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D.V.Shirkov

# ANNUAL REPORT

## Bogoliubov Laboratory of Theoretical Physics

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

Dubna 1996

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The 79th Session of the JINR Scientific Council endorsed as an important field of activity the theoretical research in particle physics, nuclear physics, and condensed matter physics, also with a view to supporting experimental work in this area. At the Bogoliubov Laboratory of Theoretical Physics (BLTP) investigations are carried out on three themes of the first priority approved by the 74th Session of the Scientific Council: Fields and Particles; Nuclear Theory; Theory of Condensed Matter. Theoreticians also participated in a number of the JINR experimental programmes and performed theoretical analysis of the data obtained. Below, we present main results of research in 1996, some aspects of the international cooperation, and of research personnel policy.

# 1 SCIENTIFIC RESEARCH

## 1.1 Fields and Particles

This theme includes a wide range of researches on actual problems of quantum field and particle theory in which 77 theorists (among them 42 working on a contract basis) organized into 8 groups (sectors) are involved. At the beginning of 1996 the following fields of investigations were determined to be of major importance:

- Supersymmetry, quantum symmetries and integrable models;
- Quantum gravity and cosmology;
- Heavy flavours and $B$-physics;
- Spin physics in QCD.

**Integrable models** play an essential role in recent investigations of superstrings, duality, and quantum gravity. SUSY, quantum and $W$ algebras provide effective tools for studying integrable models and constructing new ones. Important results have been obtained in developing and applying these new tools.

A new $N = 2$ supersymmetric extension of the KdV hierarchy with $N = 4$ superconformal algebra as the Hamiltonian structure has been constructed. Via its reduction, a few previously unknown fermionic extensions of the KdV hierarchy have been found [F. Delduc, L. Gallot and E. Ivanov, Preprint ENSLAPP-L-623/96, Preprint JINR E2-96-394 (1996)].

Based on the linearization procedure previously proposed for $W$ algebras and embedding the $W(sl(N+3), sl(3))$ algebras into the appropriate linear algebras, new realizations of $W_3$ modulo null fields have been constructed. The possibility to predict the central charge spectrum for minimal models of the $W(sl(N+3), sl(3))$ algebras has been established [S. Bellucci, S. Krivonos, A. Sorin, Phys. Lett. **B 366** (1996) 104].

A natural Hopf-algebraic setting for the differential calculus on quantum groups has been found. It provides helpful tools for deriving a variety of commutation relations between functions, forms, vector fields, etc. [A.A. Vladimirov, Czech J. Phys. **47** (1997) 131].

A new approach to the problem of quantizing the differential calculus over groups has been suggested. The use of this approach allows one to correctly quantize the differential calculus for simple Lie groups of the type $SL(N)$ [L.D. Faddeev and P.N. Pyatov, In "Contemporary Mathematical Physics". Eds. R.L. Dobrushin, A. Minlos, M.A. Shubin, and A.M. Vershik, AMS Translations - Series 2, **175** (1996) pp.35-47].

More traditional approaches to constructing new integrable systems were also used. A new class of integrable models of two-dimensional dilaton gravity coupled to electromagnetic and scalar fields has been found. The models are related to the Liouville field theory which is known to have a rich quantum symmetry algebra. It has been proven that there are no static black holes in dilaton gravity coupled to a scalar field. [A.T. Filippov, Mod. Phys. Lett. **A11** (1996) 1691].

The method for constructing integrable systems including magnetic monopoles has been developed. This method is applied to describe the particle-vortex and particle-dyon bound systems [A. Nerssissian, V. Ter-Antonyan, and M. Tsulaya, Mod. Phys. Lett. **A11** (1996) 1605; A. Sissakian and V. Ter-Antonyan, Preprint JINR E2-96-327 (1996)].

Nonperturbative approaches to gauge theories were based on string and instanton models.

In the framework of the Nambu-Goto string with massive quarks at its ends, the interquark potential and deconfinement temperature have been calculated. It has been shown that, in infinite space-time dimensions, nonphysical properties of this potential at small distances disappear if a string is anchored at one end to an infinitely heavy quark and at the other end to a quark with vanishing mass. In the one-string approximation, the deconfinement temperature is found to be independent of the quark masses [G. Lambiase and V.V. Nesterenko, Phys. Rev. **D54** (1996) 6387; H. Kleinert, G. Lambiase and V.V. Nesterenko, Phys. Lett. **B384** (1996) 213].

The instanton model calculation of the pion wave function and the pion form factor has been performed. This allows one to express the phenomenological parameters of the pion wave function in terms of the fundamental parameters of the instanton QCD vacuum [A.E. Dorokhov, Nuovo Cim. **109A** (1996) 391].

In the supersymmetric extension of Standard Model and quantum chromodynamics important results were obtained.

Within the Minimal Supersymmetric Standard Model, the upper bound on the lightest Higgs boson mass has been estimated. For the low $\tan\beta$ scenario this mass is expected to be less than 103 Gev. The cross-section at a LEP II energy of 192 Gev



is shown to be sufficient to find or exclude the Higgs boson in this case. For the high $\tan\beta$ case the Higgs mass is predicted between 105 and 125 Gev, which is beyond the limits of LEP II [W. de Boer, R. Ehrer, D.I. Kazakov, A.V. Gladyshev, Z. Phys. **C71** (1996) 415].

It has been argued that a technique called analytical perturbation theory leads to a well-defined method for analytical continuing the QCD running coupling constant from the spacelike to the timelike momentum. The corresponding $\beta$-function is proportional to the spectral density, which confirms a hypothesis due to Schwinger [K.A. Milton and I.L. Solovtsov, Preprint Oklahoma University OKHEP-96-08].

Essential contribution to the study of the nucleon-spin structure was made. First, the sum rule method of quantum chromodynamics (SR QCD) (developed by Radyushkin and Mikhailov) has been applied to calculate the singlet axial constant $\Sigma$ of the proton [A.V. Belitskii, O.V. Teryaev, Phys. Lett. **B366** (1996) 345] interpreted in the parton model as a total contribution of spins of all quarks (and antiquarks) to the nucleon spin. The result obtained $\Sigma^{theor} = 0.20 \pm 0.07$ at $Q^2 \approx 10$ ГэВ$^2$ is in good agreement with the experimental value [1] $\Sigma^{exp} = 0.21 \pm 0.08$ measured by SMC at CERN (with JINR's participation) and SLAC.

Second, the so-called "evolution equations" have been derived for the probability of deep inelastic electroproduction of a photon on a nucleon (i.e., for its dependence on the momentum transferred by an electron $Q$) recently proposed for measuring the contribution of *orbital motion* of quarks and gluons to the nucleon spin [A.V. Radyushkin, Phys. Lett. **B385** (1996) 333].

The twist-2 contribution to the polarized structure functions in deep inelastic lepton-hadron scattering has been calculated including the exchange of weak bosons and using both the operator product expansion and the covariant parton model. A new relation between two structure functions leading to a sequence of new sum rules is established. The light quark mass corrections to the structure functions were derived in the lowest QCD order [J. Blümlein, N. Kochelev, Phys. Lett. **B381** (1996) 296].

Studies on various aspects of hadron spectroscopy were continued.

A relativistic model for QCD bound states composed of light and heavy quarks has been applied to study the properties of baryons containing a single heavy quark. In particular, the observables of semileptonic decays of bottom and charmed baryons (the Isgur-Wise functions, asymmetry parameters, decay rates and distributions) have been calculated. The model was also used for investigating heavy-to-light semileptonic processes. This activity was motivated by recent observation of the $\Lambda_c^+ \to \Lambda^0 e^+ \nu_e$ decay by the CLEO Collaboration. The calculated form-factor ratio, decay rate and asymmetry parameter $\alpha$ are in good agreement with measured values [M.A. Ivanov and T. Mizutani, Few-Body Systems **20** (1996) 49].

[1] Recall that the naive quark model predicted for it a value close to unity, which was the reason of the so-called "Spin Crisis" widely discussed for the recent ten years.

The strange quark contributions to the magnetic moment and charge (Dirac) radius of nucleons in the model of quark diagrams with meson currents taken into account have been found to be $\mu(\bar{s}s) = 0.065$ n.m, $< r_1^2 > (\bar{s}s) = -0.013$ fm$^2$. These results can be verified in experiments on weak neutral currents in the $\nu N$ and $\vec{e}N$ scattering [S.B. Gerasimov, Chinese J. Phys. **34** (1996) 848].

In connection with the experiment being prepared by the DIRAC collaboration at CERN, the first-order correction to the $(\pi^+\pi^-)$ atom lifetime due to strong interactions has been calculated within the framework of the Bethe–Salpeter approach. The relative value of the correction is $\sim 10^{-3}$. [V.E. Lyubovitskij and A.G. Rusetsky, Phys. Lett. **B389** (1996) 181].

A new value of the mixing angle of scalar mesons has been found in a quark chiral $\sigma$-model. This angle plays an important role in determination of the mass of scalar isoscalar $f_0$(400-1200) meson; the experimental data on the existence of this meson have appeared recently [D. Ebert, M.K. Volkov, Preprint DESY 96–074 (1996); to be published in Yad. Fiz. **60** (1996) No 4].

On the basis of the $K$- and $S$-matrix approaches, the appearance of the fictitious states in low-energy hadron spectra has been demonstrated; the data on $\pi\pi$-scattering below 1.6 GeV have been analysed, indicating a significant 4-quark component in $f_0$(980) [D. Krupa, V.A. Meshcheryakov, Yu.S. Surovtsev, Nuovo Cim. **109A** (1996) 281].

Computation of radiative corrections in QED, QCD, and electroweak theory, as well as the creation of computer programs for experiments at HERA (DESY) and SPS, LEP1 and LHC (CERN) were continued [A. Arbuzov, D. Bardin, L. Kalinovskaya, and T. Rieman, Comput. Phys. Comm. **94** (1996) 128].

A cross section of electron-positron (Bhabha) scattering at small angles with an accuracy higher than 0.1% was calculated [A.B. Arbuzov, V.S. Fadin, E.A. Kuraev, L.N. Lipatov, N.P. Merenkov, L. Trentadue, Nucl. Phys. to be published].

An interesting prediction has been obtained in the neutrino physics. It is known that there are three sorts of experiments indicative of the neutrino oscillation corresponding to three different scales of the mass-squared difference: it is the deficit of "solar" and "atmospheric" electronic neutrinos corresponding to the difference $10^{-5}$ eV$^2$ and $10^{-2}$ eV$^2$ and recent data from Los-Alamos corresponding to the difference $\approx 1$ eV. To explain them, at least *four* neutrinos are required. It has been shown in the framework of the Pontecorvo-Bilenky formalism that *only two* mass spectra are allowed with two pairs of neutrinos close in mass, separated by an interval of about 1 eV. Choice between the two possibilities can be accomplished by future experiments on double neutrinoless $\beta$-decay and on measurement of the tritium $\beta$-spectrum with a sensitivity of about 1 eV [S.M. Bilenky, A. Bottino, C. Giunti and C.W. Kim, Phys. Rev. **D54** (1996) 1881].



## 1.2 Nuclear Theory

The theoretical nuclear physics staff of BLTP amounts to 56 members, including 27 working on a temporary contract basis. They are organized into 4 groups. Main research directions in the area "Nuclear Theory" in 1996 were:

- Subnuclear degrees of freedom;
- Few-body systems;
- Heavy-ion collisions;
- Structure of exotic nuclei.

The first topic had many branches, including: properties of highly excited nuclear matter at distances much smaller than typical internuclear ones and behaviour of nuclear constituents participating in high energy reactions; new strategy of searching for QCD phase transition in heavy ion collisions; studies of nuclei with some exotic constituents like $\Lambda$- hypernuclei and $\eta$- nuclei and others. The new variable - the dilepton decay asymmetry - which is most sensitive to a modification of the $\rho$- meson self-energy in medium at finite temperature and density was proposed and analysed. It has been demonstrated that the pole positions and the values of the imaginary parts of the self-energy for different polarization states have different functional dependence on dielectron invariant mass $M$ and $|\mathbf{p}|$, which leads to the perceptible asymmetry of the dielectron angular distribution. This work is deeply related to the HADES (GSI) experimental problems [A.I. Titov, T.I. Gulamov, B. Kämpfer, Phys. Rev. **D53** (1996) 3770]. A possibility for the so-called "$\eta$ - nuclei" - bound systems of nucleons and $\eta$- meson – to exist was studied. It has been shown that for light nuclei ($A \leq 4$), existence of "$\eta$ - nucleus" is more favorable for the $^4$He case [S.A. Rakityansky, S.A. Sofianos, M. Braun, V.B. Belyaev, W. Sandhas, Phys. Rev. **C53** (1996) R2043].

In the field of the few-body physics the role of near threshold nuclear resonances in two- and three-atomic molecules, properties of nonsymmetric muonic molecules and antiprotonic helium atoms were studied. Large discrepancies have been found between the first data on asymmetries for $\pi^+$ elastic scattering from polarized $^3$He at incident energies which pass through the $\Delta(1232)$ $\pi$-nucleon resonance and calculations that use the multiple scattering formalism and Faddeev wave functions. Another calculation that included a $\Delta$-neutron spin-spin interaction term gave a greatly improved representation of the data. Knowledge of the strength of the spin-dependent (and spin-independent) parts of the $\Delta$-nucleon interaction is needed to test meson-exchange and quark models of the baryon-baryon interaction [M.A. Espy, D. Dehnhard, C. M. Edwards,...C. Bennhold, S.S. Kamalov, Phys. Rev. Lett. **76** (1996) 3434]

Many efforts were devoted to consistent relativistic description of the deuteron structure. The Bethe–Salpeter equation with a one-boson-exchange kernel with a

full set of mesons ($\pi, \rho, \sigma, \eta, \omega$ and $\delta$-mesons) was considered. A numerical method to solve the corresponding system of coupled integral equations for partial amplitudes has been developed and applied to extract the neutron spin structure function from the deuteron data in the resonance region [C. Cioffi degli Atti, L.P. Kaptari, S. Scopetta. A.Yu. Umnikov, Phys. Lett. **B376** (1996) 309].

Some aspects of the theory of electromagnetic processes on deuteron at high transferred momenta were investigated. Current theories of electromagnetic processes on bound multiparticle systems (and nuclei in particular) do not ensure gauge-invariance which demands a consistency of conserved electromagnetic current and wave functions of a system. Starting from the Ward–Takahashi identity the conditions for separation of the elastic electron–nucleus scattering amplitude into two gauge independent parts have been established. The first term is the one-particle contribution and the second one includes the many-particle contributions due to the interaction currents. In the framework of the Bethe–Salpeter formalism those conditions are shown to be satisfied in the $ed$- and $e\pi$ scattering if a fermion–fermion interaction is of the ladder or separable type [V.V. Burov, S.M. Dorkin, A.Yu. Korchin, V.K. Lukyanov, A.V. Shebeko, Yad. Fiz. **59** (1996) 822].

In theoretical studies of heavy-ion collisions at low and intermediate energies two different approaches were used. In the framework of one of them, which has earlier been suggested and developed at BLTP, a microscopic model of multinucleon transfer reactions was applied to thoroughly study a possibility to produce exotic nuclei in heavy ion reactions. The yield of isotopes near the heaviest $N = Z$ neutron-deficit nucleus $^{100}Sn$ has been calculated. The doubly-magic $^{100}Sn$ nucleus is expected to be the heaviest $N = Z$ nuclear system which is still bound. The formation of the $^{100}Sn$ isotope and study of its properties is quite important for further development of the shell model and, in particular, for a comparative study of proton-neutron interactions occupying the same orbits. Large influence of nuclear shell structure on production of exotic nuclei has been demonstrated. The reaction $^{54}Fe + ^{106}Cd$ has been predicted to be most favourable for producing primary $Sn$ isotopes which may survive if the excitation energy in the entrance reaction channel is less than about 100 $MeV$ [N.V. Antonenko, A.K. Nasyrov, T.M. Shneidman, V.D. Toneev, Preprint GANIL P 96 31, Caen (1996) 1]. This work was made in close contact with experimenters from the Flerov Laboratory of Nuclear Reactions (JINR) and GANIL (Caen, France).

Different nuclear models (microscopic, algebraic, semiclassical etc.) were developed to interpret in a proper way a large amount of new precise experimental data on nuclear excitations especially in nuclei far from the stability line. Investigations of cluster properties of nuclei, super- and hyper-deformed nuclei in the new regions of the nuclide chart, structure of halo nuclei, and octupole correlations in neutron deficient nuclei have been performed. In particular, a new method for calculating nonstatistical particle decay of excited states in odd nuclei has been elaborated.



Partial cross sections and branching ratios for the neutron decay of the high angular momentum states in $^{209}$Pb and $^{91}$Zr excited by means of the ($\alpha$,$^3$He) reaction have been calculated using the quasiparticle-phonon model. Theory reproduces partial branching ratios. This work was done in the framework of the agreement IN2P3 - JINR in collaboration with theoreticians and experimenters from the Institute of Nuclear Physics at Orsay [N. Van Giai, Ch. Stoyanov, V. Voronov, S. Fortier, Phys. Rev. **C53** (1996) 730].

It seems worth mentioning a new research direction that appeared in the nuclear theory area. Within the last decade, new mesoscopic systems such as nanoscale electronic devices and clusters of atoms and molecules have become the subject of intense experimental and theoretical studies. Nuclear concepts turn out to be quite useful for elucidating certain cluster phenomena. Cluster physics may provide a fresh view on some problems of nuclear physics. The investigations in this field have recently been undertaken at the BLTP. A role of pairing correlations in metallic clusters has been investigated. The use of number-projection and shell-correction methods which are well-known in nuclear theory have given a possibility for the first time to take into account both the influence of pairing between valence electrons and the shape deformation on the ionization potentials of sodium clusters. It has been shown that in the sodium clusters only weak pairing can exist [N.K. Kuzmenko, V.O. Nesterenko, S. Frauendorf, V.V. Pashkevich, Nuovo Cim. **D18** (1996) 645].

## 1.3 Theory of Condensed Matter

37 theorists including 21 working on a contract form 4 groups. They are working in the field of condensed matter physics, statistical mechanics and mathematical physics.

The main topics under consideration in 1996 were:

- Mechanisms HTSC;
- Non-linear phenomena and self–organization;
- Liquid $He^4$

A theoretical study of electronic, magnetic and superconducting properties of copper oxides in the framework of electronic models with strong correlations was the principal long–term objective. The main results obtained in the field of strongly correlated systems and HTSC are the following:

1. The optical conductivity for the two-band asymmetric Hubbard model and the $t - J$ model were investigated by applying the memory function technique in terms of the Hubbard operators. It is shown that the Drude relaxation rate vanishes for the symmetrical Hubbard model while for the $t - J$ model

it has a final value. For a model with an incoherent spectrum for one-hole excitations a universal form for frequency dependence of relaxation rate and conductivity were obtained which could explain anomalous infrared absorption in high-temperature superconductors. [N.M. Plakida, J. Phys. Soc. Jpn. **65** (1996) No. 12; Zeit. Phys. B (accepted)].

2. The $SU(2|1)$ representation of Hubbard variables is used in a new version [E.A. Kochetov, Phys. Lett. **A 217** (1996) 65] of path integral for the Anderson and $t-J$ models of correlated electrons. This representation provides a new description of the dynamics of strongly correlated electrons in terms of even- and odd-valued trajectories on a relevant superphase space, those trajectories corresponding to charge and spin degrees of freedom, respectively. $C$-number trajectories, respectively. In this way, no kinematic constrains appear, which makes it possible to directly justify an adiabatic hypothesis for heavy electrons in the Anderson model [V.S. Yarunin, E.A. Kochetov, M.E. Zhuravlev, Proc. JINR Path Integral Conference, (1996) 264–268].

In the field of non-linear equations and self-organized criticality the following main results were obtained:

1. An efficient method has been suggested to prove completeness of the basis formed by eigenfunctions of a wide class of linear differential operators. The method is applied to correct determination of the basis in the scattering problem of the KdV and non-linear Schrödinger equations. In particular, the perturbation theory for the multi-soliton problem in these non-linear equations is constructed [V.K. Mel'nikov (to be published)].

2. An essentially new model of self-organized criticality has been proposed: A particle is dropped at random on a medium and moves through it using renewable resourses. As it moves, it changes the direction of motion and modifies the medium. On closed graphs these walks form the Euler circuits and the operators corresponding to particle addition generate an Abelian group. Critical steady state and some critical exponents have exactly been evaluated , using this correspondence [V.B. Priezzhev, D. Dhar, A. Dhar, S. Krishnamurthy, Phys. Rev. Lett. **77** (1996) 5079].

3. Kinetic equations, which explicitly take into account the branching nature of sandpile avalanches, has been derived. The dynamics of the sandpile model is described by the generating functions of a branching process. The real space renormalization group approach to the critical behavior of this model is formulated in terms of the generating functions describing in detail toppling processes inside the blocks. The obtained height probabilities and critical exponent are in excellent agreement with the corresponding exact values [E.V. Ivashkevich, Phys. Rev. Lett. **76** (1996) 3368].



4. The regular algorithm for RG-type symmetry revealing was formulated for a class of boundary value problems in classical mathematical physics [V.F. Kovalev, V.V. Pustovalov and D.V. Shirkov, Preprint JINR E5-96-209 (1996)].

   This algorithm, based upon the Lie group analysis and embedding procedure, was applied to the system of nonlinear differential equations for non-linear optics. New solutions in laser beam focusing problem have been found: [V.F. Kovalev, Preprint JINR P5-96-477 (1996)].

Besides, several important problems of Statistical Mechanics were considered, among them, the polaron problem and the Thomas-Fermi approximation:

1. A condition of the bipolaron stability has been reformulated [A. A. Shanenko, M. A. Smondyrev, J. T. Devreese, Solid State Commun. **98** (1996) 1091] to take into account the fact that a bipolaron is a part of the charge carrier system. Usually, a single bipolaron decays into two polarons being stable in rather a narrow region of values of the system parameters. It is shown that when a bipolaron is surrounded by a gas of polarons, its stability region is enlarged significantly because of the Fermi motion of polarons and their interactions.

2. The Thomas-Fermi approach is generalized [A. A. Shanenko, Phys. Rev. **E54** (1996) 4420] to consider the particle correlations in many-body systems with non-Coulomb interaction potentials. The key points of the generalization consist in using integral formulation and extracting a pair correlation function. The latter has been found to obey the integral equation which, in the classical limit, is reduced to the well-known equation for distribution functions in the superposition approximation.

# 2 COMPUTER FACILITIES

(Project "SPEKTR")

Our SPEKTR ("Set Personal'nykh Komp'yuterov dlya Teoreticheskikh Rabot" - Net of Personal Computers for Theoretical Works) includes about 150 personal computers of different types connected to each other via the local area network (LAN) with the Lab. Computer Center.

This Center consists of 6 PC's of different type, SPARC Station 5 and SPARC Server 1000E which are installed in the shared area (SPEKTR room), thus allowing the lab's users and visitors, to do their jobs using most powerful computers.

SPARC Server is the main computational facility at the Laboratory. With its two processors and fast disks it allows many people to run their jobs, read and write e-mail, and to have access to Internet via Netscape. SPARC Server is also the main communication and e-mail server at the Laboratory. Software installed in PC's allows processing of e-mail messages off-line with the maximum comfort while

SPARC Server is sending and collecting new messages. SPARC Server also provides world-wide access to the Laboratory's official, group-wide and personal information published via HTTP server ttp://thsun1.jinr.dubna.su). To satisfy ever growing requirements of users we are going to install in the SPEKTR room more computers of the SUN SPARC line.

Three PC's are equipped with extra computing subsystem based on RISC Intel 80860, thus rising the power of each up to 6 MFlops while using NDP FORTRAN. There is also a multiprocessor computer Alliant FX2800 which may deliver the power of its 8 processors to users whose tasks are most suitable for treatment by the Parallel Fortran. In the SPEKTR room File Server is installed which is based on the powerful Pentium 133 MHz processor with shared disk storage of 4 GB.

The software installed in the server's disk includes dozens of popular programs which are ready for use at each computer connected to LAN. Among others there are publishing systems EmTEX, ChiWriter, Word, the systems for analytical calculations Mathematica, Maple, graphics package Corel Draw, Windows 3.1 etc. It also includes the system NICE developed at CERN which provides a user-friendly access to a collection of Windows applications stored in File Server.

The File Server is also working as a gateway from two subnets in the Laboratory to the large Institute's network. As a gateway it provides separation of data streams inside and outside the Lab, thus reducing network load and speeding up data transfer for local users. Every day the File Server delivers 1–1.5 GB of information to client computers inside the Lab. It is the demand of our time to have powerful PC's at each workplace with access to the Institute's facilities via high speed network and with good connection with Internet. Development and improvement of the local network is a high priority aim of the Laboratory's administration. Today, the network with overall cable length of about 2000 m provides connection at almost every workplace and the nearest task for us is a better quality of services at every connected PC. With the availability of Pentium PC's and Windows 95/NT this goal appears to be real.

Most of the computers are located at the working places of employees. Currently, every room at the Laboratory is equipped with a personal computer (PC). Low end PC like AT-286 ( 50 ), AT-386 ( 20 ) and medium range AT-486 ( 46) are used for text processing (writing e-mail, papers etc.), local communication, Internet access and simple calculations. High end computers like Pentium (more than 40) are used for the most complicated tasks to decrease working load at the Lab Computing Center.

The total average performance of high end computers is more than 800 MFlops (Millions of Floating Point Operations per Second). To "normalize" we mention here that the peak performance of the most powerful cluster of CONVEX-220 & CONVEX-120 in LCTA is about 120 Mflops.



# 3 EXTERNAL COUNCIL ON THEORETICAL PHYSICS

The External Council on Theoretical Physics (ECTP) was set up in 1994 as a consultative body of the BLTP Directorate. Ten prominent European theorists – L. Alvarez-Gaume (CERN), A. Bassetto (Padova), G.N. Filippov (Kiev), W. Nawrocka (Wroclaw), W. Plessas (Graz), P. Quentin (Gradignan), H. Rollnik (Bonn), V. Rubakov (Moscow), I. Todorov (Sofia), J. Zinn-Justin (Saclay)) – were invited as full members. Five theorists from JINR (A. Baldin, V. Burov, G. Rēpke, D. Shirkov, and A. Vdovin) were nominated as *ex officio* members (without right to vote).

Two sessions of ECTP (6–9 Oct. 1994 and 7–10 Sept. 1995) were devoted to analysis of research performed at BLTP on all three themes of the first priority - "Particles and Fields", "Nuclear Theory", and "Theory of Condensed Matter". "The Council feels that the Laboratory has reached a good balance between more abstract theoretical physics and theoretical physics closer to experimental programmes. ECTP was "impressed by the breadth and interdisciplinarity of the research" and certified that "in all fields represented at BLTP high quality work has been done". The Counsil also noted:

"The Laboratory has reached a good balance between the activities in Particle and Nuclear Physics. The existence of groups working in Condensed Matter Physics is beneficial to the Laboratory. However, we believe that activities in those aspects of general Statistical Mechanics that are of a unifying character should be expanded."

Very valuable for us were several concrete critical remarks made on some specific scientific items.

ECTP commented also on a number of organizational matters. The "current policy of increasing the number of fixed-term contracts" has been supported. At the same time "as a general rule we advise against their systematic renewal, and recommend the introduction of an upper limit of six years for all temporary positions". Since young physicists were not employed for permanent positions at BLTP over a long time, ECTP has recommended to have regular openings of a limited number of tenure positions. The members of BLTP were encouraged to participate in teaching students and training young associates.

Next session of ECTP will be held in April 1997. At present, consultations are conducted concerning the session's programme and a new body of ECTP which, according to the decision, is to be renewed by one third every two years.

# 4 INTERNATIONAL COLLABORATION

The Laboratory actively collaborates with scientific centres of Member States. Despite economic difficulties, geography of collaboration is expanding. In 1996, about 150 (of total amount $\sim$ 600) papers and conference reports written down together

with theorists of West European scientific centres have been published.

At the end of 1995, the protocol on the collaboration between INFN (Italy) and JINR in the area of field theory and particle theory was signed and in the current year 6 BLTP's researchers worked at Italian centres during a month each. It was for the first time that within the recent agreement between CERN TH and BLTP 3 our researchers worked at CERN for a month in 1996, 50% of staying expenses being paid by the host side. The agreement between ICTP and BLTP is in force. Collaboration with German institutions is in progress within the framework of the Heisenberg–Landau programme (HLP).

Table 1. Statistical Overview on the Heisenberg–Landau Programme

| Year | Expenditure (in kDM) | Number of supported Workshops & Schools | Research Projects | Number of visits from Germany | to Germany | Joint Papers |
|---|---|---|---|---|---|---|
| 1991 | — | — | — | 34 | 45 | 28 |
| 1992 | 33 | 3 | — | 61(15) | 62 | 38 |
| 1993 | 102 | 4 | 19 | 60(12) | 59 | 42 |
| 1994 | 162.5 | 7 | 30 | 83(23) | 79 | 48 |
| 1995 | 120 | 6 | 31 | 80(28) | 85 | 62 |
| 1996 | 140 | 8 | 33 | 81(24) | 78 | >60 |
| 1997 | 140 | 7 | 35 | | | |

Remarks: In brackets, the data on visit numbers without attending of meetings are given; Only expenditures from the BLTP budget are given.

Theorists also participate in experimental programmes of JINR, CERN, DESY, GSI, CEBAF, and some other centres.

Table 2. Data on BLTP budget of International collaboration, computers, visits of our scientists, meetings, and publications

| | Expenditure (in k$) Int. Coop. | HLP | Computers | Number of Visits | Meetings | Papers |
|---|---|---|---|---|---|---|
| 1993 | 135 | 70 | 30 | 184 | 10 | 600 |
| 1994 | 130 | 102 | 98 | 261 | 11 | 530 |
| 1995 | 112 | 114 | 35 | 321 | 9 | 600 |
| 1996 | 84 | 100 | 41 | ~300 | 12 | ~600 |

For the last two years, the number of visits (including conferences) amounts to ~ 320 per year, among which ~ 25% to the Member States and ~ 15% to the traditional Member States. We would like to draw attention to the fact that the share of financing the collaboration with Germany within the Lab. budget in 1996 exceeded half financing of the whole international collaboration.



Extra sources of financing the collaboration are grants of diverse foundations. Below we present information on the grants obtained by BLTP researchers in 1996. Grants of the scientific Funds: RFBR[2]–DFG (joint project) - 3, RFBR–INTAS (joint project) - 3, CRDF [3] - 1, NREL[4] - 1, INTAS - 10, RFBR - 30, the International Center for Fundamental Physics in Moscow - 3, the State Committee of the RF for Education - 4, the National Program of RF - 2.

About 10 visits of BLTP researchers to conferences are supported by the Russian Academy of Sciences. In some cases, part of the expenses are covered by the host side.

An important aspect of the BLTP's activity is the organization of conferences. Here we list meetings organized by BLTP in 1996, as well as some others with our participation in organization.

1. *Conference "Hadron Structure'96. High Energy Interactions: Theory and Experiment"*, [Feb. 12–16, Stará Lesná, Vysoké Tatry, Slovakia], jointly organized by JINR and Slovak Academy of Sciences. About 80 participants, with 29 from JINR including 13 from BLTP.

2. *X Conference on Problems of Quantum Field Theory*, [Alushta, the Crimea, Ukraine, May 12–18, 1996], jointly organized by the BLTP and ITP (Kiev). More than 100 participants from Russia, Ukraine, Uzbekistan, Bulgaria, the Great Britain, Germany, Holland, Israel, Italy, Poland, Slovakia, the USA, Czechia, Japan, and JINR. Financial support by RFBR, the National Academy of Sciences of Ukraine and by HLP (BLTP budget).

3. *3rd German–Russian Workshop "Heavy Quark Physics"*, [May 20–22, Dubna]. 65 participants: Russia (25), JINR (15), and 25 from abroad (France, Germany, the Great Britain, Italy, Poland, Switzerland, and the USA). Supported by RFBR and HLP.

4. *Seminar "Path Integrals: Theory and Applications and 5th International Conference on Path Integrals from mev to Mev" (= PI '96)*, [May 27–31, Dubna]. More than 80 participants: Germany (24), Russia (23), the USA (5), Japan (5), Italy (2), Belarus (2), Canada (1), Belgium (1), Switzerland (2), Thailand (1), Malaysia (1), and JINR (14). Supported by HLP, RFBR, and International Foundation for Fundamental Research (Dubna).

5. *Workshop on "Nuclear Methods for Transmutation of Nuclear Waste: Problems, Perspectives, Cooperative Research (NMTW'96)"*, [Dubna, May 29-31, 1996], organized by the BLTP and the Florida State Univ., supported by the Los Alamos National Lab. About 80 participants from Russia (44), JINR (20), and 16 from abroad (Czechia, Finland, France, Germany, Poland, Sweden, China, and the USA). Fifteen Russian institutions were represented.

[2]Russian Foundation for Basic Research.
[3]U.S. Civilian Research and Development Foundation for the Independent States of the FSU.
[4]National Renewable Energy Laboratory, the USA.

6. *3rd Meeting on the Prospects on NN Spin Physics at HERA*, [June 27-30, Dubna]. 30 participants from Germany (6), the Netherlands (1), Russia (6) JINR (17), supported by HLP and RFBR.

7. *II Workshop on Classical and Quantum Integrable Systems. Algebraic Methods and Lie Algebra Contractions (=IWCQIS'96)*, [July 8-12, Dubna]. 50 participants from Russia, Germany, Bulgaria, Canada, Czechia, Finland, France, India, Mexico, Slovenia, South Africa, Spain, Turkey, the USA, and the JINR, supported by the State Committee of RF for Science and Technology Policy.

8. *III Conference "Renormalization Group - 96"(=RG '96)*, [Dubna, Aug. 26-31, 1996]. Over 70 participants from Russia, Ukraine, Belarus, Kazakhstan, Armenia, Georgia, Bulgaria, Slovakia, Germany, the Great Britain, Italy, France, Japan, the United States, Ireland, Spain, the Netherlands, Austria, Finland, Slovenia, Mexico, Taiwan, and the JINR, supported by RFBR and HLP.

9. *XIII International Seminar on High Energy Physics Problems "Relativistic Nuclear Physics and Quantum Chromodynamics"*. [Dubna, September 2-7, 1996], jointly organized by JINR and the Academy of Sciences of Russia, supported by RFBR and the State Committee of RF for Science and Technology Policy, about 200 participants from JINR, CERN, Russia, Germany, France, Japan, Italy, Spain, Taiwan, Ukraine, and the USA.

10. *Russian-German Workshop "Collective Modes in Fission: Regular and Chaotic Aspects"*, [Sept. 12-14, Dubna], over 50 participants: Russia (10), Germany (3), Italy (3), Sweden (1), France (1), Kazakhstan (1), Poland (1), Ukraine (1), the USA (1), Japan(1), and JINR (30), supported by HLP.

11. *Workshop "Supersymmetries and Quantum Symmetries"*, [Dec. 2-4, Dubna], 35 participants: Russia (13), Ukraine (13), Germany (1), and JINR (8), supported by the Intern. Center for Fundamental Physics in Moscow.

12. *IX Seminar "Gravitational Energy and Gravitational Waves"*, [Dec. 9-12, Dubna]. 30 participants from Russia, Poland, Bulgaria, and JINR. The seminar was supported by the State Committee of RF for Science and Technology Policy.

In 1996, about 550 scientists from many countries, including ~ 350 from Member States (20 from traditional ones), participated in our meetings. Let us emphasize some specific features of our conferences:

- the majority of conferences were held beyond the budgetary financing (at the expense of grants and registration fees);
- a wide geography of participants;
- interdisciplinary character of conferences (RG'96, PI'96, IWCQIS'96).

It is to be noted that in 1996 two representative conferences were held in the JINR Member States (Slovakia and Ukraine).



We conclude our review of BLTP international activity by stating that it is successfully developing. Special emphasis has to be given to reduction of visits to Dubna, especially middle-term ones (for 1-2 months) from Member States. To prevent and possibly to overcome this tendency, the Laboratory has recently proposed to introduce a new form of cooperation - "temporary working groups":

In the world practice of organization of scientific studies, temporary research groups have become of increasing importance. This form allows a relatively small number of scientists to effectively collaborate in the field of pure theory as well as in processing and interpreting experimental data. BLTP intends to establish the system of Research Workshops that follows this tendency and is aimed at rising the role of middle-term visits to Dubna. The main form of realization of the project is to carry out specialized research workshops that will last from 1 to 2 months and gather a small number (3-5) of qualified specialists interested in mutual contacts and short-term collaboration on a given subject, as well as a group of (5-10) young and beginner scientists, who wish to improve their qualification in the field.

Six workshops are planned for 1997 (see the list of meetings for 1997). We hope that the project will allow the number of middle-term (about month) visits from Member States to be increased appreciably.

# 5 LABORATORY STRUCTURE, PERSONNEL

At BLTP, studies are carried out on three themes: Fields and Particles, Nuclear Theory, Theory of Condensed Matter. The research personnel comprises permanent and temporary staff members. The personnel is divided into 16 administrative units - sectors. In 1997 a new sector on Many Particle Physics will be established at the Laboratory.

Table 3. Distribution of the research personnel for three themes

| Theme | Permanent | Temporary | Total for the Theme |
|---|---|---|---|
| Fields and Particles | 35 | 42 | 77 |
| Nuclear Theory | 29 | 27 | 56 |
| Theory of Condensed Matter | 16 | 21 | 37 |
| Total for the Lab. | 80 | 90 | 170 |

The temporary personnel noticeably increased for the past four years at the expense of the personnel from the JINR Member States from FSU (the so-called personnel of the Directorate). Part of the permanent staff members of the Laboratory signed finite-term contracts (11 for the past four years).

Table 4 . **Personnel of the Directorate**

A. The traditional Member States and other countries

| | 1993 | 1994 | 1995 | 1996 |
|---|---|---|---|---|
| Bulgaria | 4 | 6 | 6 | 7 |
| Czechia | 1 | 1 | 1 | 1 |
| Germany | 2 | 3 | 3 | 3 |
| Mongolia | 7 | 5 | 2 | 1 |
| Poland | 1 | 1 | 1 | 1 |
| Romania | 1 | 2 | 1 | 1 |
| Slovakia | 1 | 2 | 3 | 2 |
| Vietnam | 2 | 2 | 1 | 1 |
| Fellows | 9 | 5 | 5 | 6 |
| Total | 28 | 27 | 23 | 20 |

B. Member States from FSU

| | 1993 | 1994 | 1995 | 1996 |
|---|---|---|---|---|
| Azerbaijan | 2(1) | 2(1) | 2(1) | 1(1) |
| Armenia | 5(2) | 7(2) | 8(2) | 6(1) |
| Belarus | 5(0) | 5(0) | 5(0) | 5(0) |
| Georgia | 3(0) | 4(0) | 6(2) | 8(3) |
| Kazakhstan | 4(3) | 5(3) | 4(1) | 3(0) |
| Moldova | 1(0) | 1(0) | 1(0) | 5(3) |
| Russia | 22(16) | 26(18) | 26(20) | 28(21) |
| Uzbekistan | 2(1) | 3(1) | 3(1) | 3(0) |
| Ukraine | 3(1) | 3(1) | 5(2) | 5(2) |
| Total | 47(24) | 56(27) | 60(29) | 64(31) |

Remark: In brackets are the data for young theorists (under 33).



Following the JINR current policy of reducing permanent positions, no-one has been taken on the Laboratory's permanent staff during this period.

The BLTP policy consists in increasing the number of fixed-term employment contracts at the expense of permanent positions and in attracting young people. We try to maintain the long-standing Lab tradition to train qualified scientists for the JINR Member States. We have advanced in this direction, and now about 50of those working on a contract are under 33; 10 post graduates are now at the Lab.

The number of fixed-term contracts is gradually increasing by employing scientists from the Member States on a contract basis for 1 to 3 years and in some cases for another 3-year term. The regular procedure of giving employement on a contract basis includes discussion of candidates with the leading staff-members and recommendation of the Lab.'s Scientific Council. The number of applications exceeds vacancies. Therefore, the Lab's Scientific Council takes decision on a competition basis by secret ballot.

Advantage is given to young and active scientists capable to lead in important directions of research. The BLTP's Directorate follows the above-mentioned recommendation of ECTP concerning influx of youth and of the upper limit of six years for all temporary positions. A nine-year term provided in the new version of the JINR Staff Regulations, in our opinion, can be considered only in special cases. Another important aspect of the personnel policy is admission to the permanent staff. Its necessity is obvious, and in 1996 we, for the first time, applied to the JINR Directorate for taking one scientist on the permanent staff.

# 6 FUTURE ACCENTS

## 6.1 Directions of research

- in "Particles and Fields"
  - Supersymmetry, quantum symmetries and integrable models;
  - Nonperturbative methods in gauge and gravity theories;
  - Heavy flavours and $B$-physics;
  - Spin physics in QCD.
- in "Nuclear Theory"
  - Subnuclear degrees of freedom;
  - Few-body systems;
  - Heavy-ion collisions;
  - Structure of exotic nuclei.

- in "Theory of Condensed Matter"
  - Strongly correlated systems and HTSC;
  - Self-organized criticality;
  - Non-linear equations.

## 6.2 Computer Facilities

- to develop CC by installing ULTRA SPARC station;
- to organize mirror sites for Servers of theoretical institutes in a number of countries (i.e. Italy (ICTP), Austria (Graz University), USA (IITAP, Iowa University) and others) in order to promote closer collaboration with this center of theoretical physics;
- to upgrade PC's (to change 286, 386 and 486 computers by Pentium) at the Laboratory.

## 6.3 General accents for the near future

- Support of research in general aspects of Statistical Mechanics and Mathematical Physics which are of unifying character.
- Favoring of exchange with institutions of Member States. Creating new forms of scientific cooperations (like "Research Workshops Program") and improving working and life conditions for visitors.
- Further efforts for attracting young researchers.



# Plans for 1997.

### Conferences and meetings.

1. VI School-Seminar "Secrets of Quantum and Mathematical Intuition", *June 17-20, Dubna*
2. International Conference "Deuteron-97", *July 2-5, Dubna*
3. 7th International Seminar "SPIN-97", *July 7-12, Dubna*
4. International Conference "Symmetry Methods in Physics", *July 14-20, Dubna*
5. Workshop "Supersymmetries and Quantum Symmetries", *July 22-26, Dubna*
6. 4th Workshop on Physics Program of Polarized *pp*- and *pn*-collisions at HERA, *August, Zeuthen, Germany*
7. International School "Strongly Correlated Systems and Critical Phenomena", *August 26- September 5, Dubna*
8. International Conference "Nuclear structure and related topics" *September 9-13, Dubna*
9. 4th German-Russian Workshop on Progress in Heavy Quark Physics, *September 20-22, Rostock, Germany*
10. International School-Seminar "Structure of Particles and Nuclei and their Interactions" (ISS97), *October 6-13, Tashkent, Uzbekistan*
11. X International Seminar "Gravitational Energy and Gravitational Waves", *December 9-11, Dubna*

### Research Workshops.

- "Nucleation, Cluster Growth and Nuclear Multifragmentation", *March-April, 1 month, Dubna*
- "Deconfinement at Finite Temperature and Density", *March 1-April 1, Dubna*
- "Current Few Body Problems", *June-July, 2 weeks, Dubna*
- "Integrable Systems, Quantum Group and Quantum Gravity", *July, 2 weeks, Dubna*
- "Strongly Correlated Systems", *Mid August, 2 weeks, Dubna*
- "Collective excitations in nuclear and mesoscopic systems", *Mid September, 2 weeks, Dubna*

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