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A.M.Baldin

RELATIVISTIC NUCLEAR PHYSICS: PROSPECT FOR 1997 — 1999

Report to the 81st Session
of the Scientific Council of JINR
January 16—17, 1997

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Relativistic Nuclear Physics (RNP). Nuclotron Development and RNP Experiments.

The research goals

At the present time the scientific programme of the Laboratory of High Energies (LHE) is concentrated around the investigations of interactions of relativistic nuclei in the energy region from few hundred MeV to few TeV per nucleon with the aim of searching for manifestations of quark and gluon degrees of freedom in nuclei, asymptotic laws for nuclear matter at high energy collisions as well as on the study of the spin structure of lightest nuclei.

Experiments along these lines are being carried out using beams of the Synchrophasotron-Nuclotron accelerator complex as well as of other accelerators at CERN (SPS. LHC), Saclay (SATURN), BNL (RHIC).

Historical background

LHE was founded in 1953 on the basis of the new accelerator – Synchrophasotron. The Synchrophasotron was commissioned in 1957 and, thus, the prerequisites were created for establishment of accelerator-based high energy physics in the JINR Member States. The studies in relativistic nuclear physics were commenced in 1971, using the Dubna Synchrophasotron, when beams of relativistic deuterons of 4.5 GeV per nucleon were obtained for the first time. The initial period RNP researches on the Synchrophasotron gave scientific and technical grounds for the construction of a superconducting nuclear accelerator — the Nuclotron (1987-92).

Main research facilities

The Synchrophasotron makes it possible to obtain beams of nuclei with momentum up to 4,5·A GeV/c with intesity 10^{12} per cycle for protons and with gradual lowering of the intensity down to $4.5 \cdot 10^3$ for sulphur. The beams of polarized deuterons and quasi-monochromatic polarized neutrons are unique in the world.

In 1993 the first special-purpose high energy superconducting accelerator of nuclei, Nuclotron, was brought into operation in the Laboratory. The Nuclotron will make it possible to obtain beams of nuclei and heavy ions with energy ranging from few MeV up to 6 GeV/nucleon with qualitatively improved space and time parameters. In 1993-96 the construction of the beam slow extraction system was continued and an internal target experiment program started.

Nowadays, the Synchrophasotron continues to attract physicists from the whole world who are interested in working with relativistic nuclei and polarized deuterons. Active work with the beams of the old machine will make it possible to retain the existing community of physicists and the developed experimental facilities up to the time of complete commissioning of the Nuclotron. This smooth transition means that the potential of the new accelerator will be exploited for investigations from the very beginning.

Main research directions

The scientific programme of the Laboratory includes two complementary directions of research: (*i*) the study of spin and effects of nonnucleon degrees of freedom in lightest nuclei

and, on the other hand, (*ii*) the study of multiple processesin nucleus-nucleus collisions with the aim of searching for collective multinucleon effects and asymptotic laws in nuclei, and transitions of proton-neutron phase of nuclear matter to quark-gluon one.

At present most relevant experiments are aimed at the study of the **transition regime.** Numerous observations indicate that this transition regime is situated at energies from hundreds of MeV per nucleon to about 3,5·A GeV, above which the asymptotic regime set ups. Nowadays, the main attention is devoted to the study of spin phenomena, including spin phenomena in cumulative processes.

Interest in the beams of the LHE accelerator comlex has also increased in connection with the topicality of studying the nuclear physics aspects of electro-nuclear method of energy generation and transmutation of radioactive waste products.

Studies are carried out mainly in the framework of existing collaborations, such as SPHERE, ALPHA, in which the JINR staff members play a uniting role. At the Laboratory there are also research groups from other institutions with own experimental equipments. The Laboratory of High Energies is an open one and the only requirement for using its accelerator facilities is the approvement by the JINR Scientific Council of the experiments proposed.

NUCLOTRON Progress in 1996

During 1996 the Laboratory of High Energies achieved the important advances in improvement of operation on the Nuclotron beam. Two beam runs were carried out. A high luminosity level had been reached in the internal target experiments. **A 10 second beam circulation had been obtained.** Due to budget limitation, only a 20% scheduled beam time was provided as well as a significant portion of the extraction system construction work wasn't fulfilled in 1996.

The concept of a superhigh energy hadron synchrotron/collider of a new generation is considered. Physics motivation for collider at energy above 14 TeV has been suggested and extrapolation of the Nuclotron-type cryomagnetic system for very big accelerators have been done. **It is shown that low-cost low-field iron dominated miniature magnets is the only feasible approach for a superhigh energy accelerator of the next generation.**

RNP Research in 1996

- In 1996 the Synchrophasotron operated during 174 hours The dominant condition of the machine operation is the attraction of the user's resources. In spite of a continious rise of the electricity cost the number of such users doesn't decrease. First of all, these are the polarized beam users. The interest to the traditional beams of light nuclei is still very great.

- Experiments of the FAZA (LNP) collaboration were continued on a carbon beam. The research goal is the study of the decay mechanism of very "hot" nuclei in a 4π-geometry. A new (fourth) decay radioactivity type was discovered in these experiments - thermal multifragmentation. In such a decay, strongly heated nucleus immediatly desintegrates into lightest nuclear fragments. The study of this process is a key to understande the "gas-liquid" transition in nuclear matter.

- A new user of the LHE beams in 1996 is the ENERGIYA-YADRO (Energy-Nucleus) enterprise working in the framework of the S. P. Korolev ENERIYA space-missile corporation. This enterprise carries out experiments on the exploration of the cosmic ray influence on microelectronic components. The ever-growing role of microelectronics in the MIR space station control gives a special topicality to the program. The application of the LHE high energy beam makes it possible to improve reliability of space research equipments. Experts of the French National Space Agency are interested in these studies too.

- Using a deuteron beam the SPHERE collaboration continued experiments development on the cumulative particle production by polarized deuterons. The Japan collaborators (Nagoya Univ.) had delivered a new aerogel Cherenkov detector. The quality of the 100 meter spectrometric channel was significantly improved. Data on pion production in a twice cumulative region were obtained. In this region the contribution of more than one nucleon in each colliding nucleus is necessary for the reaction to proceed.

- Data on the total cross-section difference of proton-neutron interaction in pure helicity states at 1.20, 2.50, and 3.66 GeV were analyzed and published. Further experiments with polarized particle beams and the polarized target make it possible to obtain unique data on the nucleon spin structure.

- The polarized neutron channel was upgraded for future use with the Saclay-ANL polarized target. The DELTA 300-channel lead glass calorimeter (Collaboration (LHE&INR RAS (Troitsk)) was tested for the first time. The nearest task is the measurement η-meson yield as function of the colliding nucleon spin orientation.

- **A new polarization solenoid was produced for the Saclay-ANL polarized target. A field magnitude and homogeneity allow one to resume new unique experiments in the next year.**

- The ALPHA collaboration continued data analysis of the polarization transfer coefficient from a vector polarized deuteron to a stripping proton for a 0-0.57 GeV/c internal momentum region. A change in the coefficient sign was demonstrated. It is necessary to explore a higher momentum region in order to establish an asymptotic behavior of the coefficient.

- A universal approach to the description of subthreshold, cumulative, and twice cumulative processes based on the self-similarity hypothesis is developed. Large experimental material on the production of mesons, protons, antiprotons, and lightest antinuclei in nucleus-nucleus collisions is analysed.

- In the framework of the development of the electronuclear method of energy generation new results have been obtained on the neutron yield energy dependence using a massive lead target irradiated by 2-8 GeV protons. On this basis the primary beam energy and the converter parameters of the subcritical assembly of the ENERGIYA setup will be optimized. In the framework of the transmutation studies the LHE&Marburg Univ. team carried out irradiation of lead, neptunium, and uranium targets in proton and nuclear beams of the Synchrophasotron.

- A 900-channel ToF hodoscope intended for particle identification in a 3-8 GeV/c momentum region has been commissioned by the SPHERE collaboration group in the CERN NA49 SPS experiment. The mean time resolution is 75 picosecond and this

permits reliable identification of charged mesons, protons, antiprotons and deuterons. Rich statistics on interactions of protons and lead nuclei with lead and lead hydrogen targets has been obtained.

Approach to resource planning in 1997-99

Status in 1997

The dominant principle, defining the Laboratory resource concentration in a situation of an extremely reduced budget, is ensuring of on-site opportunities for fundamental research.

The following items are attributed to the unconditional RNP budget expenses: personnel salaries and civil infrastructure costs for heat, water, electricity without the accelerator complex. At present expenses for providing of the research programme include the Nuclotron's ring operation, support & upgrade of ongoing first priority experiments and the Nuclotron development (slow extraction, linac, ion sources). Smoothly reducing expenses for the Synchrophasotron operation are covered due to attraction of user resources.

In general, the existing approach to research planning and budget scheme will be maintained in 1997-99.

Priorities for 1997-99

The first priority will be given to the Nuclotron operation for the internal target experiments (up to 2000 hours per year), obtaining of extracted beam, and injection system upgrade.

Among experiment projects the first priority will be assigned to already ongoing experiments which are further planned to run with the Nuclotron extracted beams, primarily:

- SPHERE, multipurpose spectrometer with 4π geometry (including small scale internal target spectrometers);
- GIBS Project (isobar exitation in nuclei and hyper nuclei);
- FAZA (LNP), 4π nuclear multifragmentation.

As first experiments in a Nuclotron extracted beam oriented on use of an improved beam duty cycle, the following ones are under preparation: search for coherent effects in isobar excitation in nuclear matter (joint efforts of **SPHERE-GIBS-DELTA** teams), studies of multifragmentation phenomena **FAZA (LNP)**) and effects of the transition regime in nuclear collisions (**MARUSYA**).

The Synchrophasotron-Nuclotron accelerator complex will save its role as a unique centre at which there is a high-intensity beam of tensor- and vector-polarized deuterons with high degree of polarization and momentum from 3 to 9 GeV/c. When the accelerated deuterons break up, it is possible to obtain quasimonoenergetic polarized neutrons and protons. **At the present time, a new generation of experiments is under preparation with the use of the Saclay-Argonne movable polarized target.**

The ratio of the accelerator and experiment related expenses was adopted at a level of 60%/40%. The new opportunities given by the Nuclotron as well as the unique Synchrophasotron beams (up to 1500 hours per year) will stay as a factor attracting users in-kind and

in-cash contributions. This creates a special topicality for the Laboratory activity related with to the support of users contributing in the development of experimentation basis and financing of the accelerator complex operation. An important factor defining priorities of experiment development is their support through such funds as RFFR, INTAS and others.

Accelerator complex development

In 1997 – 99 the construction of the **Nuclotron** beam slow extraction system is considered to be the main task for the accelerator development. This system is scheduled to be completed in 1998 in the case of an adequate funding support. Appropriate support should be given to the injection system development.

At present the **Synchrophasotron** operation is provided by non-budgetary resources on user's requests (mostly polarized deuterons and applied research). After appropriate training the Synchrophasotron personnel is transferred to the Nuclotron exploitation and development. The termination of the Synchrophasotron exploitation in the coming years will be fulfilled according to the concept of experiment smooth transition from the Synchrophasotron to the Nuclotron without losses in the accelerator complex potential.

This substitution is divided into three major stages:

1. obtaining of Nuclotron extracted beams of light nuclei with intensities of 10^7-10^8 particles per spill; providing of the Nuclotron operation duration of 1500 hours per year; termination of the Synchrophasotron operation for low and moderate intensity experiments;
2. increasing of the Nuclotron unpolarized beam intensities to 10^{10} particles per spill; 2000-hour operation of the Nuclotron per year; termination of the Synchrophasotron operation with unpolarized particles;
3. providing of Nuclotron polarized deutron intensities at a level of 10^9 particles per second in the main experimental hall; increasing of the Nuclotron operation time to annual duration of 3000 hours; completion of the Synchrophasotron operation.

The basic condition of feasibility of such a staging consists in that the annual expenses for operation and development of the accelerator complex should be at a 10% level of the JINR budget with exception of the JINR infrastructure expenses (3 M$ with respect to the 1996 budget). Taking into account the RNP experimental programme and the LHE infrastructure expenses the annual LHE budget should be at a level not less than 4.5-5.0 M$. These goals can be reached within 2 years under condition that the respective funding profile will be provided.

The most topical and perspective project to be commenced in 1997-99 is the **250 MeV/nucleon Nuclotron booster** (cost of 3 M$). Its construction will make it possible to increase significantly the efficiency of the Nuclotron. Implementation of the project will give a rise in intensity of two orders of magnitude as well as provide a solid basis for future development of the accelerator complex of relativistic nuclei and for a wider applied use.

Application of 1-2 GeV/nucleon beams for an accelerator driven nuclear energy production is a most important field of applied nuclear energy research. In this respect **the LHE advances in a accelerator magnet miniaturization provide for development of new concepts of compact accelerators for nuclear power plants.** This R&D activity is becoming very important for the LHE staff in 1997-99.

Cooperation at accelerators of other centres

- During 1992-96 collaborative work was established in CERN experiments **NA45, NA49, WA98, EMU01** running in SPS nuclear beams. Essential contributions of various type detector equipment were made for these facilities. Therefore, it is expected that qualitatively new physical data will be available for analysis in 1997-99.

- New research prospects of relativistic nuclear physics research will be opened in the energy range of the order of few TeV per nucleon. In this respect the **ALICE** and **CMS** experiments at the LHC will give new and complementary information on detailed picture of multiple production and hard QCD processes including intermediate vector boson production at ultrarelativistic collision energy. In 1997-99 it is planned to work over the physics programmes of the experiments and detector development.

- For the **HADES** experiment at the SIS synchrotron at GSI (Darmstadt) it is planned to construct a system of multiwire drift chambers. The production was started in 1996.

- It is planned to continue activity in the **STAR** and **PHENIX** collaborations at BNL (RHIC) provided that essential support is given by the collaboration and the JINR Directorate.

RNP priority summary

1. There now exists an understanding that **experiments with relativistic nuclei present one of main prospects of nuclear physics research.** With the commissioning of the Nuclotron, ongoing experiments and those under development at the Nuclotron offer qualitatively new possibilities for studying the picture of nucleus at the subnucleon level. Many of currently existing restrictions on the beam parameters–the charge of the accelerated ions, the beam extraction time, the intensity, and the geometric size of the beam – are lifted. The investigations can also be extended into the region of lower energies–down to a few hundred MeV per nucleon.

2. **It is necessary to provide an adequate support for the Nuclotron runs, extracted beam system and first priority experiments in its beams.**

   Development of the **Nuclotron injector** is the next essential step on the way of qualitative improvement of the LHE accelerator complex.

   The Synchrophasotron operation will continue until the external beam becomes available at the Nuclotron, provided nonbudgetary sources of financing are available.

3. At the Nuclotron internal target priority should be given to the studies started in the framework of the SPHERE collaboration on energy dependence of hadron production and including spectra transition to asymptotic behaviour in the energy range from few hundred MeV to few GeV.

4. The start-up of operation of the movable polarized target at the LHE accelerator complex and the polarized neutron channel with the world highest energy open new possibilities for spin phenomena study and for further development of international scientific cooperation around JINR-based facilities.

5. The success of the first experiment with the movable polarized target using the polarized neutron beam to measure the total cross-section difference as well as the experiments to study cumulative production spin dependence (SPHERE, KASPIY, DISK, SMS MSU) demonstrate the LHE potential in the transition energy regime.

6. The successful experience of the LHE activity in 1992-96 has justified the unification into two first priority topics of the experiment facility projects in accordance with basic scientific interests and beam type requests (nuclei/polarized deutrons). In this way a cooperation between physics groups is established more simply.

7. International cooperation on the LHE beams should be supported by the development of computer network infrastructure and providing of the main experiments (SPHERE, ALPHA, GIBS) by UNIX workstations.

8. The development of the international scientific and technical cooperation in other accelerator centers on relativistic nuclear physics is grounded on the JINR priority advances and closely related to research progress at the JINR basic accelerator facility. The activity in this respect strongly needs an additional financial support. Taking into account a growing importance of participation on ALICE, HADES, STAR, CMS (heavy ion program) projects to are be considered as first priority activity for 1997-99.

9. During 1992-96 important result were obtained in the framework of the LHE **second priority topics. These topics allow to use intensively the JINR infrastructure, attract additional budget resources, and support external user activity.** The LHE second priority topics (WASA at CELIUS, Polarization Technologies, Crystalloptics, FOTON, KASPIY, SMS MSU) will continue in 1997-99 provided that they can be funded from nonbudgetary funds.

10. The LHE beams present a special interest for applied nuclear physics research, especially for the development of experimental aspects of an electronuclear method of energy production. In the framework of this research are:

    - provision of nuclear constants in R&D activities;
    - development of the methods for computer simulation of nuclear processes related with a target-blanket configuration design.
    - theoretical study of adequate accelerator types, development of accelerator units and target complex.

11. The LHE advances in a superconductive magnet technology gives a basis for a development of a concept of an accelerator driven nuclear power production as well as for progress of a next generation of superhigh energy hadron colliders

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