BOGOLIUBOV LABORATORY OF THEORETICAL PHYSICS

At the Bogoliubov Laboratory of Theoretical Physics (BLTP), studies are carried out on the following four themes: Fields and Particles, Modern Mathematical Physics, Nuclear Theory, and Theory of Condensed Matter. Important components of BLTP's activities are theoretical support of experimental research to be carried out with JINR's participation and recruiting of young researchers, students, and post-graduate students to the Laboratory.

FIELDS AND PARTICLES

Theoretical research in the *Fields and Particles* division of BLTP covers a wide field of activity in *quantum field theory* (QFT) and *phenomenology of particle physics*.

Phenomenology of particle physics includes the Standard Model of fundamental interactions and its extension, as well as high- and low-energy hadron physics. A new direction, started in 2005, was theoretical research into heavy-ion collisions. The main topics were:

- Nonperturbative methods and QCD phenomenology;
- Studies of Standard Model and its extensions;
- Mixed phase in heavy-ion collisions.

Last year, considerable progress was achieved in several directions. Below one can find a brief description of selected results obtained at BLTP in 2005.

It is shown that an excess of diffuse gamma rays above 1 GeV as measured by the EGRET collaboration can be interpreted as a dark matter signal. This interpretation is consistent with supersymmetry. It is found that the EGRET excess combined with all electroweak constraints is fully consistent with the minimal SUGRA model for scalars in the TeV range and gauginos below 500 GeV [1].

The so-called coannihilation region of the MSSM parameter space is analyzed and it is shown to be consistent with the WMAP restrictions on the amount of the dark matter in the Universe. In this region, *staus* might be long-lived and go through the detector. Due to a relatively small mass (150–850 GeV) their production cross section at LHC may reach a few % pb [2].

The structure of the UV divergencies in higher dimensional nonrenormalizable theories is analyzed and it is shown that the leading divergencies (asymptotics) are governed by the one-loop diagrams the number of which, however, is infinite. The explicit expression for the one-loop counter term in an arbitrary D-dimensional quantum field theory without derivatives is suggested. This allows one to sum up the leading asymptotics which are independent of the arbitrariness in subtraction of higher-order operators [3].

Radiative corrections (RC) to the Compton scattering cross section are calculated in the leading and next-to-leading logarithmic approximation to the case of colliding high-energy photon–electron beams. RC to the double Compton scattering cross section in the same experimental setup are calculated in the leading logarithmic approximation. The case when no pairs are created in the final state was considered. It is shown that the differential cross section can be written in the form of the Drell–Yan process cross section. Numerical values of the K factor and the leading order distribution on the scattered electron energy fraction and scattering angle are presented [4].

The process of muon (pion) pair production with small invariant mass in electron–positron high-energy annihilation, accompanied by emission of a hard photon at large angles, is considered. The Drell–Yan picture for the differential cross section was found to be valid in the charge-even experimental setup. Radiative corrections for both the electron block and the final-state block are taken into account [5].

Starting from the gauge invariant effective action in the quasi-multi-Regge kinematics (QMRK), the effective reggeized gluon (R)–particle (P) vertices of the following types: RPP, RRP, $RRPP$, $RPPP$, $RRPPP$, and $RPPPP$ were obtained where the *on*-mass-shell particles were gluons, or sets of gluons with small invariant masses. The explicit expressions satisfying the Bose-symmetry and gauge invariance conditions are obtained. As a comment to Feynman rules for derivation of the amplitudes in terms of effective vertices we present a «vocabulary» for practitioners [6].

An explicit calculation of the contribution to the lepton pair production in the collision of two nucleus in the frames of QED is reported. Multiple photon exchange between ion and lepton is considered. The motivation of this work is that the recent analysis of nuclear distortions in DIS off nuclei revealed a breaking of the conventional hard factorization for multijet observable [7].

QCD predicts that the Sivers parton distribution functions responsible for the left–right asymmetry of parton distribution in transversally polarized nucleon possess a specific «universality property», namely, they have opposite signs in deep-inelastic semi-inclusive processes and in the Drell–Yan process. On the basis of existing HERMES data it is discussed how this remarkable QCD prediction could be checked in future experiments of the PAX and COMPASS collaborations (see Fig. 1) by the measurement of single spin asymmetries connected with the Sivers effect [8].

In pp collisions antiquark distributions are inevitably involved, and the counting rates are smaller. It was demonstrated that the Sivers effect SSA in DY can, nevertheless, be measured at RHIC with an accuracy sufficient for an unambiguous test of the sign prediction [9]. In particular, by focusing on certain kinematic regions the effect of the unknown Sivers antiquark distribution function can be minimized. And, by focusing on the opposite kinematic regions one can gain first information on the Sivers antiquark distribution itself.

The modification of the Jacobi polynomial expansion method (MJEM) was proposed which is based on the application of the truncated moments instead of the full ones. This allows one to reconstruct with high precision the local quark helicity distributions even for the narrow Bjorken x region accessible for measurement using as an input only the first four moments extracted from the data in NLO QCD. The variational (extrapolation) procedure is also proposed which allows one to reconstruct the distributions outside the accessible Bjorken x region using the distributions obtained with MJEM in the accessible region. The numerical calculations encourage one that the proposed variational (extrapolation) procedure could be applied to estimate the first full (especially important) quark moments [10].

The Drell–Yan (DY) processes with unpolarized colliding hadrons and with the single transversely polarized hadron were considered. The possibility of direct (without any model assumptions) extraction of both the transversity and the accompanying T-odd parton distribution functions (PDF) was discussed. For DY process measurements, planned at GSI, the preliminary estimations demonstrate that it is quite real to extract both the transversity and the accompanying T-odd PDF in the PAX conditions [11].

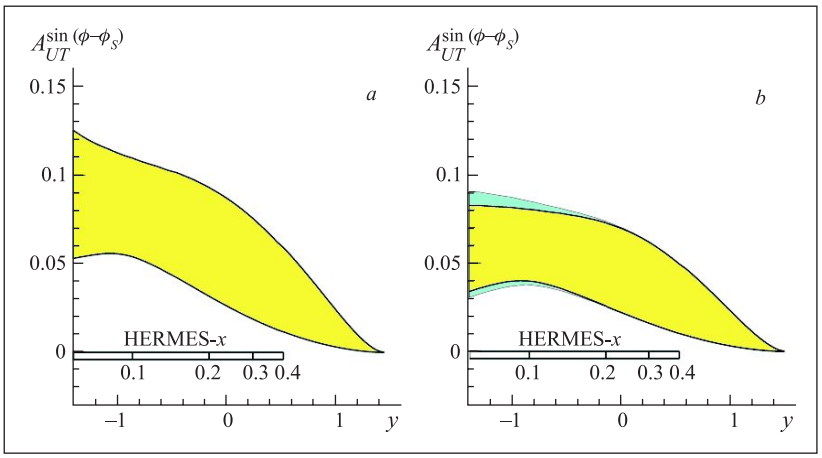

Fig. 1. Azimuthal asymmetries $A_{UT}^{\sin(\phi_h-\phi_S)}$ in production of the Drell–Yan lepton pair, $p^{\uparrow}h \to \mu^+\mu^-X$, depending on rapidity y: *a*) for kinematics of the PAX experiment, where hadron $h = \bar{p}$; *b*) for kinematics of the COMPASS experiment, where $h = \pi^-$. The shaded area corresponds to 1σ uncertainty of the fit

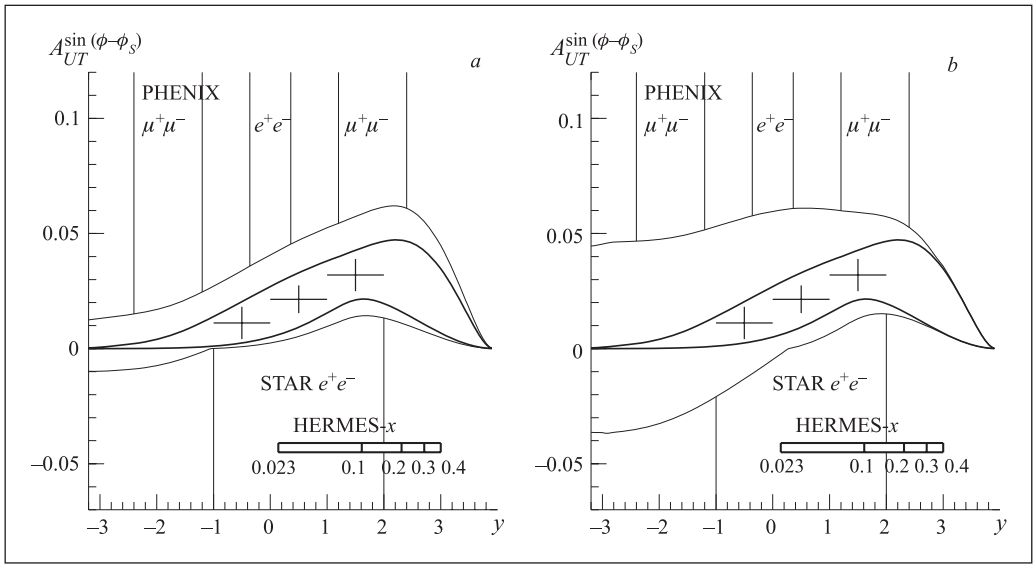

Fig. 2. The azimuthal SSA $A_{UT}^{\sin(\phi-\phi_S)}$ in the Drell–Yan lepton pair production, $p^\uparrow p \to l^+l^-X$, as a function of y for the kinematics of the RHIC experiment with $\sqrt{s} = 200\,\mathrm{GeV}$. *a* and *b* correspond to different ansatze for Sivers antiquark distributions. For $Q = 4\,\mathrm{GeV}$ we show the estimated statistical error for STAR

A generalization of the nonpower, QCD analytic perturbation theory (APT) of Shirkov–Solovtsov (without Landau pole) is developed which enables one to apply a renormalization group and other approaches to sum higher-order corrections for any processes. The one-loop running coupling $\mathcal{A}_\nu(L)$ appears to be an entire function in ν in both the space-like and time-like domains. This allows one to replenish the linear space of the objects that can be treated in APT by including elements typical of higher-order perturbative calculations. The algorithmic rules to obtain analytic-coupling expressions within the proposed generalized APT from the standard QCD power-series expansion were supplied which are ready for phenomenological applications [12]. This approach was shown to reduce significantly the renormalization-scheme sensitivity, and the dependence on the renormalization and the factorization scale of the QCD predictions [13].

The hadronic corrections to the anomalous magnetic moment of the muon coming from hadronic vacuum polarization, the effective $\gamma\gamma Z$ vertex and the light-by-light amplitude are estimated within the instanton liquid model of QCD vacuum. To this end, the anomalous amplitude including the vector and axial-vector current correlator in the external electromagnetic field is studied. In general, this amplitude has two Lorentz structures: longitudinal w_L and transversal w_T with respect to axial-vector index. It is known that in the limit of massless quarks the longitudinal w_L and transversal w_T structures are free from perturbative corrections in accordance with the Adler–Bardeen and Vainshtein theorems. Within the instanton model we show that the anomalous w_L structure has no nonperturbative corrections in accordance with the 't Hooft duality principle, while the transversal amplitude w_T calculated at arbitrary space-like momentum transfer q has only exponentially suppressed corrections at large q^2. This property reflects nonlocal properties of QCD vacuum [14].

The reliable knowledge of symmetries and other more detailed properties of the nucleon wave function in the configuration space of the relativistic valence quarks is among the top priority problems in the hadron spectroscopy. The dispersion and current algebra sum rules for the nucleon resonance photoexcitation, which are known to follow from very general principles, are used to define, within the saturation scheme of the sum rules by the known nucleon resonances in the mass range up to about 2 GeV, the quark correlation function moments. Thus, for the first time the evidence was derived of the quark coordinate correlation function asymmetries following directly from the experimentally measured resonance cross sections treated in the framework of rather a model-independent theoretical approach. Quantitative measures of these asymmetries are characterized by the numerical difference of the calculated mean values of the quark electric dipole operators referring to either the «even» (i.e., identical, q_1 and q_2) quarks or to the «odd» q_3 quark:

$$\langle \mathbf{d}_1^2 \rangle = \langle \mathbf{d}_2^2 \rangle = (0.62 \pm 0.06)\ \mathrm{fm}^2,$$

$$\langle \mathbf{d}_3^2 \rangle = (0.78 \pm 0.12)\ \mathrm{fm}^2,$$

$$\langle \mathbf{d}_1 \cdot \mathbf{d}_2 \rangle = (-0.18 \pm 0.04)\ \mathrm{fm}^2,$$

$$\langle \mathbf{d}_1 \cdot \mathbf{d}_3 \rangle = \langle \mathbf{d}_2 \cdot \mathbf{d}_3 \rangle = (-0.25 \pm 0.07)\ \mathrm{fm}^2,$$

where the averaging is understood over the nucleon state at the «infinite momentum» reference frame (or over the light-front coordinates).

A very good correspondence of the calculated and experimental values of isoscalar, mean-squared Dirac radius, $\langle r_1^2 \rangle^S = (0.34 \pm 0.04)\ \mathrm{fm}^2, (\exp: 0.336\ \mathrm{fm}^2)$, in

which the nonvalence degrees of freedom effects (e.g., the pion currents, etc.) are absent or minimal, confirms the adequacy of the duality relation of the valence quark dynamics to the nucleon resonance exchanges in the direct channel and nonvacuum Regge trajectory exchanges in the crossed channel of the reaction [15].

The triquark correlations in pentaquark were studied within the QCD sum rule approach. Two quasi-bound light $ud\bar{s}$ color quark clusters of 800 and 930 MeV were obtained. A full QCD sum rule calculation to determine the mass and the parity of the lowest lying pentaquark state was performed. The operators up to dimension $d = 13$ in operator product expansion and direct instanton contributions were included. An evidence for the exotic positive parity Θ^+ pentaquark state was found [16].

The theoretical estimate for the cross section of exclusive $\rho^+\rho^-$- and $\rho^0\rho^0$-meson production in two-photon collisions when one of the initial photons is highly virtual is presented [17]. The focus was made on the discussion of the twist-4 contributions which are related to the production of an exotic isospin-2 resonance of two ρ mesons. The analysis shows that the recent experimental data obtained by the L3 collaboration at LEP can be understood as a signal for the existence of an exotic isotensor resonance with a mass around 1.5 GeV. The sizeable cross section for deep exclusive electroproduction of an exotic $J^{PC} = 1^{-+}$ hybrid meson in the Bjorken regime was estimated [18].

In view of intensive recent (Mainz microtron, MAMI) and ongoing (CERN, COMPASS collaboration) experimental activities focused on determination of the pion polarizabilities, improvement of theoretical computations of polarizabilities has become an important task. The cross section for the reaction $\gamma+\gamma \to \pi^0+\pi^0$ was computed by virtue of the chiral Lagrangian at order p^6 with the use of improved techniques. Analytic results for the dipole and quadrupole polarizabilities were obtained and compared with a recent evaluation of data on $\gamma + \gamma \to \pi^0 + \pi^0$ [19].

It is known from the previous studies that the lepton number violating decays $K^+ \to \pi^- + l_1^+ + l_2^+$ have good prospects to probe new physics beyond the Standard Model and provide valuable information on neutrino masses and mixing. These processes were analyzed with an emphasis on their hadronic structure aspects by applying a relativistic constituent quark model. It is shown that the previously ignored contribution associated with the t-channel Majorana neutrino exchange is comparable with the s-channel one in a wide range of neutrino masses. Model-independent absolute upper bounds on neutrino contribution to these decays were also derived [20].

Two-photon decays of vector mesons ω, ρ, and ϕ, strong decay $\rho \to \eta\pi$ and dilepton decays of scalar mesons σ, a_0, and f_0 are described within the Nambu–Jona-Lasinio model. These decays are completely forbidden in vacuum. However, they occur at values of chemical potential μ and temperature T near the phase transition of hadron matter to quark-gluon plasma. The decay $\rho \to \gamma\gamma$ containing an intermediate a_0 meson is especially interesting. The propagator of this meson takes the form of a sharp resonance in the vicinity of the critical values of T and μ, that strongly increases the width of this decay and makes it comparable with the allowed decays, for instance, $\eta \to \gamma\gamma$, $\sigma \to \gamma\gamma$ and $a_0 \to \gamma\gamma$. In this domain, the decay $\omega \to \pi\pi$ is also noticeably enhanced, in comparison with vacuum. These results can be used in the description of heavy-ion collision experiments planned at JINR (Nuclotron) and GSI (SIS-300) [21].

A physical programme is formulated for new facilities opened in Dubna for acceleration of heavy ions with an energy up to 5 $A \cdot$ GeV [22].

MODERN MATHEMATICAL PHYSICS

The topics of main focus in the theme were:

- Supersymmetry and superstrings;
- Quantum groups and integrable systems;
- Quantum gravity and cosmology.

Below, we present some results obtained in 2005 on these subjects.

A 6D-supersymmetric gauge theory involving four derivatives in the action was constructed and disscussed. The theory involves a dimensionless coupling constant and is renormalizable. At the tree level, it enjoys $N = (1, 0)$ superconformal symmetry, but the latter is broken by quantum anomaly [23].

A two-dimensional $N = 8$ supersymmetric quantum mechanics on the basis of (2, 8, 6) supermultiplet was constructed. It inherits the most interesting properties of $N = 2$, $d = 4$ supersymmetric Yang–Mills theory. The most general superfields action for this supermultiplet was constructed, and it was demonstrated that this action possessed duality symmetry [24].

Surprising relations between higher spin theory and nonlinear realizations of the supergroup $OSp(1|8)$ (which is a minimal superconformal extension of $N = 1$, 4D supersymmetry with tensorial charges) were exhibited. The covariant superfield equation encompassing the component ones for all integer and half-integer massless higher spins are shown to amount to the vanishing of covariant spinor derivatives of the suitable Goldstone superfields [25].

A wide class of fermionic Toda-type hierarchies was proposed, and their Lax pair and Hamiltonian descriptions were derived in the framework of the developed generalized graded r-matrix formalism [26].

The earlier proposed class of integrable constrained Liouville models of 1+1 dilaton gravity coupled to N scalar fields was studied in detail. The structure of the space of the chiral moduli fields in terms of which their general solution was expressed, was identified as a pair of N-dimensional unit spheres to which the left and right moduli fields should belong. The reduction of the two-dimensional theory to the one-dimensional cosmological models and static (in particular, black hole) solutions emerges when the moduli fields are constants. In addition to the mentioned reduced solutions, there exists a new class of wave-like solutions. Under certain conditions these waves may be localized in space and time and, thus, may be regarded as solitary gravitational waves. It was shown that there existed a close relation between main gravitational objects — black holes, cosmologies, and waves. This relation was studied in detail for the case of static states and cosmologies and it was naturally called a «static–cosmological» duality (SC-duality). In the integrable models these ideas, which do not actually require integrability, may open a way to study connections between all mentioned apparently diverse physical objects [27].

It was proved that the superstring inspired supergravity equations for purely time-dependent cosmological backgrounds, which reduce to those of a sigma model, admit a Lax pair representation and are fully integrable. In the case when the corresponding sigma model is on a maximally split noncompact manifold (maximal supergravity or subsectors of lower supersymmetry supergravities) it was demonstrated that it was related to the generalized Toda-lattice equations, and as a consequence admits a completely explicit analytic integration algorithm to construct its general solution. It was shown that the entire cosmic evolution can be seen as a billiard scattering with quantized angles defined by the Weyl group of the sigma-model symmetry group [28].

It was demonstrated that the three-string vertex coefficients in light-cone open superstring field theory (SFT) satisfied the Hirota equations for the dispersionless Toda-lattice hierarchy, and using the latter we calculated the correlators of an associated quantum system where the Neumann coefficients represented the two-point functions. It was shown that the three-string vertex coefficients of the light-cone SFT on a maximally supersymmetric pp-wave background satisfied the Hirota equations for the full Toda-lattice hierarchy at least up to second order in the «string mass». The main value of these results is that they pointed out the existence of an integrable model (of which the Hirota equations are a signal) underlying the SFT structure, very likely a matrix model which, once uncovered, would greatly improve our knowledge of SFT. The fact that this is probably true also for a nontrivial background, such as the pp-wave one, may suggest a way to approach the problem of defining SFT on more general backgrounds [29].

The spectral analysis of the Maxwell equations on the background of an infinitely thin flat plasma layer was carried out. This model is loosely imitating a single base plane from graphite and it is of interest for theoretical studies of fullerenes. Both the sectors of the model, the TE and TM modes, have positive continuous spectra, but the latter has in addition a bound state, namely, the surface plasmon. This analysis relies on the consideration of the scattering problem in the TE and TM sectors. The spectral zeta function and integrated heat kernel were constructed for different branches of the spectrum in an explicit form. A new method was demonstrated for deriving the fundamental solution to the heat conduction equation (or to the Schrödinger equation) on an infinite line with the δ-like source [30].

The Hamiltonian approach to cosmological perturbations in General Relativity (GR) in finite space-time is developed. The essential point of this approach is the identification of the cosmological scale factor with spatial averaging of the metric determinant logarithm. This identification preserves the number of variables and energy constraints in GR. The Hamiltonian approach enables one to explain the «primordial power spectrum» of Cosmic Microwave Background Radiation and to consider other topical problems of modern cosmology from this stand-point [31].

Recently, it was argued that the open topological B model whose target space is a complex (2–4)-dimensional minisupertwistor space with $D3$- and $D1$-branes added, corresponds to a super Yang–Mills theory in three dimensions. Eventually, we have presented solution generating techniques based on the developed twistorial description together with some examples [32].

Ward's generalized self-duality equations for the $U(2n)$ Yang–Mills theory on R^{4k} and their noncommutative deformation were investigated. Two types of explicit solutions, which generalize the 't Hooft and BPST instantons from R^4 to noncommutative R^{4k}, were found by employing an extended ADHM construction [33].

The structure theory of the quantum supermatrices of the $GL(m|n)$ type was constructed. The notion of the spectral values for these quantum supermatrices was introduced. The Cayley–Hamilton identities and Newton relations were generalized for the case of the quantum supermatices of $GL(m|n)$ type [34].

It was shown that from the spectra of the $U_q(sl(2))$ symmetric XXZ spin-1/2 finite quantum chain (at exceptional values of the deformation parameter q) one can obtain the spectra of certain XXZ quantum chains with nontrivial boundary conditions. For the finite chains the origin of the remarkable spectral identities can be found in the representation theory of one and two boundaries of Temperley–Lieb algebras at exceptional points. Inspired by these observations other spectral identities between chains with different boundary conditions were discovered [35].

Mathematical structures which are behind a phenomenon of exact solvability of the nontrivial quantum models were investigated. These structures were used to obtain exact results in quantum 2D and 3D integrable systems [36].

Two equivalent formalisms describing hyper-Kähler torsion (or heterotic) geometries in four dimensions were considered. Certain examples were presented, some of which are described by the metrics of the Callan–Harvey–Strominger type [37]. The Feynman path integral technique was applied to superintegrable systems on two-dimensional spaces of nonconstant curvature: these spaces are called Darboux spaces D_{I}–D_{IV}. The path integral can be evaluated in most of the separating coordinate systems leading to expressions for the Green functions, the discrete and continuous wave functions, and the discrete energy spectra [38].

NUCLEAR THEORY

In 2005, investigations within the area «Nuclear Theory» were carried out in accordance with the four projects:

- Theory of nuclear excitations;
- Dynamics and manifestation of structure in nuclear and mesoscopic systems;
- Few-body physics;
- Relativistic nuclear dynamics.

The following main results were obtained in the field of *nuclear structure theory*:

A finite rank approximation for the Skyrme forces was suggested and generalized to take into account the pairing correlations and the phonon–phonon coupling effects. The energies and transition probabilities of the low-lying 2^+ and 3^- states and the strength distributions in a broad excitation energy interval for spherical nuclei with different mass numbers, were calculated and good agreement with experimental data was obtained. Effects of the coupling with two-phonon states are studied for low-lying 2^+ states in neutron-rich tin isotopes [39].

The microscopic quasiparticle–phonon nuclear model is extended for a systematic study of the low-lying excited 0^+ states observed in large abundance in some deformed nuclei. Through the investigation of the energy levels, the wave functions, the $E0$ and $E2$ transition probabilities, and, especially, the two-nucleon transfer spectroscopic factors, a deep insight into the nature of these states is achieved. The study shows that it is necessary to go beyond the mean field and the random phase approximations (RPA) in order to account for a large number of 0^+ levels observed in ^{168}Er [40].

Experimental data showing a significantly larger value of the $E2$ transition probabilities between the negative-parity states compared to the positive-parity ones in ^{144}Ba are explained in the framework of the cluster approach. It is demonstrated that a higher weight of the alpha-cluster component in the wave function of the negative-parity states compared to the positive-parity ones is responsible for such an effect [41].

New results were obtained in theoretical investigations of *nuclear reactions*.

The production cross sections of neutron-rich isotopes ^{24,26}O, ^{32}Ne, ^{36,38}Mg, ^{42}Si, and ^{52,54,56,58,60}Ca in diffusive multinucleon transfer reactions $^{48}\mathrm{Ca} + {}^{124}$Sn, ^{197}Au, ^{232}Th, ^{238}U, ^{248}Cm at incident energies close to the Coulomb barrier are predicted. The global trend of production cross section with the charge (mass) number of a target in reactions with ^{48}Ca beam is analyzed for future experiments [42].

A semianalytic connection between matter and charge radii for the Borromean halo nuclei is derived. It is based on the three-body core $+N+N$ cluster structure of those halo nuclei and the knowledge of the corresponding radii for the constituents. The charge form factor of ^{6}He is predicted [43].

The model of the nucleus–nucleus microscopic optical potential was developed which successfully explained experimental data on scattering of different pairs of nuclei including exotic ones. The charge form factors of several unstable neutron-rich nuclei were calculated and compared to those of stable isotopes in the same isotopic chains [44].

A variety of problems were under study within the project *Few-Body Physics*. The corresponding results are:

It is shown that in the low-energy limit the triplet *pp*-scattering differential cross section, generated by the sum of nuclear and magnetic interactions in the Coulomb field of protons, oscillates rapidly and has the second-order poles in the directions of forward and backward scattering. In order to extrapolate such a cross section to the energy region below 10 MeV, a simple low-energy approximation was proposed. New phenomena — proton–proton analogs of the Mott and Schwinger effects — are discussed [45].

A self-consistent analysis of pion scattering and pion photoproduction within a coupled-channels dynamical model was performed. The results of this analysis indicate the existence of the third and fourth

S_{11} resonances with the masses of (1803 ± 7) and (2117 ± 64) MeV. This result is consistent with predictions based on the recent constituent quark models. In the case of pion photoproduction, large negative background contributions to the imaginary part of the S-wave multipole were found. Due to this fact much larger resonance contributions are required in order to explain the results of the recent multipole analyses. For the first $S_{11}(1535)$ resonance the following value of the electromagnetic helicity amplitude was obtained: $A_{1/2} = (72 \pm 2) \cdot 10^{-3}$ GeV$^{-1/2}$. Close values can be derived from the eta-photoproduction analysis if one takes the same total width ($\Gamma_R = (95 \pm 5)$ MeV) as in pion scattering and pion photoproduction [46].

The main results of the project *Relativistic Nuclear Dynamics* are:

A simple quasiparticle model, motivated by the lowest-order perturbative QCD, is proposed. It is applied to interpret the lattice QCD equation of state. A reasonable reproduction of the lattice data is obtained. In contrast to existing quasiparticle models, the present model is formulated in dynamical rather than thermodynamical terms and is easily applicable to a system with finite baryon density. In particular, the model simulates the confinement property [47].

It was shown for the first time that if Θ^+ exists and decays to NK pairs, then it must manifest itself in the associated $\Lambda(1520)$ Θ^+ photoproduction off a deuteron independently of the Θ^+ photoproduction mechanisms in the elementary $\gamma n \to \Theta^+ K^-$ or $\gamma p \to \Theta^+ K^0$ reactions [48].

The processes ${}^2\mathrm{H}(e, e'p)n$, ${}^3\mathrm{He}(e, e'p)X$, and ${}^3\mathrm{He}(e, e'N)2N$ were theoretically investigated using realistic three-body wave functions, and treating the final state interaction within a Feynman diagram approach, using a generalized eikonal approximation. The approach does not contain any adjustable parameter and the agreement with existing experimental data is very good [49].

Moreover, new results were also obtained in *the Vavilov–Cherenkov radiation theory*. The motion of a charge in the medium, in a finite space interval, is considered. The charge is subsequently accelerated, moves with a constant velocity and finally is decelerated. The space-time distribution of the shock electromagnetic waves arising when the charge velocity coincides with the light velocity in medium is found. These results may be useful in experimental search for shock waves [50].

THEORY OF CONDENSED MATTER

Theoretical investigations in the Theory of Condensed Matter were continued in the framework of the following projects:

- Strongly correlated systems;
- Dynamical systems: chaos, integrability, and self-organization;
- Disordered structures: glasses, topological defects, nanostructures and the Josephson junction;
- Mesoscopic and coherent phenomena in quantum systems.

A number of important new results were obtained in the field of *strongly correlated systems* among which are the following:

The Bose–Einstein condensation of magnons in a quasi-two-dimensional spin-1/2 frustrated antiferromagnet Cs_2CuCl_4 induced by magnetic field B_c was studied. A phase boundary and a critical temperature $T_c(B)$ were calculated within a spin Hamiltonian with the coupling parameters taken from inelastic neutron-scattering measurements. A good agreement with experiment was found [51].

A consistent theoretical approach to calculation of quasiparticle excitations in complex magnetic materials as magnetic semiconductors was formulated. The theory was applied to study the acoustic and optical branches of the spectra for a generalized spin-fermion model describing the interacting localized and itinerant magnetic subsystems [52].

In the field of the theory of *dynamical systems: chaos, integrability, and self-organization*, the finite-size corrections of the dimer model on the $\infty \times N$ square lattice were investigated for two different boundary conditions: free and periodic. It is found that the finite-size corrections in a crucial way depend on the parity of N; it is also shown that such an unusual finite-size behavior can be fully explained in the framework of the $c = -2$ logarithmic conformal field theory [53].

In the investigations of *disordered structures* the following main results were obtained: It was shown that the presence of a reasonable density of optically vibrating dislocation dipoles provided a good fit to the thermal conductivity in plastically deformed samples of Al, Ta, and Nb at low temperatures. The internal friction experiments can be described within the standard fluttering string mechanism by assuming random forces acting on the dislocation dipoles [54].

It was shown that experimentally observed thermal conductivity in single-grain i-AlPdMn quasicrystals can be described by a combination of wedge disclination dipole scattering and quasi-umklapp scattering processes [55].

Based on the model of dislocation-induced Josephson junctions and their arrays, the magnetic field induced electric polarization effects in intrinsically granular superconductors were studied. In addition to a new phenomenon of chemomagnetoelectricity, the model predicts also a few other interesting effects, including charge analogues of Meissner paramagnetism (at low fields) and «fishtail» anomaly (at high fields) [56].

The main topics of *mesoscopic and coherent phenomena in quantum systems* covered the expansion of basic quantum effects to the cases of finite (mesoscopic) systems.

A general theory is developed for describing the nonlinear relaxation of spin systems from a strongly nonequilibrium initial state when, in addition, the sample is coupled to a resonator. These processes are characterized by nonlinear stochastic differential equations. This makes these strongly nonequilibrium processes principally different from the spin relaxation close to an equilibrium state which is represented by linear differential equations. The consideration is based on a realistic microscopic Hamiltonian including the Zeeman terms, dipole interactions, exchange interactions, and a single-site anisotropy. The influence of cross correlations between several spin species is investigated. The critically important function of coupling between the spin system and a resonant electric circuit is emphasized. The role of all main relaxation rates is analyzed. The phenomenon of self-organization of transition coherence in spin motion, from the quantum chaotic stage of incoherent fluctuations, is thoroughly described. Local spin fluctuations are found to be the triggering cause for starting the spin relaxation from an incoherent nonequilibrium state. The basic regimes of collective coherent spin relaxation are studied [57].

The possibility of coherent radiation by molecular magnets is investigated. It is shown that to realize the coherent radiation, it is necessary to couple the considered sample to a resonant electric circuit. A theory for describing this phenomenon is developed. The role of hyperfine interactions between molecular and nuclear spins is studied. Numerical solutions of the spin evolution equations are presented [58].

DUBNA INTERNATIONAL ADVANCED SCHOOL OF THEORETICAL PHYSICS (DIAS-TH)

In 2005, the research-educational project DIAS-TH was successfully continued. The following activities in the framework of DIAS-TH were:

- III Winter School on Theoretical Physics (January 29 – February 6), supported by RFBR and UNESCO (ROSTE);
- Helmholtz International Summer School on Heavy Quark Physics, supported by the Heisenberg–Landau Programme (HLP), UNESCO (ROSTE), and Helmholtz Association;
- IX Research Workshop «Nucleation Theory and Applications» (June 20 – July 20), supported by RFBR, HLP, and UNESCO (ROSTE);
- Advanced Summer School on Modern Mathematical Physics (July 14–26), supported by RFBR, HLP, the Votruba–Blokhintsev Programme, and Helmholtz Association;
- Helmholtz International School on Nuclear Theory and Astrophysical Applications (July 26 – August 4), jointly organized with the JINR University Centre, supported by RFBR, HLP, the Votruba–Blokhintsev Programme, and Helmholtz Association;
- School on Modern Cosmology and Astrophysics (October 3–7);
- Lecture course on Conformal Field Theory was given for students and post-graduates;
- Computer processing of video records of lectures was continued;
- A new lecture hall for DIAS-TH was opened;
- Web-site of DIAS-TH was supported.

COMPUTER FACILITIES

The local computer network was extended to include «DIAS Hall» and a number of new workplaces. In total, the network cable was drawn to 48 new locations. The capacity of the stack of network switches has grown by 72 ports after installation of two new devices. To improve network management the databases describing the local network were created. This allowed us to automate checks of allocation of network resources. Introduction of databases in e-mail processing allowed to block more than 90% of the junk mes-

sages (spam). The disk space for user home directories at the server THEOR was increased up to 140 GB. The server THPROXY got twice as large disk space to store the file archive and video records of lectures given at DIAS-TH. Two dual-processor servers based on 64-bit Opterons which was purchased at the end of the year 2004 were brought into operation. The memory of those servers was extended to 12 and 8 GB; 17 personal computers based on Pentium 4 were installed in work places.

MEETINGS, SCIENTIFIC COLLABORATION

In 2005, besides the schools organized in the framework of DIAS-TH, the Laboratory participated in the organization of 8 international conferences and workshops held in Dubna and Prague.

In 2004, the Laboratory participated in the organization of the XVII International Baldin Seminar on High-Energy Physics Problems (27 September – 2 October, Dubna) and 3 conferences in Prague: «Quantum Groups and Integrable Systems» (17–19 June); «Symmetry Methods in Physics» (21–24 June), and «Symmetries and Spin» (5–10 July).

In 2005, the international collaboration was supported by grants of the Plenipotentiaries of Bulgaria, the Czech Republic, Poland, the Slovak Republic, Hungary, Romania and the JINR Directorate; the collaboration with German theorists was based on the Heisenberg–Landau Programme; with Polish theorists, on the Bogoliubov–Infeld Programme; with Czech theorists, on the Blokhintsev–Votruba Programme; and with Roumanian theorists, on the Titeica–Markov Programme.

Some studies were carried out in collaboration with scientists from Western Europe in the framework of the JINR–INFN, JINR–IN2P3 agreements and on the projects supported by INTAS, RFBR–DFG, RFBR–CNRS.

The agreement for collaboration between the Bogoliubov Laboratory and CERN TH is functioning.

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