Introduction

In the year 1974, collected articles entitled **"The Nuclotron and Relativistic Nuclear Physics. Research Problems and Experimental Techniques"** (JINR Communication, 8309, Dubna, 1974) were published. These are talks delivered at a meeting devoted to physical grounds for an accelerator complex designed at the Joint Institute for Nuclear Research which was intended to replace the Synchrophasotron. Major trends of the development and concrete proposals of experiments were considered. It was shown that relativistic nuclear physics had good prospects of development at the operating Synchrophasotron and operating experimental setups. Techniques used in performing experiments were discussed.

Since then many seminars, meetings and conferences (including international ones) have been held and appropriate conference proceedings have been published. Of special importance are the Proceedings of the Conferences-Seminars **"Relativistic Nuclear Physics and Quantum Chromodynamics"**. Abstracts of the research projects of the Laboratory of High Energy Physics for the period from I991-I995 were also published (JINR Communication, P1,2-89-631, Dubna, 1989).

Relativistic nuclear physics became a major scientific trend. Many of the suggestions entering the abovementioned proceedings have been realized. Some of the results preliminarily discussed were then recognized worldwide. Prognoses and hopes suggested have mainly been justified.

The main problem of relativistic nuclear physics - study of the properties of highly excited states of nuclear matter at small distances - grew into the problem of investigation of relativistic multiparticle systems. It became clear that experiments in this domain bore a direct relation to the central problem of strong interaction physics - quantum chromodynamics of large distances (or, more exactly, of small relative four-dimensional velocities) and the problem of quark confinement. The Proceedings of the Seminar **"Relativistic Nuclear Physics and Quantum Chromodynamics"** have given a rather complete idea about the development of this area in different countries and research centres for nearly twenty-five years.

The present collection contains information about experiments and projects in which collaborators of the Laboratory of High Energy Physics of JINR are participating or will participate. The projects are worked out by groups, collaborations and divisions of the Laboratory of High Energy Physics, as well as by other JINR Laboratories and institutes of the JINR member-countries and some other countries. The lists of the authors and the relevant institutes are appended to each abstract of the project.

A large number of Laboratory's problems is concentrated on a single scientific trend, namely search for regularities in the behavior of relativistic multiparticle systems. The study of these regularities is of much importance for astrophysics and cosmology, and for understanding phenomena occurring at the moment of formation of Universe as a result of Big Bang. These laws are also needed to create systems for electronuclear power engineering and solving the oblems of reduction and destruction of radioactive waste from atomic electric power stations. In addition, for applications it is important to accumulate and describe quantitatively experimental data on interactions of relativistic ions with matter.

The main fraction of the abstracts is devoted to experiments on the Synchrophasotron-Nuclotron accelerator complex. It is just at the Laboratory of High Energy Physics that one has discovered and is studying a universal law which makes it possible to describe cumulative, subthreshold inclusive processes, antimatter production processes, as well as transition processes in the region where a transition from nucleon to quark-gluon variables proceeds. The most urgent problem of today is the discovery of the boundaries of validity of this universal law.

The basic variables on which the cross section for multiple particle production in the interaction of a relativistic nucleus I with a nucleus II in the reaction

$$I + II \rightarrow 1 + 2 + 3 + \ldots \quad (1)$$

depends are invariant intervals in the four-velocity space:

$$b_{ik} = -(u_i - u_k)^2 = 2[(u_i u_k) - 1] = 2\{[E_i E_k - (\mathbf{p}_i \mathbf{p}_k)]/m_i m_k - 1\},$$

where $E_{i,k}$, $\mathbf{p}_{i,k}$ and $m_{i,k}$ are the energy, three-dimensional momentum and the mass of particle i or k, respectively, and $u_{i,k} = \{E_{i,k}/m_{i,k}\, ;\ \mathbf{p}_{i,k}/m_{i,k}\}$. The indices i and k take all possible values for process (I): I, II, 1, 2, 3, …

In many formulations of the problems described in the present paper the cross sections are studied as functions of the quantities $b_{I\,II}$, b_{Ik} and b_{IIk} forming a triangle in the four-velocity space. Also it is possible to describe correlation phenomena in terms of the variables b_{ik}. For orientation we note the relation of the variables b_{ik} to the kinetic energy of relative motion of particles in the rest frame of one of them:

$$b_{ik} = 2(T_{i,k}/m_{i,k})$$

In the rest frame of one of the nuclei the quantity $b_{I\,II} = 2(T_{II,\,I}/m_{II,\,I})$, that is, the value of this variable $b_{I\,II}$ is proportional to the kinetic energy per nucleon of colliding nuclei.

The universal law has been established on the basis of experimental data obtained in the seventies at the Laboratory of High Energy Physics, the Institute of Theoretical and Experimental Physics (Moscow), the Institute of High Energy Physics (Protvino), and others in the range $2 \leq b_{I\,II} \leq 10$.

It was also established that the asymptotic regime is setting up at energy 3.5 - 4 A GeV per nucleon for $b_{Ik} << b_{I\,II}$. The transition to the asymptotic regime is interpreted as a transition from the nucleon degrees of freedom to the quark-gluon ones. This result has been used when choosing the energy of the Nuclotron beams at oblems of reduction and destruction of radioactive waste from atomic electric power stations. In addition, for applications it is important to accumulate and describe quantitatively experimental data on interactions of relativistic ions with matter.

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In the mid-1980s experiments with relativistic nuclei started at CERN (Switzerland) and Brookhaven National Laboratory (USA). Of special interest are experiments with relativistic Pb nuclei at an energy 158 A GeV, in which collaborators from our Laboratory are also taking part (see appropriate abstracts of the projects).

The main task of experiments in Pb beams is the search for quark-gluon plasma production in ultrarelativistic nuclear collisions. The same problem is the main one for experiments on nuclear colliders now being under construction (RHIC at Brookhaven National Lab. and LHC at CERN). Physicists and engineers of the Laboratory of High Energy physics also participate in the preparation of experiments on nuclear colliders.

In spite of numerous theoretical investigations dealing with quark-gluon plasma production in relativistic nuclear collisions, so far one has not succeeded in linking measurable parameters of quark-gluon plasma with the parameters describing the final state of relativistic nuclear collisions. Moreover, according to the universal regularity the effective number of nucleons involved in interaction decreases with increasing energy per nucleon of colliding nuclei. In this connection, experiments with ultrarelativistic nuclei can yield no positive results on the discovery of quark-gluon plasma. In particular, this is seen from the predictions of the universal regularity obtained at the Laboratory. For example, for experiments on the SPS accelerator this regularity has been used to predict qualitative relationships between the production cross sections for antinuclei and nuclei and the production cross sections for direct photons and neutral mesons.

Nevertheless under certain conditions quark-gluon plasma can arise in a continuous medium, i.e. under quite different initial and boundary conditions in comparison with ultrarelativistic nuclear collisions, for instance, in stars. Processing of the available experimental data carried on at the present time will answer many questions. It should be noted that, according to the universal law, the dependence of the inclusive particle production cross sections upon the nucleus collision energy $(u_I \cdot u_{II})$ is of the form:

$$(u_I \cdot u_{II}) \cdot (b_{ik}/b_{IIk}).$$

In the region $b_{Ik} << b_{IIk}$ and $b_{Ik} << b_{I\,II}$ this quantity transforms into $b_{Ik}/2x_k$, x_k where is the light cone variable. Hence, it is seen that the validity of the limiting fragmentation hypothesis by Yang et al is confirmed starting from the universal law. Therefore numerous experiments on the verification of the limiting fragmentation hypothesis should be considered as an experimental check of a more general regularity. Universality of the regularity in question consists in its validity not only in the region of limiting fragmentation, but also in the region of subthreshold processes. Besides, this universality is revealed in a very weak dependence of the cross sections of nucleus collisions upon flavors of produced particles and in a general character of the dependence of the cross sections upon the energy $(u_I \cdot u_{II})$

(the so-called transition regime).

The region in which the universal law is expected to be violated corresponds to $b_{ik} \leq 10^{-2}$ where of importance are nucleon variables and the coulomb interaction of produced particles. For this region there exists a large program of experiments on Nuclotron's internal targets partially given the collection in the present book. Unfortunately the collection does not discuss problems dealing with the study of hard nucleus-nucleus collisions (large transverse momenta, cumulative quark and gluon jets and so on), in which deviations from the universal law in question are possible and QCD calculations are needed.

Polarization experiments presented in it have a very good perspective, though theory in this domain gives only preliminary results and investigations are aimed at search for empiric regularities. Nevertheless, thanks to unique polarized beams of deuterons, protons and quasimonochromatic neutrons on the accelerator complex and original experimental techniques available the Laboratory occupies a leading position worldwide.

Among experiments on the Synchrophasotron- Nuclotron complex discussed in the present book of special importance are experiments with French-American's polarized target modernized at JINR. As is shown by theorists of the Laboratory of Theoretical Physics, in these experiments there can appear multiple particle interactions in the initial state described by instantons.

The Laboratory plans to obtain polarization data in the relativistic domain. They are certain to play an important part in the construction of strong interaction theory.

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