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 investigations were continued in the framework of the following projects:

- Standard Model and Its Extensions;
- QCD Parton Distributions for Modern and Future Colliders;
- Physics of Heavy and Exotic Hadrons;
- Mixed Phase in Heavy-Ion Collisions.

The O(α) and O($\alpha^3 \ln(\alpha)$) corrections to the total decay width of orthopositronium were obtained in a closed analytic form, in terms of basic transcendental numbers, which can be evaluated numerically to arbitrary precision. The results reproduce the best numerical evaluations within their accuracy. Orthopositronium is the system suitable for precision tests of the validity of electrodynamics, it plays an important role in atomic and particle physics. The results of this work are of fundamental importance [1].

A full Leigh–Strassler deformation of the $N = 4$ Supersymmetric Yang–Mills (SYM) theory was considered and the conditions under which the theory would be conformally invariant and finite were discussed. A family of theories which are conformal up to 3 loops in the nonplanar case and up to 4 loops in the planar one was constructed by virtue of the algorithm of perturbative adjustments of the couplings. In the planar case, when the conformal condition appeared to be exhausted in the one-loop order, particular solutions were found. Some of them happened to be unitary equivalent to the real beta-deformed $N = 4$ SYM theory. Validity of these solutions at any loop order was analyzed [2].

The possibility of existence of relatively light charged superparticles in the framework of the Minimal Supersymmetric Standard Model (MSSM) was analyzed. Long-lived superpartners of tau-leptons were predicted in the so-called coannihilation region of the MSSM parameter space. Scenarios with long-lived top-squarks and/or charginos can be realized with a large negative value of the soft supersymmetry breaking parameter A. Production cross sections of this sort of particles at the Large Hadronic Collider can reach a few per cent of picobarn for tau-sleptons and a few tens of picobarn for top-squarks and charginos [3].

Prospects for observing a signal from two gluinos were investigated within a certain region of the mSUGRA parameter space. In this region, the lightest stable neutralinos can serve as cold dark matter particles and present a natural explanation of the excess of diffuse galactic gamma rays observed by the EGRET space apparatus. The event selection relies on a very clear signature when decay products of each gluino contain one $b\bar{b}$ pair, one or two $\ell\bar{\ell}$ pair(s), and a neutralino. It was found that the clear signatures of the selected processes demonstrate a good prospects for discovering gluinos at the LHC [4].

The studies of transverse spin and momentum-dependent parton distributions which are objects of investigations at many current and planned experiments (including spin program at NICA) were continued. The parton distribution function of the leading twist h_{1T} (so-called «pretzelosity») was studied. An interesting relation in the majority of relativistic models was noticed: the difference between helicity and transversity distributions is nothing more than pretzelosity. From the data of HERMES and BELLE the Collins fragmentation function was extracted for the first time. On this basis a new approximate relation of the «Wandzura–Wilczek-type approximation», connecting the functions $h_{1L}^{(1)}(x)$ and $h_1(x)$ was checked and predictions for the asymmetry $A_{UL}^{\sin 2\phi}$ as well as for the azimuthal asymmetry connected with pretzelosity $A_{UT}^{\sin(3\phi-\phi_S)}$ were given for future experiments CLAS12 and COMPASS [5].

The nature of a couple of scalar mesons with rather different masses (observed experimentally) was discussed within the instanton model of QCD vacuum. It was shown that the mass splitting in the scalar sector of meson spectrum could be unexpectedly strong due to the effects of instanton liquid excitations [6].

The reasonableness of the use of perturbative QCD notions in the region close to the scale of hadronization, i.e., below 1 GeV was studied. The interplay between higher orders of pQCD expansion and higher-twist contributions in the analysis of recent Jefferson Lab (JLab) data on the Bjorken Sum Rule function $\Gamma_1^{p-n}(Q^2)$ at $0.1 < Q^2 < 3$ GeV^2 was considered. It was shown that the inclusion of the higher-order pQCD corrections could be absorbed, with good numerical accuracy, by change of the normalization of the higher-twist terms. The issue of unphysical singularity (Landau pole at $Q = \Lambda \sim 400$ MeV) was avoided by the use of the ghost-free Analytic Perturbation Theory (APT) that has recently proved to be an intriguing candidate for a quantitative description of light quarkonium spectra within the Bethe–Salpeter approach. The values of the twist coefficients μ_{2k} extracted from the mentioned data by using the APT approach gave a better convergence of the higher-twist series than with the common pQCD. As the main result, a good quantitative description of the JLab data down to $Q \approx 350$ MeV was achieved [7].

The reactions of quasielastic production of Λ, Σ^-, and Σ^0 hyperons in antineutrino interactions with nucleons crucial for studies of neutrino oscillations were studied. The most general formulae connecting the structure functions for quasielastic ηN and $\overline{\eta}N$ scattering off nucleons with the (complex) hadronic-current form factors accounting for the final lepton mass and nonstandard (G parity violating) second-class currents were derived. A statistical analysis of all available accelerator data on the total and differential cross sections was performed. The world-averaged value of the axial mass of the nucleon $M_A = (0.999 \pm 0.011)$ GeV/c^2 was obtained. This result is concordant with the results obtained by fitting the data on exclusive and inclusive ηN and $\overline{\eta}N$ reactions [8].

Accuracy of theoretical description of the Drell–Yan processes at LHC was improved due to systematic accounting of the Standard Model corrections. The contribution of subprocesses with initial state photons was investigated. The results were used for precise comparison of various predictions for the Drell–Yan processes. The achieved increase of accuracy is of vital importance for the LHC physical program. The new systematical methods for calculations of the next-to-leading order QED corrections were derived. The methods are based on the use of renormalization group and stratification of the phase space of kinematic variables [9].

Renormalization group properties of the gauge-invariant transverse-momentum-dependent parton distribution functions (TMD PDFs) were studied. In the light-cone axial gauge, the one-loop anomalous dimensions of these functions were calculated. The relations between additional UV-divergences and properties of the Wilson exponentials in TMD PDFs were established. It was shown that the time-reversal-odd effects arose already in the anomalous dimensions in the form of purely imaginary contributions of the Glauber gluons. These effects are responsible for such phenomena as single-spin asymmetries. The generalized definition of TMD PDFs was proposed. It includes an additional soft factor which compensates the undesirable UV-singularities of the straightforwardly determined functions. The evolution equation analogous to the Collins–Soper equation was obtained [10].

Analytical properties of the hard exclusive process amplitudes were studied. It was found that QCD factorization for deeply virtual Compton scattering and hard exclusive vector meson production resulted in the subtracted dispersion relation with the subtraction constant determined by the Polyakov–Weiss D-term [11].

QCD sum rule analysis for f_0 light tetraquark was performed taking into account the contribution of the two-pion intermediate state and direct instantons. It has been argued that the $f_0(600)$-meson state can be treated as the four-quark bound state in the instanton field which has a rather strong coupling to the two-pion state. A new nonperturbative mechanism of the energy loss of energetic parton jets in quark–gluon plasma above the deconfinement temperature T_c was suggested. The mechanism relates to the scalar and pseudoscalar glueballs. It can play the crucial role in the jet-quenching [12].

The Mellin–Barnes representation was employed in order to improve the theoretical estimate of mass corrections to the width of light pseudoscalar meson decay into a lepton pair, $P \to \ell^+\ell^-$. The full resummation of the terms $\ln(m_l^2/\Lambda^2)(m_l^2/\Lambda^2)^n$ and $(m_l^2/\Lambda^2)^n$ to the decay amplitude was performed. It was demonstrated that the total effect of mass corrections for the e^+e^- channel was negligible, and it is of order of a few per cent in the case of the $\mu^+\mu^-$ channel. This work is a continuation of a series of papers devoted to accurate calculations of strong interaction contributions to some low-energy processes which play an important role in the Standard Model tests [13].

The semileptonic baryon octet–octet transition form factors were calculated within the manifestly Lorentz covariant quark model approach based on the factorization of the contribution of valence quarks and chiral effects. A detailed analysis of $SU(3)$ breaking corrections to the hyperon semileptonic decay form factors was performed. Complete results on decay rates and asymmetry parameters including lepton mass effects for the rates were obtained [14].

Three-flavour chiral perturbation theory including virtual photons was investigated in the limit where the strange quark mass is much larger than the external momenta and the up and down quark masses, and where the external fields are those of two-flavour chiral perturbation theory. In particular, the strange quark mass dependence of the electromagnetic two-flavour low-energy constants C and k_i was worked out. These relations are useful for a more precise determination of the electromagnetic low-energy constants [15].

The atomic mass of electron was determined from the laser spectroscopy of the antiprotonic helium atoms $A_r(e) = 0.000\,548\,579\,908\,81(91)[1.7 \cdot 10^{-9}]$. This exotic atomic system may serve as a new alternative and competitive tool in measuring the fundamental physical constants [16].

MODERN MATHEMATICAL PHYSICS

The topics of main focus in the theme were:

- Supersymmetry and Superstrings;
- Quantum Groups and Integrable Systems;
- Quantum Gravity and Cosmology.

Representative results obtained in 2008 on these subjects are described below.

An overview of recent progress in constructing and studying superextensions of the Landau problem of a quantum particle on a plane in the uniform magnetic field and its Haldane's S^2 generalization was presented. The main attention was paid to the planar super Landau models. These models are invariant under the inhomogeneous supergroup $ISU(1|1)$, a contraction of the supergroup $SU(2|1)$, and can be seen as minimal superextensions of the original Landau model. Their common notable feature is the presence of a hidden dynamical worldline $N = 2$ supersymmetry. It exists at the classical and quantum levels and is revealed most naturally while passing to the new invariant inner products in the space of quantum states [17].

Superconformal extensions of $d = 1$ Calogero-type systems were obtained by gauging the $U(n)$ isometry of matrix superfield models. The cases of $N = 1$, $N = 2$ and $N = 4$ one-dimensional supersymmetries were considered. The bosonic core of the $N = 1$ and $N = 2$ models is the standard conformal A_{n-1} Calogero system, whereas the $N = 4$ model yields the $U(2)$-spin Calogero system [18].

The most general $N = 4$ superconformal 3-particle systems with translation invariance were constructed. In the basis with decoupled center of mass the supercharges and Hamiltonian possess one arbitrary function which defines all potential terms. With the proper choice of this function one may describe the standard, A_2 Calogero model as well as BC_2, B_2, C_2 and D_2 Calogero models with $N = 4$ superconformal symmetry. The main property of all these systems is that even with the coupling constant equal to zero they still contain nontrivial interactions in the fermionic sector. In other words, there are infinitely many nonequivalent $N = 4$ supersymmetric extensions of the free action depending on one arbitrary function [19].

Hierarchical relations for the Bethe vectors were formulated as inverse generating series, taking values in quantum algebra of currents. In the framework of these investigations a new type of the hierarchical relations for the universal Bethe vectors was found. This type of the relations allows one to address the question of the universal Bethe equations, or, in other words, to formulate the rule about the structure of the universal Bethe vectors when their parameters satisfy the universal Bethe equations. This rule is an algebraic justification of the nested Bethe ansatz [20].

A new construction of the primitive idempotents of the Hecke algebras associated with the symmetric groups was given. The idempotents were found as evaluated products of certain rational functions thus providing a new version of the fusion procedure for the Hecke algebras. The normalization factors which occur in the procedure are related to the Ocneanu–Markov trace of the idempotents [21].

The noncanonical ghosts and antighosts for nonlinear algebras, like W-algebras, were introduced. In terms of these ghosts the BRST operator (for the W_3 and $W_3^{(2)}$ algebras) with the conventional cubic form was constructed. The important feature of this construction is the use of noncanonical ghost algebra, which in general is represented as Nichols algebra defined by the special elements (shuffle elements) in the braid group ring. Multiplicative analogues of the shuffle elements of the braid group rings are obtained; in local representations they give rise to new graded associative algebras (b-shuffle algebras) [22].

New nontoric Lagrangian fibrations of two-dimensional quadric were found in terms of birational maps. A new method for constructing the toric and nontoric Lagrangian fibration of toric Fano manifolds was proposed [23].

Recently established relation between static states, cosmologies, and waves was extended to a new class of integrable two-dimensional dilaton gravity theories in which scalar matter satisfies the Toda equations. The simplest cases of the Toda system are considered in detail, and it is shown how the wave-like solutions of the general Toda systems can be simply derived. In the dilaton gravity theory these solutions describe nonlinear waves coupled to gravity [24].

It was shown that eigenvalues of the family of Baxter Q-operators for supersymmetric integrable spin chains constructed with the $gl(K|M)$-invariant R-matrix obey the Hirota bilinear difference equation. The nested Bethe ansatz for superspin chains, with any choice of simple root system, was then treated as a discrete dynamical system for zeros of polynomial solutions to the Hirota equation. Our basic tool is a chain of Backlund transformations for the Hirota equation connecting quantum transfer matrices. This approach also provides a systematic way to derive the complete set of generalized Baxter equations for superspin chains [25].

The early-time and late-time universe evolution is described in the framework of modified gravity nonminimally coupled with matter Lagrangian. Such $F(R)$ ($F(G)$) gravity in the absence of nonminimal coupling is a viable theory which passes the local tests and reproduces the ΛCDM era. For qualitatively similar choice of a nonminimal gravitational coupling function it is shown that the unified description of early-time inflation and late-time cosmic acceleration is possible. It is interesting that matter (scalar) which supports the inflationary era is gravitationally screened at late times. Hence, it may be effectively invisible at current universe [26].

Some physical applications of the algebraic geometry approach in gravitational theories with covariant and contravariant metrics and connections have been considered. It was proposed that corrections to the extradimensional volume should be taken into consideration due to the non-Euclidean nature of the Lobachevsky space–time. It was demonstrated that in the Higgs mass generation model with two branes (a «hidden» and a «visible» one), to any mass on the visible brane there could correspond a number of physical masses. Algebraic equations for 4D Schwarzschild Black Holes in higher dimensional brane worlds were obtained [27].

Kinks and bounce-type solutions of the plane wave matrix model and a matrix analog of the ϕ^4 kink model were constructed. Explicit instanton, dyon, monopole and monopole–antimonopole chain of solutions of pure Yang–Mills theory on $R^2 \cdot S^2$ and $R \cdot S^3$ was obtained by symmetry reduction to the above-mentioned matrix models. It was shown that there was a Lax representation of equations of motion of the plane wave matrix model that implies its nonperturbative integrability [28].

When constructing quantum field theory with allowance for the space–time curvature the methods of spectral geometry and spectral summation were widely used. Recently, this technique was applied effectively in calculating the vacuum effects in nanophysics problems. The Casimir force was investigated between two dissimilar plane mirror material properties which are described by Drude or Lorentz models. The short and long distance asymptote of the force was calculated analytically and related to the influence of interacting surface plasmons. Conditions needed for obtaining the Casimir repulsion in this case were discussed too [29].

NUCLEAR THEORY

In 2008, investigations within the area «Nuclear Theory» were carried out in accordance with the four projects:

- Nuclear Structure Far from the Valley of Stability;
- Nucleus–Nucleus Interactions and Nuclear Properties at Low Excitation Energies;
- Exotic Few-Body Systems;
- Nuclear Structure and Dynamics at Relativistic Energies.

The approach based on the numerical separabelization of the Skyrme-type interaction within the «Hartree–Fock–BCS + QRPA» procedure was extended to take into account the residual interaction in the particle–particle channel. As an application the evolution of 2^+_1 state energies and $B(E2)$-values in even–even nuclides $^{126-130}$Pd, $^{124-132}$Cd, $^{124-134}$Sn, $^{128-136}$Te, $^{134-138}$Xe was investigated with the same set of interaction parameters. The residual particle–particle interaction reduced somewhat the collectivity of vibrational states. The isotopic and isotonic dependences of $E(2^+_1)$ and $B(E2)$-values were described correctly. The structures of the 2^+_1 states in $^{126-130}$Pd and $^{124-132}$Cd nuclides were predicted. Moreover, it was found that the 2^+_4 state in ^{130}Te is a candidate to be a mixed-symmetry state [30].

The isovector dipole giant resonance (GDR) in deformed nuclei was analyzed over a sample of 18 rare-earth nuclei, four actinides, and three chains of superheavy elements ($Z = 102$, 114, and 120). The description was based on the self-consistent separable random-phase approximation with the Skyrme force SLy6. The model well reproduces the experimental data in the rare-earth and actinide nuclei. The trend of the resonance peak energies follows the estimates of collective models, showing a bias to the volume mode for the rare-earth isotopes and an interplay of volume and surface modes for actinides and superheavies. The widths of the GDR are mainly determined by the Landau fragmentation, which in turn is found to be strongly influenced by deformation. A deformation splitting of the GDR can contribute to about one-third of the width [31].

The structure of the low-lying states in ^{188,190,192}Os nuclides was investigated within the quasiparticle–phonon nuclear model. The calculation accounted fairly well for the observed properties of the $K^\pi = 2^+$ and $K^\pi = 4^+$ lowest bands and of the low-lying $K^\pi = 0^+$ bands. Most of the physical quantities characterizing the low-lying 0^+ states were reproduced with fair accuracy. The trend with the mass number of $E2$ and two-nucleon transfer reaction strength, supplemented by the analysis of the microscopic structure of the 0^+ states, suggested a shape evolution as one moves from ^{188}Os to ^{192}Os. Special attention was devoted to the 4_3^+ state. This state is found to be composed of a large double-γ phonon component coexisting with an even larger one-phonon hexadecapole piece. Such a mixed phonon structure explains the observed, apparently contradictory, properties of the 4_3^+ states in Os isotopes [32].

The Bohr Hamiltonian in the intrinsic frame with three different mass coefficients was applied to consideration of the well-deformed axially symmetric nuclei. It is shown that this Hamiltonian can describe a situation where the collectivity of the vibrational states is rather low, but their excitation energies are relatively small, while the $E2$ transitions inside the bands are very strong [33].

In connection with recent experiments, the renewed calculations of the valleys on the potential energy surface (PES) of ^{226}Th were performed. In the present calculations the deformations of higher order from the 1st to 21st ones were taken into account in the process of minimization in multi-dimensional space of the deformation parameters with two constrains provided that the global features of the nuclear shape such as elongation or asymmetry and the neck thickness are fixed. In the present calculations the fission process was developing along three valleys. This was a result of the flexibility of the present parameterization of the shape of the fissioning nucleus. Thus, one can trace finer details on the PES, as compared to the other approaches. In each valley the shapes differ in the parameters of the higher order. The calculations explained qualitatively the main experimental data on the properties of the fission modes in ^{226}Th [34].

In view of the planned experiments the production cross sections of neutron-rich nuclei of the elements Mg, Al, Si, P, S, Cl, Ar, K, Ca, Sc, and Ti in the diffusive multinucleon transfer reactions ^{48}Ca(64 MeV/nucleon, 140 MeV/nucleon) + ^{181}Ta and ^{48}Ca(142 MeV/nucleon) + $^{\rm nat}W$ were estimated. The process was considered as a diffusion of the dinuclear system (DNS) in the charge and mass asymmetry coordinates, which were defined by the charge and neutron numbers of the DNS light nucleus. A good agreement of the theoretical results with the available experimental data confirms the mechanism of multinucleon transfer in almost peripheral collisions at intermediate energies. The predicted production cross sections for new exotic isotopes ^{47}P, ^{51,53,55,57}Cl, ^{52,54}Ar, ^{56,58,60}Ca, ^{59,61,63}Sc, and ^{62,64,66}Ti appear to be larger than 0.1 pb. Thus, they can be synthesized and detected at present experimental possibilities. The global trend of production cross section with the charge (mass) number of target in reactions with ^{48}Ca beam was discussed [35].

The production of unknown neutron-deficient isotopes of U, Np, Pu, Am, Cm, and Cf in various complete fusion reactions was analyzed within the dinuclear system model. The cross sections of the formation of these isotopes in xn and αxn evaporation channels were predicted. A special adjustment to the selected evaporation channel was not carried out. The deexcitation of the compound nucleus was treated within the statistical model using the level densities from the Fermi-gas model. The results agree well with the available experimental data. It was suggested to employ the asymmetric reactions with Na, Mg, Al, Si, and S and the reactions with Ca to extend the region of neutron-deficient isotopes of U, Np, Pu, Am, Cm, and Cf with cross sections above the 1 nb level. The alpha decay half-life times in the neutron-deficient actinides were discussed as well [36].

The low-energy resonances in the Λ-nuclear systems were studied. Possible bound and resonant states of the hypernuclear systems Λnn and $\Lambda\Lambda n$ were sought as zeros of the corresponding three-body Jost functions calculated within the framework of the minimal approximation of the hyperspherical approach with local two-body S-wave potentials describing the nn, Λn, and $\Lambda\Lambda$ interactions. By locating the S-matrix pole on the second (unphysical) sheet of the complex energy surface, it was shown that the system Λnn has a very wide near-threshold resonant state. The position of this resonance turned out to be sensitive to the choice of the Λn potential. Bound Λnn state only appears if the two-body potentials are multiplied by a factor of ~ 1.5. The system $\Lambda\Lambda n$ can only have a near-threshold resonance with the $\Lambda\Lambda$ potential which overbinds the hypernucleus $\Lambda\Lambda^6$He [37].

The six-dimensional Schrödinger and Faddeev equations for a three-body system with two-body central potentials of a more general type than the Coulomb one were studied. The regular general and particular physical solutions of these equations were represented as infinite series in integer powers of the distance between one particle and the center of mass of two other particles and the sought functions of other three-particle coordinates. In the angular basis, formed by the spherical and bispherical harmonics or the symmetrized Wigner D functions, the construction of these functions was reduced to solving simple algebraic recurrence equations. For the projections of the physical solutions to the Schrödinger and Faddeev equations onto angular basic functions the boundary conditions in the limit of the linear three-body configuration were derived [38].

A grid method was developed for the study of multichannel scattering of atoms in a waveguide with harmonic confinement. This method was employed to analyze the transverse excitations and deexcitations as well as resonant scattering processes. Collisions of identical bosonic, fermionic, and distinguishable atoms in harmonic traps with a single frequency allowing the center-of-mass separation were explored. In the zero-energy limit and single mode regime the known confinement-induced resonances for bosonic, fermionic and heteronuclear collisions were reproduced quite well. Furthermore, a series of Feshbach resonances in the transmission behavior were identified and analyzed. The dual confinement-induced resonances leading to a complete quantum suppression of atomic scattering were revealed in multichannel scattering processes. Possible applications include, e.g., cold and ultracold atom–atom collisions in atomic waveguides and electron-impurity scattering in quantum wires [39].

It was shown that, within the Quasiparticle Random Phase Approximation (QRPA) and the renormalized QRPA (RQRPA) based on the Bonn CD nucleon–nucleon interaction, the competition between the pairing and the neutron–proton particle–particle and particle-hole interactions causes contributions to the neutrinoless double-beta decay matrix element to nearly vanish at internucleon distances of more than 2 or 3 fm. As a result, the matrix element is more sensitive to short-range/high-momentum physics than one naively expects [40].

The proposed earlier by the authors relativistic mean-field model where hadron masses and coupling constants depend on the σ-meson field (SHMC) was further elaborated. The boson excitation terms were incorporated in the equations of motion and then calculated thermodynamic quantities (including boson excitation parts). Corrections to the effective masses of the σ, and ω–ρ-nucleon excitations turned out to be minor for $T \leqslant 100-120$ MeV and grew with the temperature increase. Corrections to thermodynamic characteristics remained moderate even at higher temperatures. With boson excitation terms incorporated into the equations of motion, the quasiparticle SHMC model fulfilled exactly the thermodynamic consistency conditions. The effects of the particle width were estimated assuming energy-dependent widths of resonances. The width effects do not change qualitative behavior of the system [41].

The multirank separable kernels of the neutron–proton interaction for uncoupled S and P partial waves (with $J = 0, 1$) and coupled $^3S_1^+ - ^3D_1^+$ state were proposed. Two different methods of a relativistic generalization of initially nonrelativistic Yamaguchi-type form factors parametrizing the kernel were considered. It was shown that they lead to minor differences in description of the phase shifts and low-energy parameters. Using the constructed kernels the experimental phase shifts for laboratory energy up to 3 GeV as well as low-energy parameters were correctly described [42].

The exclusive process $^3\mathrm{He}(e, ep)^2\mathrm{H}$ was analyzed using realistic few-body wave functions corresponding to the AV18 interaction and treating the final state interaction within the eikonal approximation to describe the multiple rescattering of the struck nucleon with the nucleons of the spectator two-nucleon system. Calculations were performed in momentum space so that the nucleon electromagnetic current could be left in the fully covariant form avoiding by this way nonrelativistic reductions and the factorization approximation. The results of calculations, which were compared with recent JLab experimental data, show that the left–right asymmetry exhibits a clear dependence upon the multiple scattering in the final state and demonstrates the breaking down of the factorization approximation for «negative» and large ($\geqslant 300$ MeV/c) values of the missing momentum [43].

THEORY OF CONDENSED MATTER

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

- Physical Properties of Complex Materials and Nanostructures;
- Mathematical Problems of Many-Particle Systems.

The research in the field of complex materials was conducted in two main directions: thermodynamic properties of strongly correlated systems, the Hubbard model, two-dimensional t–J model, Anderson impurity model, and the theoretical description of new materials — high-temperature superconductors and cold atoms trapped in optical lattices. Note that the study of the latter, which was started in 2008, is very promising in view of their possible implementation in quantum computers.

A new approach to treat strongly correlated electron systems was developed. In contrast to earlier investigations, the present one enables to treat the local electron correlations in a controlled way. Within that approach, the t–J model was mapped onto a Kondo–Heisenberg lattice model. Such a mapping highlights important physical similarities between the quasi two-dimensional heavy fermions and the high-T_c superconductors. In particular, the recent important results on the small versus large Fermi surface crossover in the high-T_c superconductors [44] can be quantitatively accounted for [45].

The electronic structure of graphene in the presence of either sevenfolds or eightfolds was studied by using a gauge field-theory model. The graphene sheet with topological defects was considered as a negative cone surface with an infinite Gaussian curvature at the center. The density of electronic states was calculated for a single seven- and eightfold as well as for a pair of sevenfolds with different morphology. The density of states at the Fermi energy was found to be zero in all cases except two sevenfolds with translational factor $M \neq 0$ [46].

Numerical modelling of coherent spin relaxation in nanomagnets formed by magnetic molecules of high spins was accomplished. Such a coherent spin dynamics can be realized in the presence of a resonant electric circuit coupled to the magnet. Coherent spin relaxation is an ultrafast process with the relaxation time that can be an order shorter than the transverse spin dephasing time. The influence of different system parameters on the relaxation process was analyzed. The effect of the sample geometry on the spin relaxation was investigated [47].

Cold atoms loaded into an optical lattice with double-well sites were considered. Pseudospin representation for an effective Hamiltonian was derived. The system in equilibrium displays two phases, ordered and disordered. The second-order phase transition between the phases can be driven either by temperature or by changing the system parameters. Collective pseudospin excitations have a gap disappearing at the phase-transition point. Dynamics of atoms was studied when they are loaded into the lattice in an initially nonequilibrium state. It was shown that the temporal evolution of atoms, contrary to their equilibrium thermodynamics, could not be described in the mean-field approximation since it resulted in a structurally unstable dynamical system. A more accurate description taking account of attenuation effects is necessary [48].

A self-consistent renormalization theory of spin fluctuaions in the paramagnetic spinel LiV_2O_4 was developed. In the family of transition metal oxides this compound was the only metallic system showing a pronounced heavy fermion behavior. In particular, in the limit of low temperatures T an anomalously large value of the specific heat coefficient $g = 1/T$ and strongly enhanced magnetic susceptibility χ_s were detected. Recently, a model has been proposed (V. Yushankhai et al., Phys. Rev. B. 2007. V. 76. P. 085111) which allows one to relate such an anomalous behavior to a strong degeneracy of the ground state and a proximity of the system to a magnetic instability as $T \to 0$. The emergence of a rather peculiar paramagnetic ground state with low-energy «critical» antiferromagnetic fluctuations is a result of strong electron correlations and the geometrical frustration of the V ion lattice. A self-consistent renormalization theory was developed to describe effects of strong coupling between spin fluctuation modes and their evolution with varying temperature and external pressure. The theory was shown to provide a firm basis for quantitative description of experimental data obtained in the inelastic neutron scattering and NMR measurements on LiV_2O_4 [49].

A fine structure of the breakpoint region in the current-voltage characteristics of the coupled intrinsic Josephson junctions in the layered superconductors was found. We established a correspondence between the features in the current-voltage characteristics and the character of the charge oscillations in superconducting layers in the stack and explained the origin of the breakpoint region structure [50].

A microscopic theory for electronic spectrum of the CuO_2 plane within an effective p–d Hubbard model is proposed. Dyson equation for the single-electron Green function in terms of the Hubbard operators is derived which is solved self-consistently for the self-energy evaluated in the noncrossing approximation. Electron scattering on spin fluctuations induced by kinematic interaction is described by a dynamical spin susceptibility with a continuous spectrum. Doping and temperature dependence of electron dispersions, spectral functions, the Fermi surface and the coupling constant l are studied in the hole doped case. At low doping, an arc-type Fermi surface and a pseudogap in the spectral function close to the Brillouin zone boundary are observed [51].

Several mathematical problems of many-particle systems were solved. A family of continuous biorthogonal functions related to an elliptic analogue of the Gauss hypergeometric function depending on eight parameters and two base variables was constructed. The elliptic beta integral and the integral analogue of the Bailey chains were used. Relations of this contruction to the elliptic Sklyanin algebra were discovered. Two elliptic analogues of the Faddeev modular double were constructed [52].

Through a series of exact mappings the Bernoulli model of sequence alignment was interpreted in terms of the discrete-time totally asymmetric exclusion process with backward sequential update and step function initial condition. Using earlier results from the Bethe ansatz the exact distribution of the length of the longest common subsequence of two sequences of finite lengths X, Y was obtained analytically. Asymptotic analysis adapted from random matrix theory allowed us to derive the thermodynamic limit directly from the finite-size result [53].

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

In 2008, the research-educational project DIAS-TH was successfully continued. The following activities in the framework of DIAS-TH took place: VI Winter School on Theoretical Physics (January 26–February 5); XII Research Workshop «Nucleation Theory and Applications» (April 1–30); Helmholtz International Summer School «Dense Matter in Heavy Ion Collisions and Astrophysics» (July 14–26); II Helmholtz International Summer School «Heavy Quark Physics» (August 11–21); Advanced Summer School on Modern Mathematical Physics (September 7–17); the regular seminars for students and postgraduates were organized; computer processing of video records of lectures was continued; Web-site of DIAS-TH was supported.

COMPUTER FACILITIES

To renew the BLTP's stock of personal computers 10 new PCs based on Intel Core 2 E8400 processors were purchased. The operational memory on main BLTP server theor.jinr.ru and database server thproxy.jinr.ru were extended from 4 GB to 8 GB. The disk space for user home directories was increased up to 300 GB. The new gigabit switch with 48 port capacity was added to the Laboratory's core stack.

MEETINGS, SCIENTIFIC COLLABORATION

In 2008, besides the Schools organized in the framework of DIAS-TH, the Laboratory participated in the organization of 10 International Conferences and Workshops held in Dubna, Pohang, Prague, Protvino and Yerevan:

- International Workshop «Classical and Quantum Integrable Systems», jointly with IHEP, Protvino (January 21–24, Protvino, Russia);
- International Conference «Symmetries in Physics», devoted to the 90th birthday of Ya. A. Smorodinsky (March 27–29, Dubna, Russia);
- XVII International Colloquium «Integrable Systems and Quantum Symmetries» (June 19–21, Prague, Czech Republic);
- XIII International Conference «Selected Problems of Modern Theoretical Physics», dedicated to the 100th anniversary of the birth of D. I. Blokhintsev (1908–1979)) (June 23–27, Dubna, Russia);
- International Workshop on cooperation between the Asia Pacific Centre for Theoretical Physics and Bogoliubov Laboratory of Theoretical Physics (June 25–29, South Korea);
- International Conference «Dubna-Nano2008» (July 7–11, Dubna, Russia);
- XXVII International Colloquium on «Group Theoretical Methods in Physics», jointly with Yerevan State University (August 13–19, Yerevan, Armenia);
- International Conference «Renormalization Group and Related Topics» (September 1–6, Dubna, Russia);
- XIX International Baldin Seminar «Relativistic Nuclear Physics and Quantum Chromodynamics» (September 29–October 4, Dubna, Russia);
- Round Table Discussion III «Physics at NICA» (November 5–6).

In 2008, 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 Romanian 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.

REFERENCES

1. *Kniehl B. A., Kotikov A. V., Veretin O. L.* // Phys. Rev. Lett. 2008. V. 101. P. 193401.
2. *Bork L. V. et al.* // JHEP. 2008. V. 0804. P. 003.
3. *Gladyshev A. V., Kazakov D. I., Paucar M. G.* // Proc. of the 15th Intern. Conf. on Supersymmetry and the Unification of Fundamental Interactions (SUSY07), 2008. P. 338; hep-ph/0811.2911. 2008.

4. *Bednyakov V. A. et al.* // Part. Nucl. Lett. 2008. V. 5, No. 6(148). P. 874–889; Phys. At. Nucl. 2009. V. 72. P. 1.
5. *Avakian H. et al.* // Phys. Rev. D. 2008. V. 77. P. 014023;
Avakian H. et al. // Ibid. V. 78. P. 114024;
Efremov A. V. et al. Presented at the 18th Intern. Spin Phys. Symp., Charlottesville, Virginia, USA, Oct. 6–11, 2008. hep-ph/0812.3246. 2008.
6. *Zinovjev G. M. et al.* // Yad. Fiz. 2008. V. 71. P. 334.
7. *Pasechnik R. S., Shirkov D. V., Teryaev O. V.* // Phys. Rev. D. 2008. V. 78. P. 071902.
8. *Kuzmin K. S., Lyubushkin V. V., Naumov V. A.* // Eur. Phys. J. C. 2008. V. 54. P. 517.
9. *Arbuzov A. B., Sadykov R. R.* // ZhETF. 2008. V. 106. P. 488;
Arbuzov A. B. et al. // Eur. Phys. J. C. 2008. V. 54. P. 451;
Arbuzov A. B., Scherbakova E. S. // Phys. Lett. B. 2008. V. 660. P. 37.
10. *Cherednikov I. O., Stefanis N. G.* // Nucl. Phys. B. 2008. V. 802. P. 146; Phys. Rev. D. 2008. V. 77. P. 094001.
11. *Anikin I. V., Teryaev O. V.* // Fizika B. 2008. V. 17. P. 151.
12. *Lee H. J., Kochelev N. I.* // Phys. Rev. D. 2008. V. 78. P. 076005;
Min D. P., Kochelev N. I. // Phys. Rev. C. 2008. V. 77. P. 014901.
13. *Dorokhov A. E., Ivanov M. A.* // JETP Lett. 2008. V. 87. P. 531.
14. *Faessler A. et al.* // Phys. Rev. D. 2008. V. 78. P. 094005.
15. *Haefeli C., Ivanov M. A., Schmid M.* // Eur. Phys. J. C. 2008. V. 53. P. 549.
16. *Korobov V. I.* // Phys. Rev. A. 2008. V. 77. P. 042506.
17. *Ivanov E.* // Theor. Math. Phys. 2008. V. 154. P. 349.
18. *Fedoruk S., Ivanov E., Lechtenfeld O.* hep-th/0812.4276. 2008.
19. *Bellucci S., Krivonos S., Sutulin A.* // Nucl. Phys. B. 2008. V. 805. P. 24.
20. *Khoroshkin S. M., Pakuliak S. Z.* // SIGMA. 2008. V. 4. P. 081.
21. *Isaev A. P., Molev A. I., Oskin A. F.* // Lett. Math. Phys. 2008. V. 85. P. 79.
22. *Isaev A. P., Krivonos S. O., Ogievetsky O. V.* // J. Math. Phys. 2008. V. 49. P. 073512; math-ph/0807.1820. 2008;
Isaev A. P., Ogievetsky O. V., Braids M. math.QA/0812.3974. 2008.
23. *Tiurin N. A.* // Proc. of Steklov MI RAS. 2009. V. 264 (in press).
24. *de Alfaro V., Filippov A. T.* // Proc. of «QUARKS-2008», Sergiev Posad, May 23–29, 2008 (submitted); hep-th/0811.4501. 2008.
25. *Kazakov V., Sorin A., Zabrodin A.* // Nucl. Phys. B. 2008. V. 790. P. 345.
26. *Nojiri S., Odintsov S. D., Tretyakov P. V.* // Prog. Theor. Phys. Suppl. 2008. V. 172. P. 81.
27. *Dimitrov B. G.* hep-th/0810.1501. 2008.
28. *Popov A. D.* // Phys. Rev. D. 2008. V. 77. P. 125026;
Popov A. D. Mod. Phys. Lett. A. (in press);
hep-th/0804.3845. 2008.
29. *Lambrecht A., Pirozhenko I.* // Phys. Rev. A. 2008. V. 77. P. 013811.
30. *Severyukhin A. P., Voronov V. V., Nguyen Van Giai* // Phys. Rev. C. 2008. V. 77. P. 024322.
31. *Kleinig W. et al.* // Ibid. V. 78. P. 044313.
32. *Lo Iudice N., Sushkov A. V.* // Ibid. V. 78. P. 054304.
33. *Jolos R. V., von Brentano P.* // Ibid. V. 77. P. 064317.
34. *Pashkevich V. V., Rusanov A. Ya.* // Nucl. Phys. A. 2008. V. 810. P. 77.
35. *Adamian G. G. et al.* // Phys. Rev. C. 2008. V. 78. P. 024613.
36. *Adamian G. G. et al.* // Ibid. P. 044605.
37. *Belyaev V. B., Rakityansky S. A., Sandhas W.* // Nucl. Phys. A. 2008. V. 803. P. 210.
38. *Pupyshev V. V.* // Theor. Math. Phys. 2008. V. 155. P. 862.
39. *Saeidian S., Melezhik V. S., Schmelcher P.* // Phys. Rev. A. 2008. V. 77. P. 042721.
40. *Simkovic F. et al.* // Phys. Rev. C. 2008. V. 77. P. 045503.
41. *Khvorostukhin A., Toneev V., Voskresensky D.* // Nucl. Phys. A. 2008. V. 813. P. 313.
42. *Bondarenko S. G. et al.* // JETP Lett. 2008. V. 82. P. 753; arXiv: 0810.4470v1. 2008.
43. *Ciofi degli Atti C., Kaptari L. P.* // Phys. Rev. Lett. 2008. V. 100. P. 122301.
44. *Doiron-Leyraud et al.* // Nature. 2007. V. 477. P. 565.
45. *Pepino R., Ferraz A., Kochetov E.* // Phys. Rev. B. 2008. V. 77. P. 035130.
46. *Kolesnikov D. V., Osipov V. A.* // Pisma ZhETF. 2008. V. 87. P. 487.
47. *Yukalov V. I., Henner V. K., Kharebov P. V.* // Phys. Rev. B. 2008. V. 77. P. 134427.
48. *Yukalov V. I., Yukalova E. P.* // Phys. Rev. A. 2008. V. 78. P. 063610.
49. *Yushankhai V., Thalmeier P., Takimoto T.* // Phys. Rev. B. 2008. V. 77. P. 125126; J. Phys.: Cond. Matt. 2008. V. 20. P. 465221.
50. *Shukrinov Yu. M., Mahfouzi F., Suzuki M.* // Phys. Rev. B. 2008. V. 78. P. 134521.
51. *Plakida N. M., Oudovenko V. S.* // Cond. Matt. Phys. 2008. V. 11. P. 495.
52. *Spiridonov V. P.* // Algebra and Analysis. 2008. V. 20. P. 154; Usp. Matem. Nauk. 2008. V. 63. P. 3.
53. *Priezzhev V. B., Schutz G. V.* // J. Stat. Mech. P. 09007. 2008.