars in the intermediate state or to the process $d + N \rightarrow d^* + N$, where $d^* \rightarrow p + N$. The first statement is, however, hardly probable. In fact, the independence of the momentum spectra of nucleons in the deuteron of isospin target-nucleus states indicates that spin-dependent effects of interaction in the final state are weak. For example, from the experiment it follows that for CH_2 and C targets the ratio of the cross sections, $R(CH_2)/R(C)$, is equal to 1.00 ± 0.07 (R =

$$= \sum_i (\sigma^i_{exp} - \sigma^i_{fit})/\sum_i \sigma^i_{fit} .$$

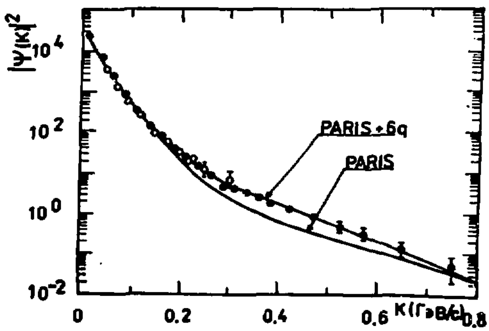

Fig. 25a

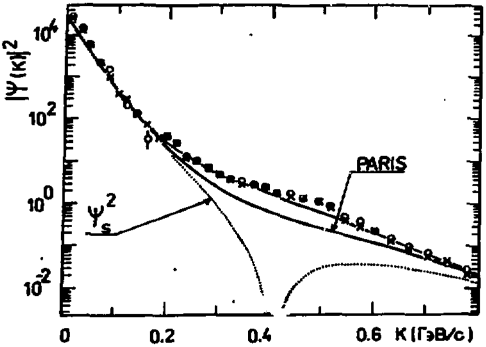

Fig. 25b

For the process with nucleon isobars in the intermediate state with isospin different from zero, this ratio should be much larger than unity (e.g., it should be ~ 1.22 for the effective number of nucleons =4 inside the carbon nucleus). Hence the enhancement observed in the experiment can be more naturally interpreted as the diffraction production of dibaryon resonance with isospin I=0 and mass M ~ 2 GeV/c^2.

To check this statement, the invariant mass spectrum of d^*-system was constructed (see fig.26). The reproduction of this process (i.e. $d + N \to d^* + N$) by Monte Carlo and its comparison with the experimental data lead to the following parameters of the dibaryon resonance: $M = (2.14 \pm 0.01)$GeV/c^2 and $= (80 \pm 10)$MeV/c^2. Such a state was predicted theoretically [54,50], but an experimental evidence for its existence was obtained for the first time. The dibaryon resonance can be interpreted as the production of 6q-bag in the interaction of deuteron with target-nucleus.

A search for multiquark resonance states was performed at the synchrophasotron in experiments on the observation of "exotic" particles not described by conventional quark models.

The existence of such particles in nature was predicted in a series of theoretical papers (see, e.g., [55]).

At the High Energy Laboratory, JINR the search for multiquark resonance states was first performed by the group of B.A.Shahbazian in 1962 [56] in the analysis of pictures obtained by means of a 24-litre propane bubble chamber irradiated with ~ 7GeV/c neutrons and 4GeV/c π^--mesons. The invariant mass spectra of 49 systems, involving Λ^0-hyperons over a broad range of hypercharge, strangeness and baryon number, were investigated.

As a result of this analysis, statistically significant peaks were observed only in the invariant mass spectra of the systems having $Y \leq 1$. A summary of the data is presented in table III. As seen, the parameters of the multiquark resonances observed in the experiment are in good agreement with predictions of the bag model. Some of the resonances presented in the table were observed in other experiments [57] devoted to studies of multiquark resonance states in Kd and πd interactions.

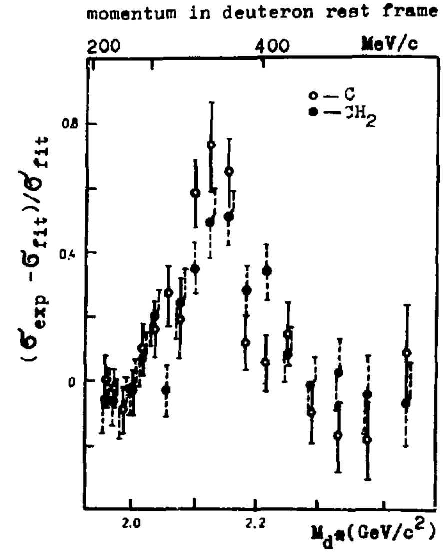

Fig. 26

Presently the search for and study of resonance states of the indicated type are being performed using the 2m propane bubble chamber exposed to beams of relativistic nuclei.

In the experiment carried out by Yu.A.Troyan's group multiquark resonance states with isospin $I > 3/2$ have been searched for and studied using a 1m hydrogen bubble chamber irradiated with monochromatic neuterons having energies of $\leqslant 5.1$ GeV [59]. In the analysis of the invariant mass spectra $p\pi^+\pi^+$ and $n\pi^-\pi^-$ from reactions $np \to p\pi^+\pi^+n\pi^-\pi^-$, statistically significant peaks were observed for masses 1438,1522 and 1894 MeV/c^2 and widths $\leqslant 30$, $\leqslant 20$ and $\leqslant 40$ MeV/c^2, respectively which points to the existence of baryon resonances with isospin $I=5/2$. All the data on parameters of these resonances, their production cross sections of theoretical models are presented in table IV. Currently the work is being performed to increase statistics and to define quantum numbers of these resonances.

4. Multiple production processes of particles/fragments in relativistic nuclear collisions

Multiple production processes of particles and fragments form a main part of the total cross section for relativistic nuclear interactions. A picture, obtained using the 2m propane bubble chamber (see fig.27) exposed to a beam of 50GeV carbon nuclei, illustrates such a type of processes. In the picture one can see not only multiple particle production but also the production of fragments of the carbon nucleus which, in its turn, interacts

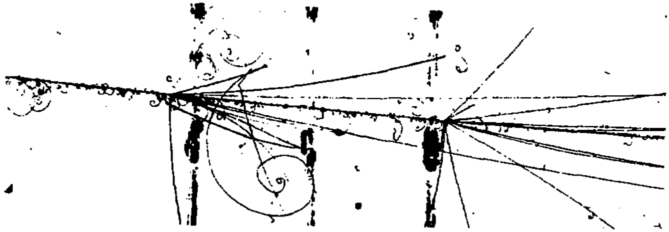

Fig. 27

with another carbon nucleus producing secondary particles.

A large amount of physics data on multiple processes has been obtained on beams of the synchrophasotron by means of track devices[60]. From these results a fairy complete picture of the mechanism of these processes emerges. In particular, it has been found that the main characteristics of nuclear processes for an energy of > 1 GeV/nucleon are well described by a superposition of the characteristics of nucleon-nucleon interactions and the average transverse momentum of secondary particles is limited to ~350 MeV/c, independent of the energy of the colliding objects. A comparison of the experimental data on multiple particle production with the theoretical calculations using additive nucleon model predictions gives good agreement for all the main characteristics of these processes. The validity of this fact follows from small momentum-energy transfers in multiple production processes that make a major contribution to the total cross section. In this case the nucleon is a "good" quasi-particle.

4.1. Inelastic cross sections of nuclear interactions

The character of the behaviour of the total inelastic cross section of relativistic nuclei is an argument in favour of this statement.

At present there are many papers [61] devoted to the measurement of total inelastic cross sections of nuclear collisions for energies above 1 GeV per nucleon. The whole complex of these re-

Table III

I. Strange dibaryons - candidates for q^6 states 1. Λp (I = 1/2, Y = 1, B = 2, S = -1					
				Bag model predictions	
M (MeV/c^2)	Γ (MeV/c^2)	Significance ($N_{st.dev.}$)	σ prod. (μb)	M (MeV/c^2)	J^P
2255.2±0.4	16.9±2.3	8.05±1.32	85.3±20.0	2241	2^+
2354.3±0.7	56.1±5.0	6.25±1.25	65.0±17.0	2353	2^-
2183.2±0.6	3.7±0.7	5.56±1.23	60.0±15.0	2169	1^+

2. $\Lambda p \pi$ (I = 3/2, 1/2, Y = 1, B = 2, S = -1					
				Bag model predictions	
M (MeV/c^2)	Γ (MeV/c^2)	Significance ($N_{st.dev.}$)	σ prod. (μb)	M (MeV/c^2)	J^P
2495.2±8.7	204.7±5.6	12.86±1.68	70.5±15.0	2500	$0^-, 1^-, 2^-$

II. Strange exotic baryons - candidates for qq^4-states $\Lambda\pi\pi$					
				Bag model predictions	
M (MeV/c^2)	Γ (MeV/c^2)	Significance ($N_{st.dev.}$)	σ prod. (μb)	M (MeV/c^2)	J^P
1704.9±0.9	18.0±0.5	5.3 ± 1.6	19.0±0.6	1710	$1/2^-$
2071.6±4.0	172.9±12.4	10.3 ± 1.5	88.0±27.0	2120	$1/2^-$
2604.9±4.8	85.9±21.5	5.2 ± 1.4	31.9±9.0	2615	$3/2^-$

sults leads to the following characteristic properties: a) within the experimental errors the cross sections are independent of the energy of colliding objects; b) there is a weak dependence of the cross sections on the size of target-nucleus (A_t) as the atomic weight of the projectile (A_i) increases; and c) the cross sections for energies above 1 GeV/nucleon are well described by a simple geometric model with overlap.

Figure 28 presents a summary of the data on total inelastic cross sections for nuclear interactions versus A_i and A_t. In the same figure are given experimental data, recently obtained at the synchrophasotron [62], on the measurement of inelastic cross sections for interactions of ^{22}Ne with C, Al, Cu and Pb nuclei at 4.1 GeV/nucleon. One can see that all the experimental data (except the $^{16}C \to C$ point from paper [63])) are well described by the geometric model with overlap, in which the parameter of overlap β depends on the atomic weights of the colliding nuclei. Approxima-

Table IV

	M_{res} (MeV/c^2)	Γ_{res} (MeV/c^2)	J^P	mode decay
exp	1438	23	$3/2^{\pm}$, $5/2^{\pm}$	$\Delta\pi$
	1522	$\lesssim 20$	$1/2^{\pm}$, $3/2^{-}$, $5/2^{+}$	$\Delta\pi$, $N\pi\pi$
	1894	$\lesssim 40$	-	$\Delta\pi$, $N\pi\pi$
B.M.	2000	-	$5/2^{-}$	-
	1450–1470	-	$1/2^{-}$	-
JSM	1550	-	$3/2^{-}$	-
	1900	-	$1/2^{+}$, $3/2^{+}$, $5/2^{+}$	-
SSR	1400–1700	$\approx$30 for M_{res} = 1438	$5/2^{+}$	$\Delta\pi$

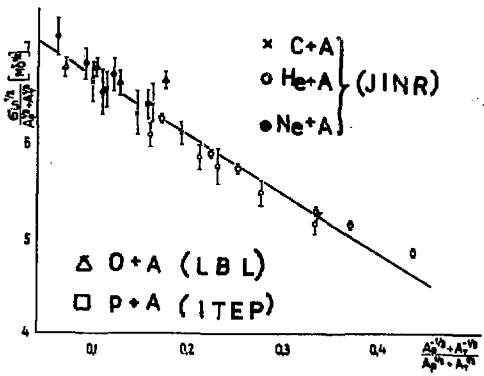

Fig. 28

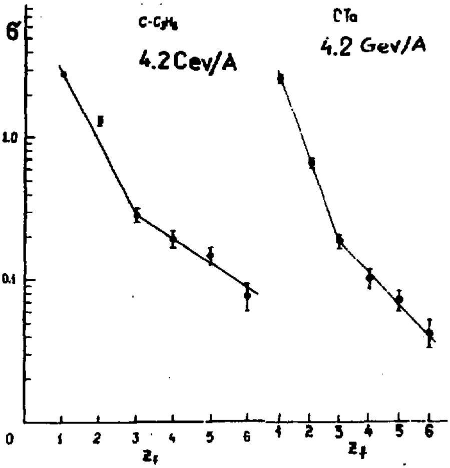

Fig. 29a

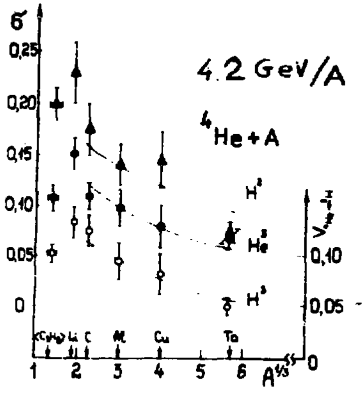

Fig. 29b

ting the experimental data by the curve from the formula

$$\sigma_{in} = 10\pi R_o^2 [A_i^{1/3} + A_t^{1/3} - \beta(A_i^{-1/3} + A_t^{-1/3})]^2 ,$$

one gets the following values for the parameters R_o=1.30 fm and β=0.93.

4.2. Multiple production of fragments and their interaction cross sections

Not all nucleons of the incident nucleus interact in the inelastic collision of relativistic nuclei with nuclei. Owing to a relatively coupling of nucleons inside the nucleus, a part of them remains spectators (stripping effect). Not only nucleons but also projectile fragments (fragmentation effect) can be such stripped objects in collisions of nuclei heavier than the deuteron.

The effect of nuclear fragmentation in nucleus-nucleus interactions has been studied at the synchrophasotron by means of the 2m propane bubble [63] and streamer chambers [64] and nuclear emulsions [65]. A great deal of information on this process has been obtained in these experiments.

Figure 29a presents data on the production cross sections for fragments of different charge versus the atomic weight of target-nucleus, and fig.29b shows the values of fragment charge obtained in ^{4}He and ^{12}C interactions with different target-nucleus for an energy of 4.2 GeV/nucleon. One can see that a) the dependence of the cross sections of fragment production on the atomic weight of target-nucleus is well described by the curve obtained from the model of multiple scattering. In so doing, the probabilities of joining noninteracting nucleons to a coupled system turn out to be rather large.

b) The behaviour of the cross sections of nuclear fragmentation versus the charge of fragment production is approximated by the curve composed of two exponents with a kick point at $Z_f=3$.

c) For ^{12}C + propane interactions an excess yield of He nuclei (α-particles) is observed which are often produced in groups. In particular, one α-particle is produced in (39±3)%, two in (51±3)% and three in (10±3)% of events.

In a number of papers [66]) devoted to the study of inelastic nuclear collisions for high energies the effect of "anomalous" increasing interaction cross sections for secondary stripping fragments having charge $Z_f \geqslant 2$ of projectiles with target-nucleus has been reported. This information has aroused considerable interest because this effect can be directly associated with the possible existence of excited fragments with an anomalously large cross section and a lifetime of $\sim 10^{-10}$s. However, the present-day experimental situation of a real existence of such fragments ("anomalons") is ambiguous and requires futher studies [67]).

An attempt to observe anomalons has been made by the group [68]) at the 2m propane bubble chamber, HEL on a beam of carbon nuclei with a momentum of 4.2 GeV/c/nucleon. Interaction cross sections of secondary fragments with $Z_f = 5$ and 6 in propane were measured. The charge of the fragments was identified by the density of δ-electrons and by evaluating the total charge of stripping fragments in primary and secondary stars [69]).

Figure 30a shows the dependence of the number of noninteracting fragments on the distance X from the primary star (open circles), i.e. the speed of decreasing the number of fragments is shown as a function of target thickness. The expected decrease (dashed lines) is evaluated using the experimental data on interaction cross sections of primary protons, deuterons, He and C nuclei in propane obtained by this group under the same conditions [70]). For the fragments with $Z_f = 6$ the slope of the line corresponds to the interaction cross sections of beam nuclei with propane, and for the fragments with $Z_f = 2$ and 5 the lines are plotted taking into account corrections to the interaction cross sections of ^{4}He and ^{12}C nuclei with propane because of the admixture of other isotope states. These data are normalized to the number of observed fragments for X = 10cm. As it follows from the figure, at small distances X(X 10cm) one can see distinctly the loss of fragments with $Z_f = 2$ and the increased number of fragments with $Z_f = 6$. This is due to the superposition of the tracks of fragments with $Z_f = 2$ (or other charged particles) in proximity to the primary star that imitates fragments with large charge.

The experimental data given in fig.30a can be represented as the dependence of cross sections of fragments on their atomic weight. Such a dependence is shown in fig.30b. The dashed line is the result of approximation of the measured interaction cross sections of primary protons, deuterons, He and C nuclei with propane (black triangles in the figure). The interaction cross sections of secondary fragments with propane are denoted by black circles. From the figure it is seen that the slope of the distribution of experimental points for fragments with $Z_f = 5$ and 6 is larger than that of the dashed lines. This means that the cross sections of fragments with $Z_f = 5$ and 6 is larger than the expected value ($\sim$10%). This result is an evidence for the possible existence of excited fragments with a lifetime of - 10^{-10} which gives an anomalous value of their croes section in propane.

4.3. Some characteristics of particles produced in inelastic nucleus-nucleus interactions

A systematic study of characteristics of secondary particles produced in inelastic nucleus-nucleus collisions for relativistic energies is the important source of information not only on one--nucleon but also on multinucleon interactions which give rise to multiple particle production. The study of properties of these particles versus the "multinucleonic degree" allows the dynamics of their production to be reconstructed fairly completely.

4.3.1. Multiplicity of secondary particles

Available experimental data obtained in hadron-nucleon and hadron-nucleus interactions for high energy demostrate a weak dependence of the ratio of the mean multiplicity of produced particles to its dispersion ($\langle n \rangle / D$) on the energy of the projectile and the atomic weight of the target-nucleus [71]. If the charge of aninitial system is taken into account in the analysis of the multiplicity distribution of secondary particles, all available data for the interactions indicated can be described by a universal dependence of the type

$$D = a\langle n \rangle + b .$$

New experimental data on the multiplicity of secondaries in *nucleus-nucleus interactions at relativistic energies do contra*dict this universality. The results obtained at the synchrophasotron show that the behaviour of the multiplicity distributions for projectiles beginning from the carbon nucleus is quite different from that observed for hadron-nucleus interactions: the value of D increases with increasing $\langle n \rangle$ much faster than the universal dependence (see fig.31). Moreover, selecting a group of events with small impact parameter (the so-called "central" interactions) out of all inelastic nucleus-nucleus collisions, a significant narrowing of the multiplicity distributions is observed [72]. These distributions differ more amd more from the universal dependence and become much narrower than the Poisson distribution as "centrality" of the collisions increases. The observed dependence of D on $\langle n \rangle$ can be explained within the framework of a model with inde-

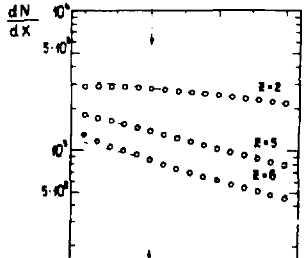

Fig. 30a

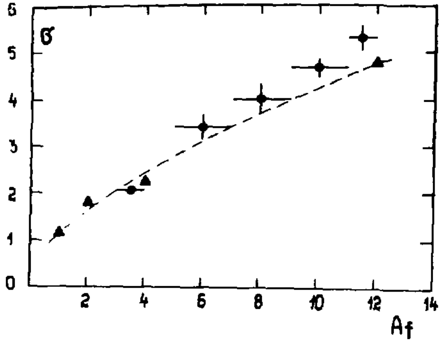

Fig. 30b

pendent interactions of projectile nucleons [73] in which the projectile nucleons (A_i) in nucleus-nucleus collisions are assumed to interact with the target-nucleus (A_t) independently. Taking these assumptions into account, one can get the following expressions for the average multiplicity, $\langle n \rangle_{A_iA_t}$, of secondaries and dispersion, $D_{A_iA_t}$, for nucleus-nucleus collisions in terms of the corresponding characteristics for nucleon-nucleus ($N + A_t$) interactions

$$\langle n \rangle_{A_iA_t} = \langle \nu_i \rangle \langle n \rangle_{NA_t}$$

and

$$D^2_{A_iA_t} = \langle \nu_i \rangle D^2_{NA_t} + \langle n \rangle^2_{NA_t} D^2_{\nu}$$

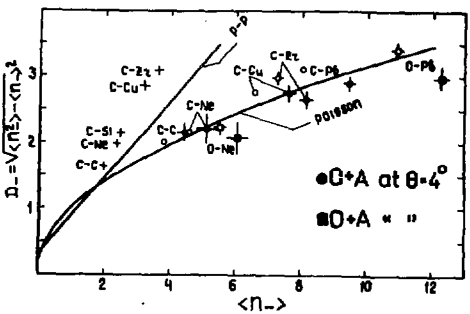

Fig. 31

where $\langle \nu_P \rangle = A_i \sigma(N + A_t) / \sigma(A_i + A_t)$ is the average number of projectile nucleons which interact with the target-nucleus; D is the dispersion of the ν_i-distribution P_ν ($\nu = 1, 2, \ldots, A_i$); $\sigma(N + A_t)$ and $\sigma(A_i + A_t)$ are the elastic cross sections for nucleon-nucleus and nucleus-nucleus interactions, respectively.

A comparison [73] of the experimental data and the calculations with the model gives good agreement.

The results recently obtained on the average multiplicity of neutral particles (γ - quanta, Λ^0 - hyperons and K^0 - mesons) in dTa and CTa interactions at 4.2 GeV/c/nucleon can be explained within the framework of the same model [74].

In this connection the experimental data on the multiplicity distributions [75] and the average values of transverse momentum [74] for charged particles do not confirm the predictions of thermodynamic model [76].

4.3.2. Momentum characteristics of secondary particles

The experimental data are discussed on momentum characteristics of secondaries produced in nucleus-nucleus interactions obtained by the groups of the 2m propane bubble [73,74] and streamer chambers [76] for projectile momenta of 4.2 and 4.5 GeV/c, respectively. The properties of π^--mesons and protons produced in nuclear reactions with small impact parameter (central interactions) were studied in these experiments.

Figure 32a,b presents the momentum characteristics of π^--mesons and protons produced in central CC interactions versus their rapidity ($y = [(E + P_\parallel)/(E - P_\parallel)]$). The limit of the kinematical region for NN collisions is denoted by a dashed line. One can see that for π^--mesons the maximum density of events is observed near $y \approx 1.1$ and for protons at rapidities beyond the limit of the fragmentation regions of projectile and target-nucleus.

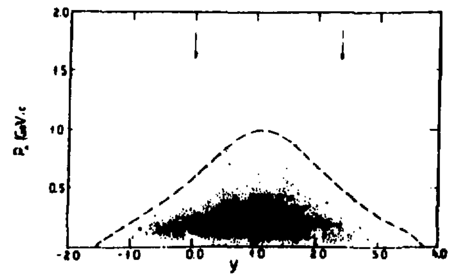

Fig. 32 a

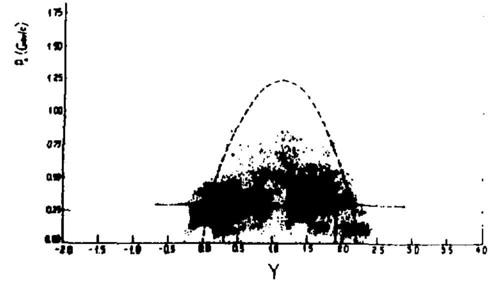

Fig. 32b

In fig. 33a,b are shown similar distributions for π^--mesons and protons produced in CTa interactions. In this case the behaviour of the characteristics significantly differs from that observed for CC interactions.

At the same time one can notice that a large number of pions and protons, the characteristics of which are beyond the limit of the kinematical region for NN collisions, is observed in CC and CTa central interactions. A similar situation takes place also for Λ^0-hyperons produced in dTa and CTa interactions for a momentum of 4.2 GeV/c per nucleon [74].

Figure 34a,b,c presents the distributions of π^--mesons and protons produced in CC, dTa and CTa central interactions versus the transverse momentum squared (P^2). The experimental data are rather well described by the curve composed of the sum of exponents:

$$\frac{dN}{dP_{\perp}^2} = A e^{-aP^2} + B e^{-bP^2} + \ldots$$

These curves are denoted by solid lines. From the figures one can draw the following conclusions:

- The slope parameters for π^--meson production in CC interactions are somewhat different from those observed in NN collisions for the same energy of projectile: a relative contribution of the second exponent is 33% in CC and 23% in NN interactions. A relative contribution of the second exponent equals 41% and 47% for dTa and CTa interactions, respectively. All the data on the slope parameter for π^--mesons are summarized in table V.
- In table V are presented the slope parameters for proton production in p, d, He and CTa interactions. One can see that the slope parameter of the second exponent does not change, within the experimental errors, with increasing the atomic weight of projectile (except CC interactions).
- An exponential dependence on $P_{\perp}^2$ having a structure at $P_{\perp}^2 = 0.5$ and $1.0 (GeV/c)^2$ is observed for all types of nucleus-nucleus interactions in which protons are produced with characteristics

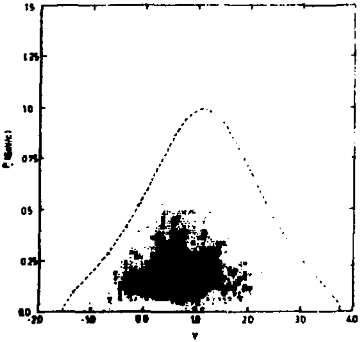

Fig. 33a

beyond the kinematical region for NN collisions. The slope parameter is 1 $(GeV/c)^{-2}$ which can be interpreted as a consequence of proton production in hard collision processes at small distances.

- A comparison of the experimental data and the calculations with the Dubna cascade model with and without taking into account the interaction of secondary particles in the final state (fig. 34b) shows that the experimental characteristics of secondaries produced in the collisions of relativistic nuclei with nuclei of large momentum transfers are not described by the cascade model.

Interesting new results on the property of the average transverse momentum $\langle P_\perp \rangle$ of π^--mesons produced in nucleus-nucleus interactions at 4.5 GeV/c per nucleon have been obtained by the group at the 2m streamer chamber. This group has been found that

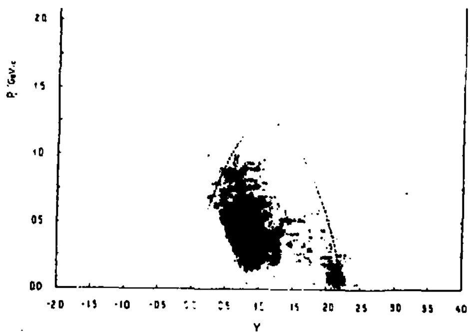

Fig. 33b

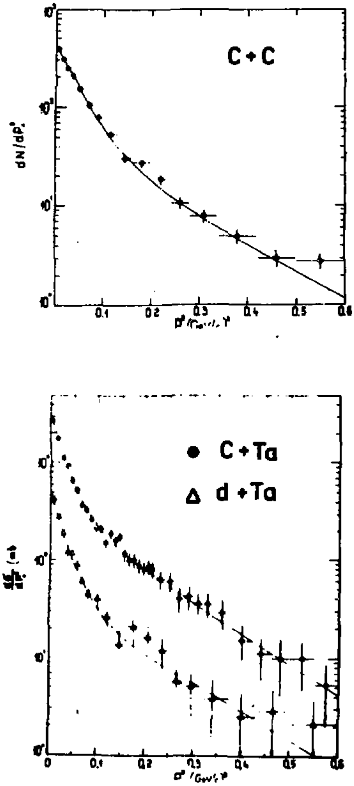

Fig. 34 a

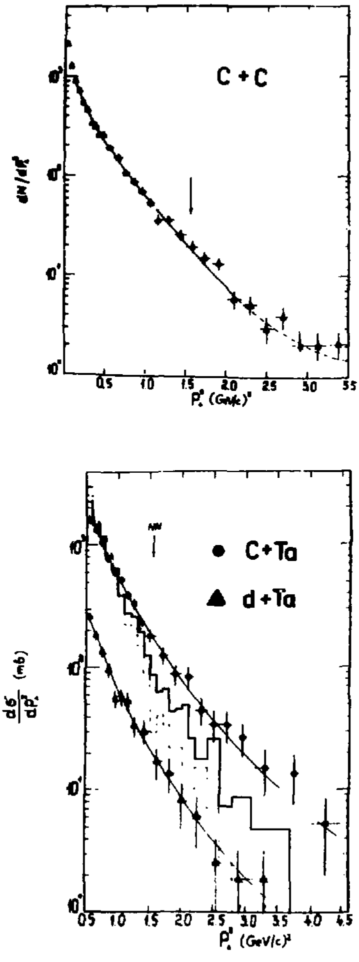

Fig. 34 b

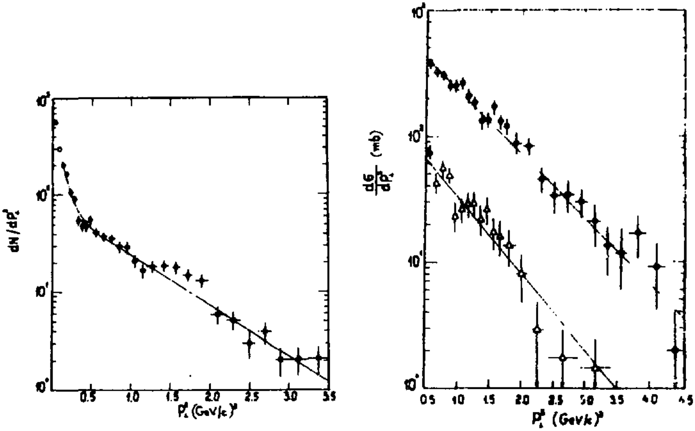

Fig. 34c

the value of $\langle P_\perp \rangle$ for pions, produced in interactions

^{4}He + (^{6}Li, C, Al, Cu and Pb), ^{12}C + (C, Ne and Cu)

and ^{20}Ne + Ne, is independent of the degree of interaction centrality, the mass of the projectile for A = 4÷20 and the mass of target-nucleus for A = 6÷64. Besides, the predictions of thermodynamic model [75] contradict all the experimental data on $\langle P_\perp \rangle$ (see fig.35).

Table V

Type of interaction	a	b	χ^2/ndf
CC	23.1 ± 1.8	6.2 ± 0.9	1.18
CTa → π^-	45.4 ± 2.8	8.3 ± 0.4	0.96
dTa	43.0 ± 4.4	7.8 ± 0.6	0.87
CC	8.7 ± 1.3	2.4 ± 0.2	0.81
CTa	2.62± 0.33	0.99± 0.54	1.05
HeTa → P	3.21± 0.35	0.44± 0.35	1.16
dTa	3.29± 0.39	0.56± 0.54	0.82
pTa	3.19± 0.62	-	0.31

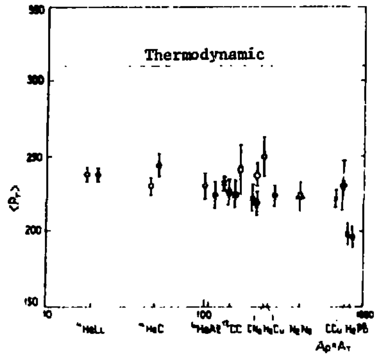

Fig. 35

4.3.3. Dimensions of radiation region of secondary particles

The method of interference of like particles, which has been put forward and developed in papers [77], is widely used to determine the space-time structure of radiation sources of secondary particles produced in multiple production processes. In particular, this method has been applied [78] to the determination of the size of the radiation region (r) for secondary pions from πp interactions at 40 GeV/c and the lifetime of this system (τ) in the laboratory system. The group has obtained that $r = (1.9 \pm 0.3)$fm and $c\tau = (0.8 \pm 0.2)$fm. Futher it has been found that for the same process in the c.m.s. there exist two radiation sources of pions, one of which is due to direct pion production ($r_1 = c\tau_1 \approx 1$fm) and another to pion production from the decay of resonances ($r_2 = c\tau_2 \approx 3$fm).

Concrete information on the space-time structure of generation sources of particles in different processes has been obtained to date using this method [36].

The group working with the 2m propane bubble chamber has obtained new data on the space size of the radiation region of negative pions in nucleus-nucleus interactions at 4.2 GeV/c per nucleon [76]. For CC interactions $r = (3.10 \pm 0.89)$fm and for CTa central interactions $r = (4.11 \pm 1.07)$fm. Note that the size of the radiation region of pions $r = (3.44 \pm 0.41)$fm for all inelastic CTa interactions.

All these data make it possible to confirm that the size of the radiation region of π^--mesons in carbon-nucleus collisions is determined by the dimensions of projectile.

5. Search for unstable superdense nuclei

The existence of superdense nuclei has been first predicted in papers [79]. During the ensuing years attempts have been made to observe this effect. A more complete review of experimental results obtained until 1977 can be found in [80].

One of the fields of a search for radioactive superdense nuclei has been proposed and implemented by A.V.Kulikov and B.M.Pontecorvo [81]. Using the setup with parameters $\tau \geqslant 5 \cdot 10^{-3}$s and $E_e > 45$ MeV, they have obtained the upper limit of the production cross section for radioactive superdense nuclei in pPb interactions.

Later on the energy threshold of electron detection was decreased in the experiments [82], in which bubble chambers were used under special conditions and targets were exposed to relativistic nuclei. This technique allowed one to detect decay particles of practically any energy but it did not allow one to obtain data in the region $\tau \leqslant 10^{-3}$s.

As shown [83], the production of metastable superdense nuclei in nuclear reactions can be observed by delaying nucleon radiation. An experimental search for in this field for the lifetime of metastable states $\tau \geqslant 1$s has been performed in the experiment [84].

Below we discuss experimental results [85] on a search for superdense nuclei unstable to β-decay for a lifetime of $10^{-8} \leqslant \tau \leqslant 10^{-6}$s and metastable superdense nuclei decaying with π°-meson emission for a lifetime of 10^{-7}-10^{-1}s. These experiments have been recently carried out at the synchrophasotron on beams of carbon relativistic nuclei. The momenta of the beam of ^{12}C nuclei extracted from the synchrophasotron were 1.68 and 4.5 GeV/c. A layout of the experiment and a trigger system are presented in fig.36. Curve 4 in fig.37 gives the upper limit (with a confidence level of 90%) of the production cross section for superdense nuclei having lifetime τ and decaying with the emission of electron or positron with $E \geqslant 45$ MeV in ^{12}CPo interactions at 4.5 GeV/c per nucleon. Curve 5 shows the upper limit (with a confidence level of 90%) of the production cross sections for nuclei, unstable to the emission of π°-mesons with a kinetic energy of ~50 MeV, in ^{12}CPb interactions for a momentum of 1.68 GeV/c per nucleon.

As seen from the figures, the probability of nucleus production having a lifetime of 10^{-8}-10^{-6}s with the emission of electron/positron with $E_e > 45$ MeV is no larger than $3 \cdot 10^{-4}$ in inelastic CPb interactions, and the probability of nucleus production having a lifetime of 10^{-7}-10^{-1}s with the emission of π°-meson does not exceed $6 \cdot 10^{-4}$ in inelastic CPb collisions.

The data on the observation of superdense nuclei are summarized in table VI.

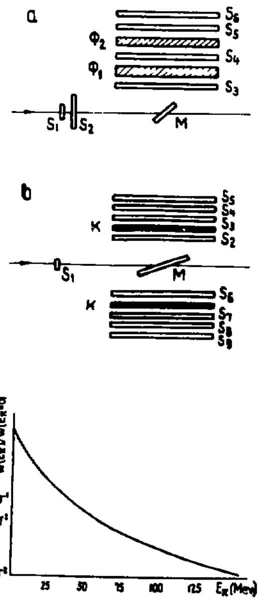

Fig. 36

Table VI

	NATURA	P(10-100)GeV	n,f	Heavy ions $E \gtrsim 1$ GeV/A
$E_s/E_0 \gg 1$	R.Holtet et al.[1] $(Rn)_s \lessdot 10^{-29}$ Si $Rn_s(n,\gamma)$, E>30 MeV S.Frankel et al.[2] (P,P′) C-Ta, 10^{-7}	B.M.Pontekorvo et al.[3] E_β >45 MeV $\tau > 5.10^{-3}$ sek $\sigma \lessdot 10^{-33} cm^2$	G.Samosvat et al.[4] E_γ, En 40 MeV $< 10^{-7}$/act	P.B.Price et al.[5] Ar+Pb $\to (fr)_s$ $< 10^{-31} cm^2$ A.Abdivaliev et al.[6] $C + A \to A_s^*$ $A_s^* \to B$, $E_\beta > 20$ MeV $10^{-29} cm^2$ M.Kh.Anikina et al.[7] $C + Pb \to A_s^*$ $A_s^* \to \pi^0, \beta$ $E_\beta > 45$ MeV $\tau > 10^{-6}$ s $\sigma < 10^{-29} cm^2$ $E_{\pi^0} \approx 50$ MeV $\tau > 10^{-7}$ s $\sigma < 10^{-29}$ s
$E_s/E_0 \ll 1$	V.Aleshin et al.[8] a) C-W, $\tau \gtrsim 10^{+21}$ years b) E_γ(Cf) 100 MeV 5 10^{-8}/act A.A.Borovoi et al.[9] E_β (Cf) > 20 MeV $< 2 \cdot 10^{-8}$/act	V.A.Karnaukhov et al.[10] Ta,Th + p,d,α → Rb, Cs, Fr T_β >1 hour, $\sigma < 10^{-32} cm^2$ A.G.Bugorsky et al.[11] P(70GeV)+A$\to X_s$ $X_s \to Y+n+\gamma$ $T_{1/2} \approx 1$ year $\sigma < 3 \cdot 10^{-34} cm^2$		S.P.Avleev et al.[12] C + Fe,Sn,Pb $\to X_s$ $X_s \to 3n + Y$ $\sigma < 10^{-29} cm^3$ $T_{1/2}$ > 1s

1. Phys. Rev. Lett., 36(1976)183
2. Phys. Rev., 13C(1976)737
3. Phye. Lett., 66B(1977)136
4. Phys.Rev.Lett., 34(1975)409
5. Ya.F., 30(1979)313
6. JETP, 81(1981)1153
7. JINR, Dubna, preprint 1-83-275(1983)
8. Letters to JETP, 24(1976)114
9. J. of Phys., G5(1980)723
10. Ya.F., 31(198)289
Nucl,Phys., A381(1982)419
11. Letters toJETP, 32(1980)487
12. JINR, Dubna, preprint P1-81-59c (1981)

6. Conclusion

From the present brief review of experimental results, recently obtained at the synchrophasotron by physicists from JINR member-countries, it follows that

- Relativistic nuclear physics as a new scientific field is successfully being developed at JINR.
- Over a relatively short period of time many results, the scientific significance of which is generally recognized, have been obtained on beams of relativistic nuclei. First of all, this concerns the studies of nuclear collisions, in which a momentum significantly exceeding a nucleon Fermi momentum in the nucleus is transferred to atomic nuclei. This is the experimental confirmation of the cumulative effect and its main properties, the existence of the region of limiting nuclear fragmentation and so on.
- New information has been obtained on the observation of multiquark states in nuclei and nuclear processes.
- Important results have been obtained on the properties of nuclear reactions at small internucleon distances that allowed one to clarify a general picture of the dynamics of these processes fairy completely.
- The program of experimental research in the field of relativistic nuclear physics being performed at the Dubna synchrophasotron directly connects to important problems of elementary particle and high energy physics, which are being solved on the largest accelerators of the world.

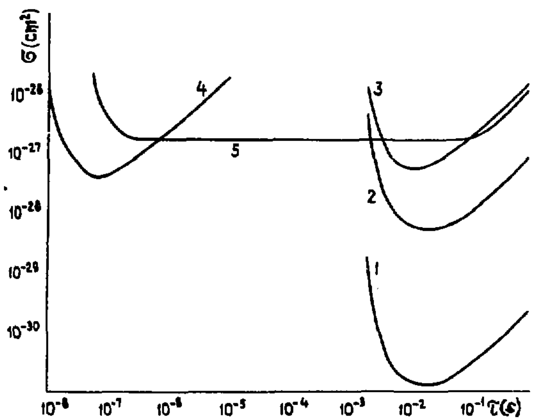

Fig. 37

References

1. Yu.D.Beznogikh et al., JINR, Dubna, preprint P9-4214(1968); Pribory i tekhnika eksperimenta, 4(1969)202; A.M.Baldin et al., JINR, Dubna, preprint P9-5244(1970).
2. A.M.Baldin, JINR, Dubna, preprint P7-5808(1971); Int.Conf. on Physics of Heavy Ions, JINR, Dubna (1971) D7-5769, p.607; V.P.Alekseev et al., JINR, Dubna, preprint 9-7148(1973).
3. A.M.Baldin, ECHAYA, v.8, is.3,(1977), p.429; V.S.Stavinsky, ECHAYA, v.10, is.5(1979), p.949; V.G.Grishin, UFN, v.127, is.1(1979), p.51; A.A.Kuznetsov, JINR, Dubna, preprint E1-82-660(1982).
4. A.M.Baldin, Proc. XIX, Int.Conf. on HEP, Tokyo, 1978, p.445; Progress in Particle and Nuclear Phys., Pergamon Press, 1980, 4, p.95; V.S.Stavinsky, JINR, Dubna, preprint P1-80-23(1980); G.A.Leksin, Proc XVIII , Int.Conf. on High Energy Physics, Tbilisi, 1976; JINR, Dubna, preprint D1,2-10400(1976).
5. A.M.Baldin, Brief Comm. on Physics, USSR Academy of Science, 1(1971)35.
6. A.M.Baldin et al., JINR, Dubna, preprint P1-5819(1971).
7. A.M.Baldin et al., YaF, 20(1974)1201; JINR, Dubna, preprint 1-8-28(1974); Proc.IV Int.Seminar on HEP Problems, JINR, Dubna, 1975, D1,2-9224.
8. J.W.Cronin et al., Phys.Rev. D11(1975)3105.
9. V.C.Stavinsky, ECHAYA, v.10, is.5(1979), p.949; A.M.Baldin et al., JINR, Dubna, preprint E1-82-472(1982).
10. I.I.Vorobiev et al., Letters to JETP, 22(1975)390; G.A.Leksin, A.V.Smirnitsky, Preprint ITEP(1977)87; Proc., VII Int.Conf. on HEP and NS(1977)311.
11. G.A.Leksin, A.V.Smirnitsky, Preprint ITEP-121(1981).
12. See e.g., Proc VI Int.Seminar on High Energy Physics Problems, JINR, Dubna, 1981, D1,2-81-728.
13. A.M.Baldin et al., JINR, Dubna, Preprint 1-82-28(1982).
14. A.M.Baldin, Proc.Meeting on Studies of Relativistic Nuclear Physics, JINR, Dubna, 1982. D2-82-568.
15. G.A.Leksin, Proc. XVIII intern.Conf. on HEP, Tiblisi, 1976, JINR, Dubna, D1,2-10400(1977).
16. K.Sh.Eginian, JINR, Dubna, D1,2-81-728,(1981)238.
17. L.S.Schroeder et al., Phys.Rev.Lett., 43, 24(1979)1787.
18. A.M.Baldin et al., JINR,Dubna, Preprint E1-82-472(1982).
19. A.M.Baldin et al., JINR, Dubna, Preprint E1-80-545(1980); Preprint 1-82-28(1982).
20. N.A.Nikiforov et al., Phys.Rev.C22(1980)700.
21. V.S.Stavinsky, JINR, Dubna, Comm. P2-80-767(1980).
22. A.M.Baldin, JINR, Dubna, Preprint E1-80-545(1980).
23. A.Argento et al., Preprint CERN/EP/81(1981).
24. Workshop on A$^{\alpha}$ Physics, Fermilab preprint Conf. 82-39(1982).
25. See e.g. refs. in B.Brown et al., Preprint Fermilab-Pub-82/74--Exp(1982).
26. W.Bell et al., Preprint CERN-EP/82-25(1982); Phys. Lett. 112B (1982)271; A.Karabarbounis et al., Phys.Lett., 104B(1981)75.
27. N.N.Nikolaev, ECHAYA, (1981), v.12, is.1, p.162.
28. G.N.Agak9shiev et al., JINR, Dubna, Preprint 1-82-783(1982).
29. B.B.Abramov et al., YaF, B1(1980)660.
30. V.I.Bogashin et al., YaF, 35(1981)4.
31. A.U.Abdurakhimov et al., JINR, Dubna, Preprint E1-80-598(1980).
32. D.Sivers et al., Phys.Rep., 23C(1976); R.D.Field, R.P.Feynman, Phys.Rev., D15(1977)2590; R.D.Field et al., Nucl.Phys. B128 (1977)1.

33. G.I.Lykasov, JINR, Dubna, Preprint E2-82-651(1982); G.I.Lykasov, B.Kh.Sherkhonov, JINR, Dubna, Preprint P2-82-665(1982); Preprint P2-82-911(1982).
34. J.W.Cronin et al., Phys.Rev., D19(1979)764.
35. A.I.Anoshin et al., JINR, Dubna, Preprint E1-82-352(1982).
36. A.A.Kuznetsov, JINR, Dubna, Preprint E1-82-660(1982).
37. M.Basile et al., Phys. Lett., 92B(1980)367; 95B(1980)311; 99B (1981)247; Nuovo Cim., 58A(1980)193; 29(1980)491; 30(1981)389; 31(1981)273;
S.P.Ratti, XX int.Conf. on HEP, 1980, Madison, Wisconsin, v.1, p.84;
R.Gottgens et al., Nucl. Phys., B178(1981)392; V.G.Grishin et al., JINR, Dubna, Preprint P1-81-542(1981);
M.Barth et al., Nucl.Phys., B192(1981)289;
D.Haidt, DESY 81-084, 1981.
38. S.Brandt, H.D.Dahmen, Z.Phys., C1(1979)61.
39. V.G.Grishin et al., JINR, Dubna, Preprint P1-82-393(1982).
40. N.N.Nikolaev, UFN, 134(1981)370; Yu.M.Shabelsky, ECHAYA, 12 (1981)1070.
41. BBCDSSTTU-BW Collabor., Phys.Lett., 39B(1972)371; N.Angelov et al., YaF, 25(1977)1013.
42. J.J.Auber et al., CERN-EP/83-14.
43. A.Bodek et al., Preprint UR 41/COO-3065-348, SLAC-PUB-3041, January 1983.
44. A.Bodek, J.L.Ritchie, Phys.Rev., D23(1981)1070; D24(1981)1400;
A.Bodek, Nucl.Inst. and Meth. 117, (1974)613; 150(1978)150.
45. V.A.Matveev, P.Sorba, Lett.Nuovo Cim., 70(1977)135; S.M.Dorkin et al., JINR, Dubna, Preprint P2-82-913(1982).
46. L.S.Azhgirej et al., YaF, 27(1978)1027; 28(1978)124; 28(1978)445; 28(1978)1005.
47. V.G.Ableev et al., JINR, Dubna, Preprint E1-82-377(1982); Preprint E1-82-516(1982); Preprint E1-82-777(1982).
48. J.Papp, Preprint LBL-3633(1977).
49. S.M.Dorkin et al., JINR, Dubna, Preprint P2-82-81(1982).
50. A.P.Kobushkin, Preprint ITP-76-145E, Kiev(1976); YaF, 28(1973) 495; A.P.Kobushkin, L.Vizireva, Nucl.Phys.G(1982)893.
51. P.Boster et al., Phys.Rev.Lett. 49(1982)1380.
52. I.L.Agranovich et al., YaF 25(1977)1123.
53. V.G.Ableev et al., JINR, Dubna, Preprint P2-82-81(1981).
54. A.W.Thomas, Pef.Th., 336B-CERN/IPP-82-29(1982);
Yu.A.Simonov et al., Phys.Lett., 107B(1981)1;
V.K.Lukjanov, A.I.Titov, Proc. of the Int.Conf. on Extreme States in Nucl.Systems, Drezden, 1980, v.2, p.60.
55. P.J.D.Mulders et al., Phys.Rev., D21(1980)2653;
H.Hogasen et al., Phys.Scripta, 24(1981)755.
56. B.A.Shahbasian et al., Nucl.Phys., A374(1982)73;
B.A.Shahbasian, JINR, Dubna, Preprint E1-82-446(1982).
57. D.Eastwood et al., Phys.Rev., 3(1971)2603; D.P.Goyal et al., Phys.Rev., D18(1978)948.
58. A.Abdivaliev et al., JINR, Dubna, Preprint D1-82-241(1982).
59. A.P.Gasparian et al., PTE, 2(1977)37.
60. B.G.Grishin, Inclusive Processes in Hadron Interactions at High Energy, Energoizdat, 1982, Moscow.
61. N.Angelov et al., JINR, Dubna, Preprint P1-80-473(1980);
V.S.Stavinsky, JINR, Dubna, Preprint 2-80-66(1980).
62. M.Kh.Anikina et al., JINR, Dubna, Preprint 1-82-553(1982).
63. A.P.Gasparian et al., JINR, Dubna, Preprint P1-81-753(1981);
Ts. Baatar et al., JINR, Dubna, Preprint P1-80-209(1980).
64. A.U.Abdurakhimov et al., JINR, Dubna, Preprint E1-80-598(1980).
65. K.D.Tolstov, Z.Phys., A301(1981)339.

66. E.M.Fridlender et al., Phys.Rev.Lett., 45(1980)1084; P.L.Jain et al., Phys.Rev.Lett., 48(1982)305; H.B.Barber et al., Phys.Rev.Lett., 48(1982)856.
67. N.Angelov et al., JINR, Dubna, Preprint P1-80-473(1980);
68. N.Akhababian et al., JINR, Dubna, Preprint E1-82-510(1981).
69. A.P.Gasparian, N.S.Grigalashvili, JINR, Dubna, Preprint 1-11335 (1979).
70. Ts.Baatar et al., JINR, Dubna, Preprint P1-81-516(1981).
71. A.K.Wroblewski, Acta Phys.Polon., B4(1973)857; J.Bartke, JINR, Dubna. Preprint E1-80-754(1980).
72. V.Aksinenko et al., Nucl.Phys., A324(1979)266.
73. N.Angelov et al., JINR, Dubna, Preprint P1-12281(1979); Yadern. Fiz., 30(1979)1590; A.U.Abdurakhmanov et al., Z.Phys., C5(1980)1; A.Bialas et al., Nucl.Phys., B111(1976)461.
74. N.Akhababian et al., JINR, Dubna, Preprint D2-82-445(1982).
75. M.Hagedorn, J.Rafelski, Phys.Lett., 97B(1980)136.
76. M.Kh.Anikina et al., JINR, Dubna, Preprint 1-82-581(1982); N.Akhababian et al., JINR, Dubna, Preprint E1-82-510(1982).
77. G.I.Kopylov, M.I.Podgoretsky YaF, 15(1972)392; 18(1973)656; 19(1974)434.
78. N.Angelov et al., YaF, 33(1981)2257; 35(1982)76; JINR, Dubna, Preprint P1-82-334(1982); Preprint P1-82-908(1982).
79. A.B.Migdal, Fermions and bosons in strong fields, Nauka,(1978), Moscow.
80. V.A.Karnaukhov, USSRAS Izvestiya, 41(1977)1538.
81. A.V.Kulikov, B.M.Pontekorvo, JINR, Dubna, Preprint P1-10202 (1976).
82. A.Abdivaliev et al., JETP, 77(1979)20; 81(1981)1153.
83. I.N.Mishustin, A.V.Karnyukhin, YaF, 32(1980)945.
84. S.P.Avdeev et al., YaF, 36(1982)315.
85. M.Kh.Anikina et al., JINR, Dubna, Preprint 1-83-275(1983).

Received by Publishing Department
on May 26 1983.

SUBJECT CATEGORIES
OF THE JINR PUBLICATIONS

Index	Subject
1.	High energy experimental physics
2.	High energy theoretical physics
3.	Low energy experimental physics
4.	Low energy theoretical physics
5.	Mathematics
6.	Nuclear spectroscopy and radiochemistry
7.	Heavy ion physics
8.	Cryogenics
9.	Accelerators
10.	Automatization of data processing
11.	Computing mathematics and technique
12.	Chemistry
13.	Experimental techniques and methods
14.	Solid state physics. Liquids
15.	Experimental physics of nuclear reactions at low energies
16.	Health physics. Shieldings
17.	Theory of condenced matter
18.	Applied researches
19.	Biophysics

Кузнецов А.А. E1-83-334

Экспериментальные исследования в области релятивистской ядерной физики на синхрофазотроне ОИЯИ

Дается краткий обзор современного состояния программы экспериментальных исследований, выполненных на синхрофазотроне ОИЯИ в области релятивистской ядерной физики. Уделено внимание существующим сегодня возможностям для постановки и проведения на синхрофазотроне исследований, а также обсуждаются наиболее значимые физические результаты, полученные разными группами физиков стран-участниц ОИЯИ в области релятивистской ядерной физики в последние годы.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1983

Kuznetsov A.A. E1-83-334

Experiments in the Field of Relativistic Nuclear Physics at the Dubna Synchrophasotron

In this report we present a brief outline of the current state of experimental research at the Dubna synchrophasotron in the field of relativistic nuclear physics. In particular, much attention is given to the available possibilities of the synchrophasotron which enable us to perform research in the field of relativistic nuclear physics and to discuss the most significant physical results that have been obtained by different groups of physicists from JINR member-countries in the last few years.

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

Preprint of the Joint Institute for Nuclear Research. Dubna 1983

Перевод Л.Барабаш.

46 коп.

Переводчик Л.Барабаш. Макет Н.А.Киселевой.

Подписано в печать 30.05.83 г.
Формат 60x90/16. Офсетная печать. Уч.-изд.листов 3,06.
Тираж 520. Заказ 32967.

Издательский отдел Объединенного института ядерных исследований.
Дубна Московской области.