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STATUS AND PHYSICS PROGRAMME AT NUCLOTRON

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1 Relativistic nuclear physics

In 1973 the Laboratory of High Energies of the Joint Institute for Nuclear Research submitted a proposal for the construction of a specialized superconducting strong-focusing accelerator of nuclei, Nuclotron [1]. Since that time an extensive R&D programme has been initiated and considerable work has been carried out to refine the design and specification of the major accelerator components, as well as the needs for research detectors, and to prepare the project for construction [2],[3]. In December 1986 the Directorate of the JINR took a decision of allocating funding to a five-year Nuclotron Project. At present the construction of the Nuclotron has been completed and the installations built make it possible to start realizing in 1993 a research programme for nucleus-nucleus collisions on the internal beams of the Nuclotron. The essential motivation for the construction of the Nuclotron was the suggestion at Dubna in 1971 and then development of a new field of high energy physics, relativistic nuclear physics.

Relativistic nuclear physics deals with the study of processes in which the constituents of nuclear matter move with relative velocities close to the velocity of light. The quantitative criteria of this closeness and the classification of nuclear interactions are presented below on the basis of a relativistic invariant approach [4] to the description of hadronic processes.

At present we have a clear notion about the general picture of nucleus-nucleus collisions in wide energy range that makes it possible to plan confidently the development of the accelerator complex and construction of installations on nuclear beams. The natural phenomena in relativistic nuclear physics having an asymptotic character have played a decisive role in a detailed construction plan and cost estimate of the Nuclotron. Therefore, before going over to the topic of the talk we should remind of the basic assumptions and ideas of the approach.

In this approach, the multiple particle production processes proceeding in collisions of particles (or nuclei) I and II:

$$I + II \rightarrow 1 + 2 + 3 + ... \qquad (1)$$

are described in the velocity space $u_i = p_i/m_i$, where p_i are the four-momenta of particles involved in the reaction: $i = I, II, 1, 2, 3, ...,$ m_i their masses. The components

$$u_i^0 = \frac{E_i}{m_i};\ u_i^x = \frac{p_i^x}{m_i};\ u_i^y = \frac{p_i^y}{m_i};\ u_i^z = \frac{p_i^z}{m_i}$$

are regarded as the Cartesian coordinates of a point in a four-dimensional space (the end point of the four-vector).

The approach enables us to use all the available experimental information on the basis of the methods of self-similarity, incomplete self-similarity, automodelity and intermediate asymptotics. Employing this method, it was found to be possible to answer the following questions:

- How to describe the states of strongly excited nuclear matter in terms of observable dimensionless quantities?

- Can anything like equilibrium of excited matter be reached in nuclear collisions?

- To what extent the quasi-stationary states of strongly excited matter are due to color degrees of freedom? Is it possible to describe them on the basis of QCD?

- How to determine the conditions for which nucleons or, in general, hadrons lose their identity so that the subnucleonic degrees of freedom play the dominant role in nuclear matter?

The approach makes it possible to i) classify hadron and nucleus interactions; ii) find the laws describing multinucleon interactions of subthreshold and cumulative particle production [4, 5]; iii) check the phenomenological theories formulated in terms of macroscopic variables (energy density, temperature, pressure, and so on).

The above mentioned problems of relativistic nuclear physics have been studied at the Laboratory of High Energies for more than twenty years. Many appropriate talks were submitted to the traditional international seminars of the present series.

Multiple particle production processes are described with the aid of relativistic invariant dimensionless quantities

$$b_{ik} = -\left(\frac{p_i}{m_i} - \frac{p_k}{m_k}\right)^2 = -(u_i - u_k)^2 = 2[(u_i u_k) - 1]. \qquad (2)$$

The relationship between these variables and the usually applied rapidities y_i, transverse momenta p_i^T and azimuthal angles φ_i follows from the well-known formula:

$$(p_i \cdot p_k) = m_i^T m_k^T cosh(y_i - y_k) - p_i^T p_k^T \cos(\varphi_i - \varphi_k),$$

where m_i^T, m_k^T are transverse masses, $m^T = \sqrt{1 + p_T^2/m^2}$ or

$$\frac{(p_i \cdot p_k)}{m_i m_k} = (u_i \cdot u_k) = \frac{E_i E_k - (\vec{p}_i \vec{p}_k)}{m_i m_k}, \qquad (3)$$

where $\vec{p}_i, \vec{p}_k$ are the three-dimensional particle momenta, and $E_i E_k$ their energies in any (e.g., Lab.) coordinate frame. In addition to the hitherto used reasons of dimensionality and invariance, we utilize a hypothesis that when certain $b_{\alpha\beta}$'s tend to infinity the cross sections possess a definite asymptotic behavior. From the mathematical point of view, the self-similarity principle for relativistic invariant distributions (cross sections) is formulated as follows [6]:

$$W(b_{\alpha k}, b_{\alpha\beta}, b_{\beta k}, ...) = \frac{1}{b_{\alpha\beta}^n} \cdot W^1\left(b_{\alpha k}, x_k = \frac{b_{\beta k}}{b_{\alpha\beta}}, ...\right). \qquad (4)$$

W^1 seems to be independent of $b_{\alpha\beta}$ and has self-similarity with respect to this variable. The self-similarity parameter x_k at $b_{\alpha\beta} \to \infty$ turns into the well-known light cone variable. The law (4) is valid with a definite accuracy and in definite limits of change of the variable $b_{\alpha\beta}$. Therefore the appropriate behavior is called intermediate asymptotics. It is easier to determine the quantities n from models or equations than to find general solutions.

As experiments show, the invariant distributions (cross sections) $W(\ldots, b_{ik}, \ldots)$ possess universal properties and are very important when planning experiments. A special case $\alpha = I$, $\beta = II$ and $n = 0$ is equivalent to the phenomenon of limiting fragmentation predicted by Benecke, Chou, Yang and Yen [7].

$$\begin{aligned} E_1 \frac{d\sigma}{d\vec{p}_1} &= F(b_{I\ II}, b_{I1}, b_{II1})|_{b_{I\ II} \to \infty} \to F(b_{II1}, x_1 = \frac{b_{I1}}{b_{I\ II}}) = \\ &= \frac{2}{m_1^2} \cdot \frac{d^2\sigma}{db_{II1} dx_1} = \varphi(\vec{p}_1) \end{aligned} \qquad (5)$$

Of two self-similarity parameters b_{II1} and x_1 only the latter is scale invariant. Hence, it follows that scale invariance is a particular case of self-similarity for fixed b_{III}. In 1971 [8] it was suggested that scale invariance shows a local character of interactions, when they proceed at distances much smaller than characteristic nuclear sizes (nucleon form factors, internucleon distances). In terms of the measurable quantities, it means that for relative nuclear velocities $b_{I\ II}$ much larger than characteristic velocities of internal motions in hadrons the cross sections are no longer dependent upon $b_{I\ II}$. Experiments show that this regime is achieved for

$$b_{I\ II} \sim 5 \div 8$$

which corresponds to the kinetic energy of a nuclear beam of $\sim 3.5\,GeV$.

One of the most important conclusions obtained from works dealing with the analysis of multiple particle processes in the velocity space is the conclusion about the existence of two characteristic scales (correlation lengths): 1) $b_{ik} \sim b_1 \approx 10^{-2}$, nuclear scale, and 2) $b_{ik} \sim b_2 \sim 1$ quark scale [9].

We suggest to perform the classification of relativistic nuclear collisions on the b_{ik} basis in the following manner:

i) The domain $b_{ik} \sim 10^{-2}$ corresponds to the interaction of nuclei as weakly bound systems consisting of nucleons. This is the domain of classic nuclear physics.

ii) The domain $0.1 \leq b_{ik} < 1$ is an intermediate one. Here the quark degrees of freedom are important in rebuilding hadron systems.

iii) In the region $b_{ik} \gg 1$ hadrons lose their meaning of the quasiparticles of nuclear matter and nuclei should be considered as quark - gluon systems. The physical meaning of the criterion $b_{ik} \gg 1$ is as follows: at rather large relative velocities the interaction between the quarks entering object i and those entering object k becomes so weak that it can be treated by perturbation theory at a constituent level.

From this classification and eqs. (4), (5) it follows that at an energy of $6\,A \cdot GeV$, the Nuclotron beams can be used for studying practically all the characteristics of strongly excited nuclear matter, including their asymptotic values.

The most striking characteristics of multiple particle production processes are clusters in the velocity space which were often discussed at the seminars of the present series. The cluster is defined as a group of points being at a short distance from one another. The cluster center, a middle

point, is given by a vector

$$V = \frac{\sum u_i}{\sqrt{(\sum u_i)^2}}. \tag{6}$$

In refs. [4, 9] one studied the properties of the particle distributions in a cluster by means of one of the self-similarity parameter

$$b_{\alpha k} = -(V_\alpha - u_k) \equiv b_k. \tag{7}$$

Maximal particle densities in the velocity space $(dN/db_k)_{max}$ correspond to the cluster centers. The independence of the cluster characteristics of $b_{I\ II}$ in the region $b_{I\ II} > 5 \div 8$ and their sizes in the velocity space $< b_k >$ determined by the order of magnitude by the mentioned correlation lengths b_1 and b_2 indicate that the Nuclotron beam parameters enable us to perform a detailed study of all global characteristics of extremely excited nuclear matter since for the Nuclotron $b_{I\ II} \approx 14$ (for the Synchrophasotron $b_{I\ II} \approx 9.7$).

2 Accelerator Centre of the Laboratory of High Energies (LHE)

Since 1957 the major research facility of LHE has been the Synchrophasotron which provides nuclear beams shown in Table 1. At present, feasibility studies are being performed for the possible concurrent use of heavy-ion beams ($0.3\, to\, 4.5\, A\, GeV$), polarized and alined deuteron beams and secondary beams (neutrons, pions). Running time is 4000h per year. Heavy-ion acceleration takes about 70 percent of the beam time. The possibilities for research will be substantially expanded after putting the world's first superconducting accelerator for relativistic nuclei, Nuclotron, into operation.

A general view of the LHE accelerator centre is given in Fig. 1 and its plan is shown in Fig. 2 and 2a. The main parameters of the accelerators are given in Table 2.

Beam	Intensity (particle per cycle)		
	Synchrophasotron (now)	Nuclotron (plan)	
		1st stage	2nd stage
p	$4 \cdot 10^{12}$	10^{11}	10^{13}
n	10^{10}	$5 \cdot 10^{9}$	10^{13}
d	$1 \cdot 10^{12}$	$5 \cdot 10^{10}$	10^{13}
$d\uparrow$	$1 \cdot 10^{9}$	$3 \cdot 10^{8}$	10^{11}
^{3}He	$2 \cdot 10^{10}$		
^{4}He	$5 \cdot 10^{10}$	$5 \cdot 10^{9}$	$2 \cdot 10^{12}$
^{7}Li	$2 \cdot 10^{9}$	$2 \cdot 10^{10}$	$5 \cdot 10^{12}$
^{12}C	10^{9}	$7 \cdot 10^{9}$	$2 \cdot 10^{12}$
^{16}O	$5 \cdot 10^{7}$		
^{20}Ne	10^{4}	10^{8}	$5 \cdot 10^{9}$
^{24}Mg	$5 \cdot 10^{6}$	$3 \cdot 10^{8}$	$5 \cdot 10^{11}$
^{28}Si	$3 \cdot 10^{4}$		
^{40}Ar	–	$3 \cdot 10^{7}$	$2 \cdot 10^{9}$
^{56}Fe	–	–	10^{11}
^{65}Zn	–	–	$5 \cdot 10^{10}$
^{84}Kr	–	$2 \cdot 10^{7}$	$5 \cdot 10^{8}$
^{96}Mo	–	–	$1 \cdot 10^{10}$
^{119}Sn	–	–	$2 \cdot 10^{8}$
^{131}Xe	–	10^{7}	$2 \cdot 10^{8}$
^{181}Ta	–	–	$1 \cdot 10^{8}$
^{238}U	–	$3 \cdot 10^{6}$	10^{8}

Table 1:

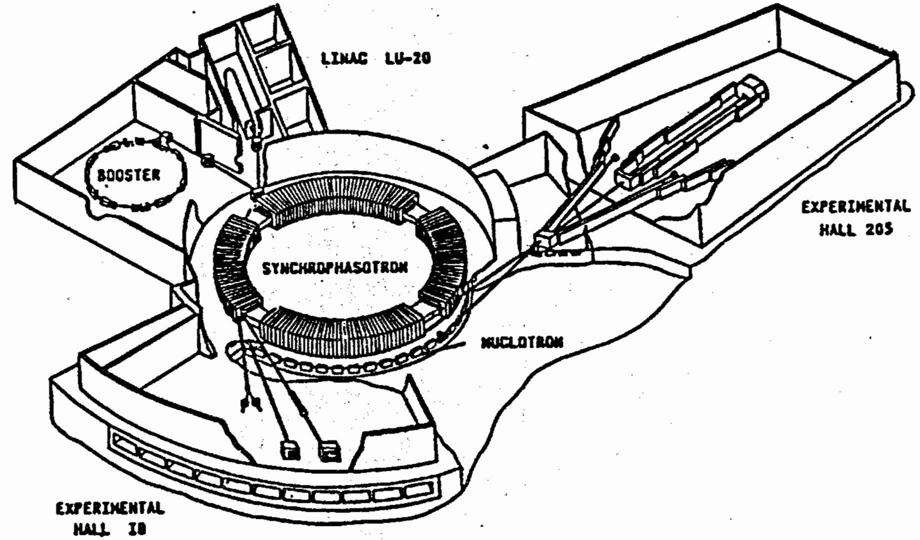


Fig. 1

Parameters		Nuclotron	Synchrophasotron
Energy (max)	A GeV	6	4
Repetition rate	p.p.s	0.5-1.0	0.1
Extraction time	s	10	0.5
Intensity	p.p.c	see Table 1	
Vacuum	Torr	$10^{-10} - 10^{-11}$	$10^{-6}(10^{-7})$
Consumed power	MW	1.5	8
Max. magnetic field in dipoles	T	2.2	1.1
Tunnel circumference	m	250	
SC dipole magnets	N	96	
SC quadrupole lenses	N	64	
Dipole aperture	mm	110	

Table 2.

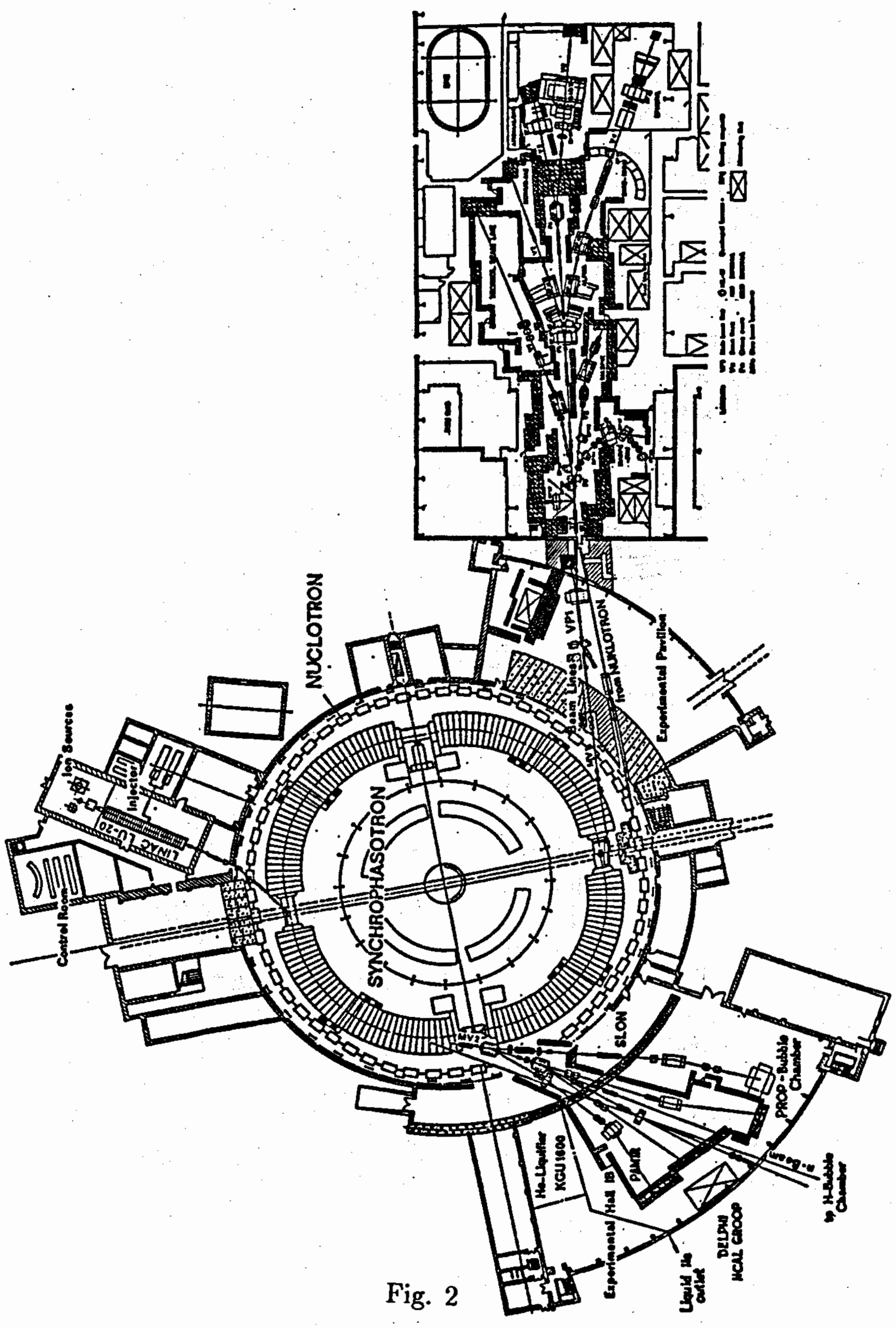

NUCLOTRON
SYNCHROPHASOTRON
Control Room
Ion Sources
Injector
LINAC LU-20
Beam Lines
VP1
from NUCLOTRON
Experimental Pavilion
SLON
PROP-Bubble Chamber
to H-Bubble Chamber
DELPHI HCAL GROUP
Liquid He outlet
Experimental Hall 1B
He-Liquefier
KGU1600
PAMIR

Fig. 2

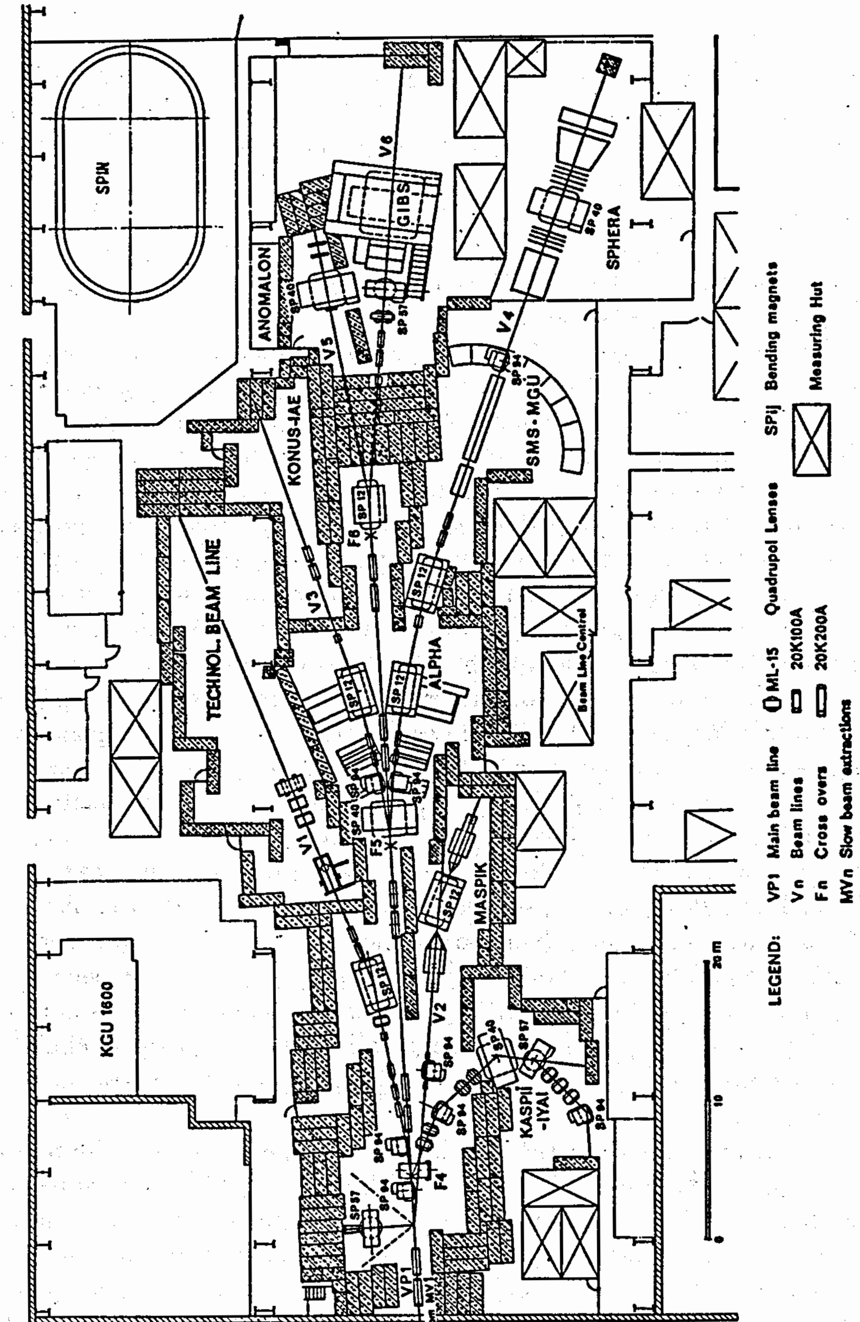

SPIN
ANOMALON
GIBS
V6
SPHERA
V4
V5
SMS-MGU
KONUS-IAE
F6
TECHNOL. BEAM LINE
V3
ALPHA
Beam Line Control
V1
F5
MASPIK
V2
KGU 1600
KASPII -IYAI
F4
VP1
from MV
LEGEND:
VP1 Main beam line
Vn Beam lines
Fn Cross overs
MVn Slow beam extractions
ML-15
20K100A
20K200A
Quadrupol Lenses
SPij Bending magnets
Measuring Hut
0
10
20 m

Fig. 2a

LHE is an open laboratory where the only access condition is the approval of experimental proposals by the JINR Scientific Council. This is reflected by the repartition of national and foreign users community and by the cooperation agreements of different types which exist between different laboratories.

Presently, about 500 researchers representing more than 100 institutions are involved in experiments at the Synchrophasotron. All the user groups working at the Synchrophasotron have suggested their research programmes for the Nuclotron.

The Nuclotron was built on the basis of special superconducting magnets which have been designed by I.A.Shelajev and his co-workers (LHE) [10] and named "Dubna magnets". They are also called "superferric" magnets. The technology of 2 to 2.5 T superconducting iron yoke magnets has been developed by the Laboratory. Such magnets have some advantages over both conventional magnets and 5 T superconducting magnets. The weight of the superconducting magnet is twenty times smaller than a "warm" magnet of the same aperture due to the high current density in the superconducting coil (up to 500 A per mm^2). Moreover, because of the small energy consumption the operation cost is much lower even taking into account costs for the cryostat and refrigerator. Comparing the Dubna magnets with 5 T superconducting magnets, the quantity of superconductor per magnet unit length is smaller by a factor of ten. This decreases energy losses under pulsed operation and field shape distortions, iherent in superconducting coils due to "frozen" currents and so on. A closely wrapped iron yoke lowers the number of required ampere turns of the coil by a factor of two, shapes the field and shields external fields. It also acts as a restraining band to fix the coil geometry. The absence of a nonmagnetic band makes the structure simpler and less expensive, as well as decreasing the stored energy. Lower stored energy affects both the necessary power supply for the accelerator magnets and their reliability, allowing easier evacuation of the energy in any accidental transition to normal state.

A further lowering of the cost is due to eliminating the helium cryostat. The magnet is then force-cooled by liquid helium in hollow superconducting cable. This brings the Dubna magnets still closer to conventional types. The first pulsed superconducting magnet with forced two-phase helium circulation was successfully tested in 1980 and had excellent characteristics [3]. The predicted field value was achieved without training

and the same field was reached when the frequency of triangular cycles was as high as 1 Hz.

Besides the magnet design, the application of superconductivity in an accelerator leads to some problems of integration of the magnets with the r.f., vacuum, injection and extraction systems, etc. A model 1.5 GeV superconducting synchrotron has been constructed at LHE to solve these problems and gain experience. The accelerator contains more than 100 superconducting dipole and quadrupole magnets, in 24 regular FODO cells each 1.5 long, and two matched 9 m straight sections.

The idea of creating economical magnets for iron accelerators with superconducting winding has also been discussed in the USA. In this connection, I would like to refer to CERN Courier (October 1982, p.332): "*There was also a first serious discussion of a very large machine, in the 20 TeV energy region .... One trigger for this discussion was a recent test at Fermilab of a* "superferric" *magnet, based on a concept of Bob Wilson and Leon Lederman. It was a cold-iron, superconducting magnet to provide a low field (for a superconducting magnet) of 2 T*".

The construction and test of a model superconducting synchrotron (SPIN) for 1.5 GeV proton energy have been performed before starting the production of the Nuclotron systems. Manufacturing of a large series of "superferric" magnets for the installation SPIN in Dubna has convincingly shown that this technology provides high reproductivity of the magnet parameters even when manufacturing them in laboratory conditions.

The Nuclotron is a strong focusing separated function synchrotron. The Nuclotron magnet lattice is assembled of 48 separate vacuum-cryostat modules, in each of which there are two dipole magnets and one quadrupole lens cooled by forced two-phase helium circulation. In the ring of the Nuclotron there are 96 dipoles, 64 quadrupoles, 8 trim quadrupoles, 16 sextupoles, 12 octupoles, and 26 magnets for correcting field perturbations. Contrary to the SPIN magnets, in the Nuclotron magnets use is made of hollow (tube-type) superconducting cable for windings. Such magnets (see Fig. 3) invented by A. A. Smirnov (LHE) [3] provide a number of technological and operational advantages: a simplified construction of the cryostat ensures easy access to the superconducting magnets, an essential decrease of liquid helium in the system makes it more reliable, the frequency of triangular cycle is as high as 1 Hz. All the Nuclotron systems and superconducting magnets have been constructed and tested in real conditions. The Nuclotron cryogenic system including two helium refrigerators with primary capacity of 1.6 kW each at about 4 K and the lines transferring helium into the ring provide stable refrigerating and superconductivity regime.

On the 7th and 8th of February, 1992 the test of the magnetic lattice with a beam was realized. The intensity of the injected deuteron beam was about $5 \cdot 10^8$ part./c. A beam signal of intensity of about 10^8 part./c. was registered by a Faraday cup installed behind the second octant of the magnet lattice. Vacuum in the acceleration chamber after refrigeration was obtained to be $10^{-10} - 10^{-11}$ Torr. All stringent requirements for ultimate magnet lattice performance have been fulfilled: magnet powering system, control and regulating system, cooling method, quench protection, dimensional and mechanical requirements.

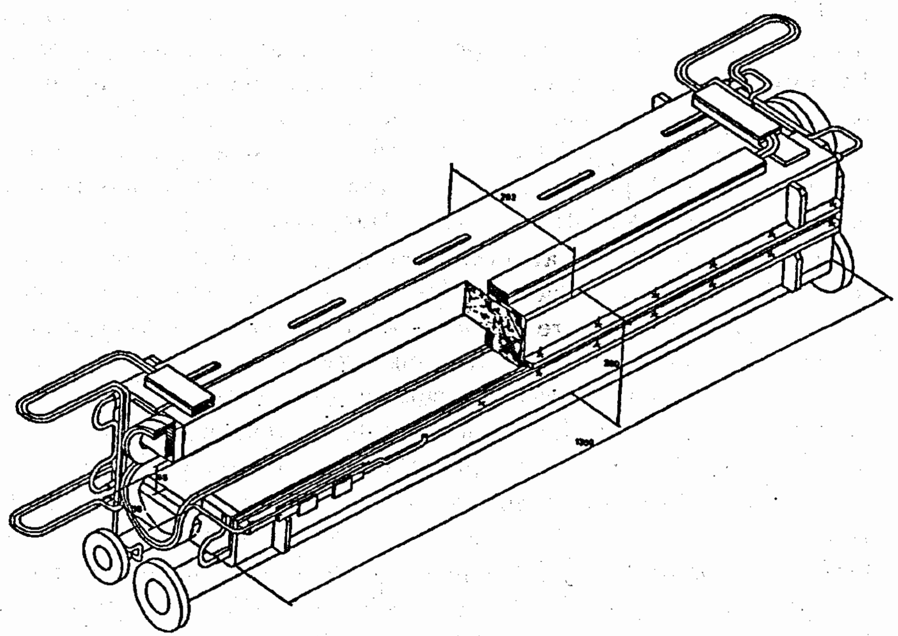


Fig. 3

In order not to interrupt users' research programmes the Nuclotron was being built in parallels with a regular operation of the Synchrophasotron. Both these machines have a common system of extracted beam channels and a common injection (see Fig.1 and 2). During transitional

period a simultaneous operation of the Synchrophasotron and Nuclotron is provided. The Synchrophasotron will be closed down when the beam quality and operation reliability of the Nuclotron will be much better than the ones of the Synchrophasotron.

3 Overview of Research Programme and Future Directions

The research programmes at the Synchrophasotron and the most essential results were reported at many international conferences on nuclear and high energy physics [11]. An overall idea about the investigations in the field of relativistic nuclear physics can be got from the Proceedings of the Dubna International Seminars of the present series. The research programme at the Nuclotron has been composed on the basis of suggestions submitted to the Users' Council of the Laboratory and published in refs. [12]-[13].

The LHE experimental programme addresses to a broad range of forefront questions in relativistic nuclear physics and includes five principal areas of investigation:

1. **Spin observables** have been exploited, both to provide new tests of QCD, and to probe previously unmeasurable aspects of structure nucleons and quark-gluon degrees of freedom of nuclei. As recent theoretical investigations show, the study of spin phenomena sheds light on the fundamental problem of quantum field theory, QCD vacuum structure. A lot of papers submitted to the present seminar are devoted to spin phenomena, including studies with the use of polarized and alined deuteron beams of the LHE accelerator complex. JINR attaches to these studies priority significance.

2. **Collective states and multiple particle production reactions in the collision of nuclei.** Basic notions and the variables describing these processes (1) are given above. Using the variables (2) it is possible to formulate a number of general and universal laws of multiple processes [4], such as correlation depletion principle, intermediate asymptotics and others. One of the most important results is that the b_{ik} distribution decreases monotonously and rapidly with increasing $b_{ik} \to \infty$. This property corresponds to a decrease of the interaction strength between the objects i and k at small spatial distances, that is, to QCD asymptotic freedom.

The study of the particle behavior in the region $b_{ik} \gg 1$ and in the transition region $b_{ik} \sim 1$ enters the research programmes of many groups of physicists at the Nuclotron. The vicinities of the points u_I and u_{II} with $b_{Ii} < 1$ and $b_{IIk} < 1$ contain maximum particle densities $(dN/db_{ik})_{max}$ in the baryon clusters centers [9]. The asymptotic properties of highly excited nuclear matter have been studied by analyzing the universal characteristics of baryonic clusters (see, e.g., ref. [14]). The investigation of baryonic clusters is an important part of all 4π detector programmes at the Nuclotron.

3. Multinucleonic interactions, subthreshold and cumulative processes

These processes are described by a self-similarity parameter

$$\Pi = \frac{1}{2}\sqrt{X_I^2 + X_{II}^2 + 2X_I X_{II}(u_I u_{II})}$$

in terms of which the cross section for a fast particle 1 is expressed as [5]

$$E_1 \frac{d\sigma}{dp_1} = A_I^{\alpha(X_I)} \cdot A_{II}^{\alpha(X_{II})} \cdot f(\Pi) \tag{8}$$

Between the X_I and X_{II} values there exist connections due to laws of energy-momentum conservation

$$(m_0 X_I u_I + m_0 X_{II} u_{II} - p_1)^2 = \left(\sum_{i=2}^{N} p_i\right)^2 = \left(\sum_{i=2}^{N} m_i\right)^2 + \sum_{i>j} m_i m_j b_{ij} \tag{9}$$

and due to minimal mass hypothesis

$$\overline{\sum_{i>j} m_i m_j b_{ij}} \ll \overline{\left(\sum_i m_i\right)^2} \tag{10}$$

where m_0 the atomic mass unit. The four-velocity of a baryonic cluster in the initial state is given by a vector

$$V^c = \frac{X_I u_I + X_{II} u_{II}}{\sqrt{(X_I u_I + X_{II} u_{II})^2}} \tag{11}$$

2Π is the number of nucleons participating in collision. The asymptotics is given by

$$(u_I u_{II}) \to \infty \quad and \quad X_I X_{II}\,(u_I u_{II}) \sim o(1)$$

and

$$X_I \quad or \quad X_{II} \sim 1/(u_I u_{II}) \to 0$$

. The importance of the region of small X's and a weak dependence of the cross sections of these processes on flavours point to their gluonic origin. The development of the programme of primary experiments at the Nuclotron has made this traditional for LHE research trend [15] of particular importance.

4. **Exotic and multiquark systems:** narrow resonances, hypernuclear and isonuclear systems, stable and metastable states are the directions which are widely presented in the research programme at the Synchrophasotron and will be further developed at the Nuclotron.

5. Jets, cumulative jets, nuclear reactions involving charmed quarks.

In our approach, the jet is thought of as a cluster of hadrons with small relative velocities $b_{ik} \sim 1$. By jet axis we mean a unit four-dimentional vector

$$V = \frac{\sum u_i}{\sqrt{(\sum u_i)^2}}$$

The summation is carried over all the particles belonging to a selected particle group. The distribution of the particles in a jet is thought of to be an invariant function $F(b_k, x_k)$ (see eq.(4)).

Numerous investigations [9] of the function $F(b_k, x_k)$ or $\frac{1}{N}\frac{dN}{db_k}$ and $\frac{1}{N}\frac{dN}{dx_k}$ have shown that clusters are characterized by universal properties, i.e. b_k and x_k are self-similarity parameters. The distribution of the two jets α and β in $\pi p, \pi^- C$ and pp collisions over their squared relative four-velocity $b_{\alpha\beta} = -(V_\alpha - V_\beta)^2$ is in full agreement with the law (4)

$$\frac{dN}{db_{\alpha\beta}} = \frac{A}{b_{\alpha\beta}^n} \tag{12}$$

$$\begin{aligned} n_{\pi^- p} &= 3.3 \pm 0.1 \quad (40\ GeV/c) \\ n_{\pi^- C} &= 3.0 \pm 0.1 \quad (40\ GeV/c) \\ n_{pp} &= 3.0 \pm 0.2 \quad (205\ GeV/c) \end{aligned}$$

A comparison of the measured at CDF the two-jet mass distribution with (12) gives

$$n_{p\bar{p}} = 3.05 \pm 0.03 \quad (p\bar{p} \quad at \quad \sqrt{S} = 1800 \quad GeV)$$

The dijet mass is connected with $b_{\alpha\beta}$:

$$M_{jj}^2 = (P_\alpha + P_\beta)^2 \approx 2(P_\alpha P_\beta) = M_\alpha M_\beta b_{\alpha\beta}$$

These results show that the universal asymptotic law (12) is valid in the range

$$5 \cdot 10^2 \leq b_{\alpha\beta} \leq 10^5$$

A jet can be observed if $(V_\alpha u_I) \gg 1$ and $(V_\alpha u_{II}) \gg 1$. That is why, in studying jets the phase volume in the velocity space should be large enough

$$b_{I\ II} \gg 1$$

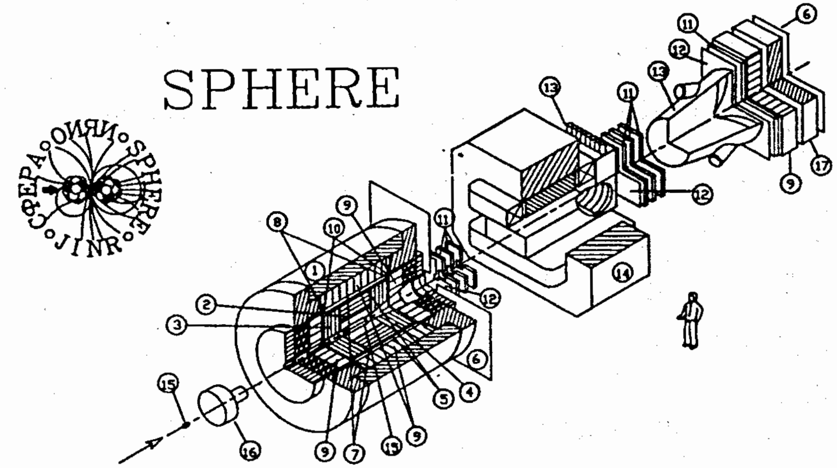
Hence, it follows that the above - mentioned phenomena can be studied at the Synchrophasotron - Nuclotron complex only in the transition region, supplementing these studies with experiments at other accelerators. The cumulative jets are distinct signals showing that a color charge is knocked out from the nucleus.

Future Directions

A general purpose installation SPHERE (Fig.4) is being worked on the Synchrophasotron beams. About 80 participants take part in this collaboration. The research programme and the first experimental results have been reported at the Seminars of this series. Further development of this installation is planned.

Also a general purpose installation is being constructed on the internal beams of the Nuclotron which will be an extended version of similar installations constructed at the LHE for internal beams of various accelerators (Synchrophasotron, Serpukhov, FNAL).

The values of the Nuclotron beam intensities given in the Table 1, last column (2nd stage) will be obtained only after a booster at an energy of 200 $A \cdot MeV$ has been constructed. According to the design [16] the booster will be located in an existing building, in immediate proximity to the linear accelerator and Nuclotron.



1–superconducting solenoid with iron yoke
2–central drift chamber
3–backward drift chambers
4–forward proportional chambers
5–cylindrical scintillation hodoscope
6–muon scintillation hodoscopes
7–cylindrical Cherenkov hodoscope
8–forward and backward Cherenkov hodoscopes
9–electromagnetic calorimeters
10–forward and backward scintillation hodoscopes
11–proportional chambers
12–scintillation hodoscopes
13–threshold gas Cherenkov counters
14–dipole magnet
15–targets
16–beam absorber
17–muon filter

Fig. 4

Further perspectives are connected with the construction of the Supernuclotron complex [12]. It consists of a 60 $A \cdot MeV$ superconducting synchrotron (first stage) and a 2×60 $A \cdot GeV$ nuclear collider (second stage). Use of the same tunnel has been suggested for the location of a 4 to 10 GeV electron accelerator [17].

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