BOGOLIUBOV LABORATORY OF THEORETICAL PHYSICS

At the Bogoliubov Laboratory of Theoretical Physics (BLTP) studies are carried out on the following four themes: Theory of Elementary Particles; Nuclear Structure and Dynamics; Theory of Condensed Matter and New Materials; Modern Mathematical Physics: Gravity, Supersymmetry, Integrability. Important components of the BLTP activities are theoretical support of experimental research to be carried out within major international projects with participation of JINR as well as Dubna based experimental programmes of JINR Laboratories, and recruiting of young researchers, students, and post-graduate students to the Laboratory.

SCIENTIFIC RESEARCH

Theory of Elementary 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.

A supersymmetric version of a unitarity cut method for form factors of operators from the $N = 4$ stress-tensor current supermultiplet was developed. The relation between the super form factor with supermomentum equal to zero and the logarithmic derivative of the superamplitude with respect to the coupling constant was verified at the tree- and one-loop level for any MHV n-point super form factor. The explicit $N = 4$ covariant expressions for n-point MHV tree- and one-loop form factors were obtained. An ansatz for the two-loop three-point MHV super form factor in the planar limit was suggested. The different soft and collinear limits in the MHV sector at the tree- and one-loop level were considered [1].

The pure leptonic decay $B_s \to \mu\mu$ was studied in the Standard Model (SM). It was shown that it can have large enhancements in Supersymmetry, especially at large values of $\tan\beta$, being proportional to $\tan\beta^6$. It was demonstrated, however, that being combined with the dark matter relic density constraint, the experimental upper limit on $\mathrm{BR}(B_s \to \mu\mu)$ did not constrain the parameter space of the CMSSM more than the direct searches and the present Higgs limits. It was also observed that there are SUSY parameter regions with negative interferences, where the $\mathrm{BR}(B_s \to \mu\mu)$ value was up to a factor three below the SM expectation, even at large values of $\tan\beta$ [2].

The theoretical description of inclusive τ-lepton hadronic decay was performed in the framework of the Dispersive approach to QCD. The significance of effects due to hadronization was demonstrated. The approach at hand is capable of describing experimental data on τ-lepton decay in vector and axial vector channels. The vicinity of values of QCD scale parameter obtained in both channels testifies to the self-consistency of the developed approach [3].

A simple formula for the total cross section $\sigma^{\nu N}$ of neutral and charged current deep inelastic scattering of ultrahigh-energy neutrinos on isoscalar nuclear targets was presented. It is shown that the total cross section is proportional to the structure function $F_2^{\nu N}(M_V^2/s, M_V^2)$, where M_V is the intermediate boson mass and s is the square of the center-of-mass energy. The coefficient of $F_2^{\nu N}$ depends on the asymptotic low-x behavior. It contains an additional $\ln(s)$ term if it scales with a power of $\ln(1/x)$. The accuracy of the approximate formula is demonstrated for different asymptotics of $F_2^{\nu N}$ [4].

The complete double logarithmic contribution to cross sections for semi-inclusive hadron production in the modified minimal-subtraction scheme was calculated by applying the dimensional regularization to the double logarithm approximation. The full double logarithmic contribution to the coefficient functions for inclusive hadron production in electron–positron annihilation was obtained in this scheme for the first time. Our result agrees with all fixed order results in the literature which extend to a next-to-next-to-leading order [5].

The field theoretical approach to neutrino oscillations developed earlier was applied to describe the well-known surprising results of the OPERA experiment indicating the propagation of superluminal signals. It was claimed that the data can be explained due to the effects of the neutrino wave packet finite size without any radical modifications of the theory [6, 7].

The interplay of multiloop QCD calculations with modifications of perturbation theory and high twist effects was investigated by comparing with very accurate data on the Bjorken sum rule for spin dependent structure functions. The indications of the manifestation of the asymptotic nature of perturbative series and duality with high twist effects at the four-loop level were found. In particular, the contributions of the third and fourth loop are comparable to each other and to experimental accuracy, while the higher twist contribution is compatible with zero [8].

The estimates for electroproduction of pseudoscalar mesons were presented. The cross sections and asymmetries were calculated within the handbag approach which was based on factorization in hard parton subprocesses and soft generalized parton distributions (GPDs). Transversity GPDs were taken into account; they were accompanied by twist-3 meson wave functions. The results are in good agrement with high-energy experiments [9, 10].

Geometrical structure and renormalization properties of the vacuum averages of the Wilson path-ordered exponentials which describe the factorized contributions of soft gluons in unintegrated parton distribution functions (TMD PDFs) were studied. The one-loop renormalization-group equations, as well as the rapidity evolution equations were obtained for the quark TMD PDFs. It is shown that the use of the light-cone integration paths in the operator definitions of the TMD PDFs is compatible with the DGLAP equations in the collinear limit and allows taking into account the time-reversal-odd effects (e.g., single-spin asymmetries) in physical gauges. The developed approach was applied to the analysis of two-particle angular correlations in pseudo-rapidity and azimuthal angle observed by the CMS collaboration at the LHC [11].

The total and differential cross sections of e^+e^- annihilation into $\pi^0\omega$, $\pi^0\gamma$, and $\pi(1300)\gamma$ were calculated in the framework of the extended NJL model. Intermediate ρ, ω, and φ vector mesons and their first radial excited states were taken into account [12, 13]. The photoproduction cross sections of η and η' mesons and their first radial excited states arising in e^+e^- collisions were calculated. The obtained theoretical predictions are relevant for experiments at VEPP-2000 (Novosibirsk) and BEPC-II (Beijing) e^+e^- colliders [14].

A new realistic estimate for the hadronic contribution to the muon anomalous magnetic moment was obtained on the basis of the pseudoscalar meson exchange [15].

Investigation of filling up the Fermi sphere by quark quasiparticles reveals new branch of solution for dynamical quark mass as a function of the chemical potential. As a consequence, the absence of jump in quark ensemble density was demonstrated, being in due time one of the important grounds for experimental programme for discovering the phase transition of chiral symmetry restoration. The quark ensemble characteristic was established and the picture character for the phase transition of gas–liquid, analogous to the phase transition in nuclear matter, was revealed. It was shown that one of the plausible scenarios of partial chiral symmetry restoration is an existence of the mixed phase of vacuum and normal baryonic matter. Description of the transition layer between two media (gas and liquid) was developed and the surface tension coefficient was found. Some properties of the quark droplets, in general very similar to the nuclei, were studied [16].

The consequences of treating the $X(3872)$ meson as a tetraquark bound state were explored by analyzing its one-photon decay $X \to \gamma + J/\psi$ in the framework of the approach developed in previous papers which incorporates quark confinement in an effective way. A nonlocal effective Lagrangian describing the interaction of the $X(3872)$ meson with its four constituent quarks was gauged by using the P-exponential path-independent formalism. The matrix element of the transition $X \to \gamma + J/\psi$ has been calculated and its gauge invariance has been proven. Also the decay width and the longitudinal/transverse composition of the J/ψ in this decay have been evaluated. For a reasonable value of the size parameter of the $X(3872)$ meson the consistency with the available experimental data was found [17].

The effective strong couplings $g_{D^*D\pi}$ and $g_{B^*B\pi}$ have been computed by using a framework in which all elements are constrained by Dyson-Schwinger equation studies of QCD. Therefore the approach incorporates a consistent, direct and simultaneous description of light and heavy quarks and the states they may constitute. These couplings were linked with the heavy-light-meson leptonic decay constants, and thereby it was obtained that $g_{D^*D\pi} = 15.9 + 2.1 - 1.$ and $g_{B^*B\pi} = 30.0 + 3.2 - 1.4$. A comparison between $g_{D^*D\pi}$ and $g_{B^*B\pi}$ indicates that if the c quark is a system's heaviest constituent, then $\Lambda_{\rm QCD}/m_c$-corrections are not under good control [18].

Effective Lagrangian for Yang-Mills fields invariant under the standard space–time and local gauge $SU(3)$

transformations was considered. It has been demonstrated that a set of twelve degenerated minima exists as soon as a nonzero gluon condensate is postulated. The minima are connected to each other by the parity transformations and Weyl group transformations associated with the color $su(3)$ algebra. The presence of degenerated discrete minima in the effective potential leads to the solutions of the effective Euclidean equations of motion in the form of the kink-like gauge field configurations interpolating between different minima.The one-loop quark contribution to the QCD effective potential for the homogeneous Abelian gluon field in the presence of an external strong electromagnetic field was evaluated. The structure of extrema of the potential as a function of the angles between chromoelectric, chromomagnetic, and electromagnetic fields was analyzed. In this setup, the electromagnetic field is considered as an external one while the gluon field represents domain structured nonperturbative gluon configurations related to the QCD vacuum in the confinement phase. Within this simplified framework it was shown that the strong electromagnetic fields can play a catalyzing role for a deconfinement transition. At the qualitative level, the present consideration can be seen as a highly simplified study of an impact of the electromagnetic fields generated in relativistic heavy-ion collisions on the strongly interacting hadronic matter [19].

Modern Mathematical Physics

The topics of main focus in the theme were:
- Supersymmetry and Superstrings;
- Quantum Groups and Integrable Systems;
- Quantum Gravity and Cosmology

The simplest class of affine theories of gravity in multidimensional space-times with symmetric connections was studied by making use of the spherical and cylindrical reductions of these theories to two-dimensional dilaton–vecton gravity field theories. The distinctive feature of these models is the presence of a massive/tachyonic vector field (vecton) with essentially nonlinear coupling to the dilaton gravity. It was shown that the vecton field can be consistently replaced by a new effectively massive scalar field (scalaron) with an unusual coupling to dilaton gravity. Special attention was payed to the study of the static solutions with horizons by making use of a local generalization of the Szekeres-Kruskal coordinates. When analyzing the simplest models having three or two integrals of motion, the notion of a «topological portrait» was suggested which gave a unified qualitative description of static and cosmological solutions of the models under consideration [20].

New cosmological models with vector fields were considered. These fields, having the geometrical origin, arise from both the cylindrical dimensional reduction and the Einstein–Eddington «affine» modification of gravity. Finally, they were described by effective dilaton–scalar gravity with the quartic potential. This shows that in the affine theory of gravity, the dimensional reduction procedure is more complicated than in the Einstein general relativity. In the non-Abelian sector, the isotropic and homogeneous pure Yang-Mills $SU(2)$ theory with the specific nonlinear dependence of the Lagrangian on the invariant is proposed. Such Lagrangians can arise due to the vacuum polarization in the strong field limit. Under some conditions, the system can simulate the slow-roll inflation [21].

New spherically symmetric, asymptotically flat black-hole solutions of $N = 2$ supergravities were constructed by making use of the integration algorithm of the relevant Lax equations developed in previous papers. The main goal of these studies is the classification of the black-hole solutions according to the H^*-orbits in which the space of possible Lax operators decomposes, H^* being the isotropy group of scalar manifold originating from time-like dimensional reduction of supergravity from $D = 4$ to $D = 3$ dimensions. The important result of this investigation was the new tensor classification of regular and nilpotent orbits in all homogeneous symmetric Special Geometries [22].

In the framework of the quantum field theory on the nonflat background, the physical consequences of the conic singularities of configuration manifolds were studied. It was shown, in particular, that the isolation of a «naked» conic singularity by introducing additional boundary conditions on a surface surrounding it, resulted in «improving» the physical consequences generated by this singularity. For example, the total vacuum energy of physical fields considered on the manifolds with conic singularity proved to be finite in this approach [23].

Comparative analysis of different techniques for exoplanet searches was conducted and it was shown that gravitational microlensing was among the most efficient techniques to find light exoplanets near the so-called snow line where a planetary surface temperature is in the range 0–1000 K [24].

Fundamental concepts, symmetries, and dynamical equations of the unified geometrical theory of microworld and macroworld (General Quantum Mechanics) were formulated. For solution of fundamental problems, General Quantum Mechanics proposes a more drastic revision of our fundamental concepts than any that has been done before and provides a new understanding of the strong interaction [25].

We overcame the barrier of constructing $N = 4$ superconformal models in one space dimension for more than three particles. The $D(2, 1; \alpha)$ superalgebra of our systems was realized on the coordinates and momenta of the particles, their superpartners and one complex pair of harmonic variables. The models were determined by two prepotentials, F and U, which must obey the WDVV and a Killing-type equation plus homogeneity conditions. We investigated permutation-symmetric solutions, with and without translation invariance. Models based on deformed A_n and BCD_n root systems were constructed for any value of α. Translation-invariant mechanics occurs for any number of particles at $\alpha = -1/2$ (osp(4-2) invariance as a degenerate limit) [26].

A new $N = 2$ supersymmetric extension of a massive particle moving near the horizon of the extreme Kerr black hole was constructed. Supercharges and Hamiltonian contain the proper number of fermions (two for each bosonic variable) [27].

It was shown that the $AdS_3 \times S^3$ and $AdS_5 \times S^5$ superstring theories in the Pohlmeyer-reduced form reveal hidden $N = (4, 4)$ and $N = (8, 8)$ worldsheet supersymmetries. The characteristic feature of these transformations is the presence of nonlocal terms [28].

The nonlinear realization method was applied for constructing Galilean conformal mechanics models. New conformally invariant actions were derived in arbitrary space–time dimension $D = d + 1$ without central charges, as well as in the special dimension $D = 2 + 1$ with one «exotic» central charge [29].

Complete systems of pairwise orthogonal minimal idempotents for Birman-Murakami-Wenzl and Brauer algebras were obtained. An evaluation homomorphism for the classical Lie algebras g_N of B, C, and D types was constructed as a map from a reflection equation algebra $B(g_N)$ to a universal enveloping algebra $U(g_N)$ [30].

Nuclear Structure and Dynamics

In 2011, investigations within the area «Nuclear Structure and Dynamics» were carried out in accordance with the four projects:

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

A schematic microscopic method was developed to analyze the $M1$ transition probabilities between the mixed-symmetry and the fully symmetric states in γ-soft nuclei. The method was based on the RPA-IBM boson mapping of the most collective isoscalar boson. All other boson modes with higher excitation energies, including the mixed-symmetry boson, were described in the framework of the RPA. The $M1$-transition probabilities were calculated for the $^{124-134}$Xe isotopes and compared with the experimental data. The results agree well with the data for the ratio $(M1; 1^+_{\rm ms} \to 2^+_2)/(M1; 1^+_{\rm ms} \to 0^+_1)$. However, some discrepancies with experimental data still remain [31].

The Wigner Function Moments method was generalized to take into account nuclear spin degrees of freedom. Equations of motion for spin-dependent collective variables were derived on the basis of time-dependent Hartree-Fock equations with the harmonic oscillator mean-field, including spin–orbit potential plus quadrupole–quadrupole residual interaction. The equations were solved in the small amplitude regime. Two isovector and two isoscalar low-lying eigenfrequencies as well as five isovector and five isoscalar high-lying eigenfrequencies were found. Three low lying states were interpreted as new types of nuclear modes where, e.g., the nucleons with spin «up» oscillated against nucleons with spin «down» [32].

The thermal effect on inelastic neutrino–nucleus scattering (INNS) off even–even nuclei in the stellar environment was studied. Allowed and first-forbidden contributions to the cross sections were calculated within the QRPA, extended to finite temperatures within the Thermo-Field-Dynamics formalism. The GT_0 strength distribution at finite temperatures was calculated for ^{54}Fe. The thermal population of the excited states significantly enhances the cross section at low neutrino energies. The enhancement of the INNS cross section was shown to be mainly due to neutrino up-scattering at $T \neq 0$, although at neutrino energies $E_\nu \geqslant 15$ MeV the cross section was dominated by the down-scattering processes [33].

The low-lying one-quasiparticle states were studied in the isotonic chains with odd neutron numbers $N = 147-155$ within the microscopic–macroscopic two-center shell model, the quasiparticle–phonon model, and the self-consistent Skyrme–Hartree–Fock–Bogoliubov approach. Qualitative predictions of all the approaches are quite close. The energies of almost all low-lying one-quasiparticle states change rather smoothly along the isotonic chains if the ground-state deformations of the isotones are close. The change of the deformation due to the proton shell effect causes the rearrangement of the one-quasiparticle states. To describe simultaneously experimental spectra in the $N = 149$ and 151 isotones, one should strongly vary the theoretical parameters [34].

The process of the resonant neutrinoless double electron capture $(0\nu ee)$ was revisited for those cases where the two participating atoms were nearly degenerate in mass. New $0\nu ee$ transitions with parity violation to the ground and excited states of the final atom/nucleus were found. The selection rules for the $0\nu ee$ transitions were established. The explicit form of the corresponding nuclear matrix elements was derived. Available data of atomic masses and nuclear and atomic excitations were used to select the most likely candidates for resonant $0\nu ee$ transitions. Assuming an effective Majorana neutrino mass of 1 eV, some half-lives were predicted to be as low as 10^{22} years in the unitary limit. According to the obtained estimates, in the case of ^{152}Gd, the sensitivity can be comparable to the favored $0\nu\beta\beta$ decays of nuclei [35].

The population of rotational bands in superheavy nuclei produced in fusion–evaporation reactions $^{206,208}\mathrm{Pb}\,(^{48}\mathrm{Ca}, 2n)\,^{252,254}\mathrm{No}$ and $^{204}\mathrm{Hg}\,(^{48}\mathrm{Ca}, 2n)\,^{250}\mathrm{Fm}$ was studied within statistical and quantum diffusion approaches. The dependence of fission barriers of shell-stabilized nuclei on angular momentum was investigated in detail. The angular momentum dependence of calculated observables, such as the relative intensities of $E2$ transitions between the rotational states, the entry spin distributions of residual nuclei, etc., mainly comes from the partial capture and survival probabilities. The results of calculations are in good agreement with the experimental data. Thus, at low and moderate angular momentum values, the centrifugal forces are not dangerous for the production of superheavy elements [36].

In numerical solutions, the Schrödinger equation is often converted to a coupled system of radial equations. Some general features of this system lead to the appearance of difficulties in the numerical solutions of coupled equations in radial regions where the motion for some channels is classically forbidden. The modified variable phase method was suggested in which the coupled equations were rearranged to a form containing free solutions only as logarithmic derivatives, i.e., a combination that minimizes variations of absolute values. As a result, the new system is less prone to develop numerical instabilities. The method is powerful for both bound and continuum states. It was applied to compute a low-lying monopole continuum state of the halo nucleus ^{6}He in a three-body cluster model using a hyperspherical harmonic expansion [37].

The description of nuclei as a system of α particles was considered using a two-variable integrodifferential equation describing A-boson systems. It was assumed that two-body forces are the dominant ones within the system. This allows one to expand the A-body wave function in Faddeev components which in turn can be expanded in potential harmonics that result either in a coupled system of differential equations in the hyperradius r or, when projected on the r_{ij} space, in a single two-variable, integrodifferential equation. The formalism can be readily applied to systems of up to $A \sim 20$. The numerical problems appearing at larger A were eliminated by transforming the equation, when $A \to \infty$, into a new one having a kernel of a simple analytical form [38].

A novel mechanism for resonant higher partial-wave interatomic interactions in bosonic quantum gases was suggested. The mechanism is based on the effect of resonant d-wave interactions for ultracold collisions in tightly confining waveguides. The d-wave resonance (DWR) observed is a shape resonance formed in the presence of both the centrifugal barrier and the confining trap. A scaling relation for the DWR position was provided. By changing the trap frequency, ultracold scattering can be continuously tuned from s-wave to d-wave resonant behavior. The effect can be utilized for the realization of ultracold atomic gases interacting via higher partial waves [39].

The space-time evolution of (electro-)magnetic fields formed in relativistic heavy-ion collisions was studied. The hadron string dynamics transport code corresponding to Kadanoff–Baym kinetic equations and treating the nuclear collisions in terms of quasiparticles with a finite width was used. The space–time structure of the fields was analyzed in detail for noncentral Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The most intensive magnetic field oriented perpendicularly to the reaction plane was formed during the time when the Lorentz-contracted nuclei were passing through each other, $t \leqslant 0.2$ fm/c. The electric field distribution, being also highly inhomogeneous, has a minimum in the center of the overlap region. It is small and can be neglected for $t \geqslant 0.20$ fm/c. The calculations did not reveal a noticeable influence of the electromagnetic fields on the effect of the electric charge separation with respect to the reaction plane [40].

Within a covariant Bethe–Salpeter approach, a relativistic complex separable kernel for the description of the neutron–proton interaction was proposed. The uncoupled partial-wave states with the total angular momentum $J = 0$, 1 were considered. The inelasticities were described in the energy range up to 3 GeV on a purely phenomenological ground transforming real parameters of the multirank separable potential elaborated earlier into complex ones. The deviation of the theoretical curve for the inelasticity parameters from the experimental values in the $^3\mathrm{P}_0^+$ partial-wave state indicate the existence of wide dibaryon resonances [41].

The emission of pairs of electrons in a polarized ultraintense electromagnetic (e.g., laser) wave field was analyzed. A method allowing for a complete summation of all partial harmonics and taking into account nonlinear electrodynamics effects as well as the peculiarities of neutrino production was elaborated. The nontrivial asymmetry between the probabilities of electron- and $\mu + \tau$ neutrino production was revealed which depends on the energy of the wave field photons and the field intensity [42].

Theory of Condensed Matter

Theoretical investigations within the theme «Theory of Condensed Matter and New Materials» were continued in the framework of the following projects:

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

The spin-excitation spectrum in the Heisenberg model in the ferromagnetic and paramagnetic states was calculated within the microscopic theory based on the projection technique for the two-time Green functions. It was proved that the latter approach was equivalent to the diagram technique for the spin operators in the leading orders of the interaction [43].

A microscopic theory of the dynamic spin susceptibility (DSS) in the superconducting state within the t–J model was presented. It is based on an exact representation for the DSS obtained by applying the

Mori-type projection technique for the relaxation function in terms of Hubbard operators. The static spin susceptibility was evaluated by a sum-rule-conserving generalized mean-field approximation, while the self-energy was calculated in the mode-coupling approximation. The spectrum of spin excitations was studied in a homogeneous phase of the underdoped and optimally doped regions. The DSS reveals a resonance mode (RM) at the antiferromagnetic wave vector $Q = (1, 1)$ at low temperatures due to a strong suppression of the damping of spin excitations. This is explained by an involvement of spin excitations in the decay process in addition to the particle-hole continuum usually considered in random-phase-type approximations. The spin gap in the spin-excitation spectrum at Q plays a dominant role in limiting the decay in comparison with the superconducting gap, which results in the observation of the RM even above T_c in the underdoped region. Good agreement with inelastic neutron-scattering experiments on the RM in $\mathrm{YBa_2Cu_3O}_y$ compounds was found [44].

The theory of the two-time Green function was used to study the magnetic reorientation phase transition shift (MRPT) in two-sublattice ferrimagnetic monolayers with spin in sublattice A and B, respectively. It was obtained that the MRPT in the sublattices A and B occurred at different reorientation temperatures. It can be assumed that the model presented confirms the possibility of the existence of two magnetic phases in ferrimagnetic systems [45].

An efficient approach to the calculation of transport coefficients in solids was developed. The generalized transport equations were derived by the method of the nonequilibrium statistical operator. On this basis a comprehensive theoretical description of the electron transport processes in metallic systems was formulated in a statistical-mechanics way. The tight-binding picture and modified tight-binding approximation (MTBA) were used for describing the electron subsystem and the electron-lattice interaction, respectively. The low- and high-temperature behavior of the resistivity was analyzed in detail. The approach used and the results obtained complement the existing theories of electrical conductivity in metallic systems. The study extends the standard theoretical format and calculation procedures in the theory of electron transport in solids [46].

The small-angle scattering curves of deterministic mass fractals were studied and analyzed in the momentum space. The curve $I(q)q^D$, where D and $I(q)$ are the fractal dimension and the scattering intensity, respectively, was found to be approximately log-periodic with the period equal to the logarithm of the fractal scaling factor. This log-periodicity of the scattering curves is a consequence of the self-similarity of the fractal. The number of periods of the curve $I(q)q^D$ coincides with the number of fractal iterations. By contrast to the standard methods, the present analysis allows one to obtain from the scattering data not only the fractal dimension and the edges of fractal region but also the fractal iteration number, the scaling factor, and the number of structural units from which the fractal is composed [47].

The possibility of realizing spin superradiance by an assembly of magnetic nanoclusters was analyzed. The known obstacles for realizing such a coherent radiation by magnetic nanoclusters are their large magnetic anisotropy, strong dephasing dipole interactions, and an essential nonuniformity of their sizes. In order to give a persuasive conclusion, a microscopic theory was developed, providing an accurate description of nanocluster spin dynamics. It was shown that, despite the obstacles, it was feasible to organize such a setup that magnetic nanoclusters would produce strong superradiant emission [48].

Double-well optical lattices were considered, each cite of which was formed by a double-well potential. The lattice was assumed to be in an insulating state, and order and disorder were defined with respect to the displacement of atoms inside the double-well potential. It was shown that in such lattices, in addition to purely ordered and disordered states, there can exist an intermediate mixed state, where, inside a generally ordered lattice, there appear disordered regions of mesoscopic size [49].

A novel concept of quantum turbulence in finite size superfluids, such as trapped bosonic atoms, was discussed. An atomic ^{87}Rb BEC was used to study the emergence of this phenomenon. In the experiment, the transition to the quantum turbulent regime was characterized by a tangled vortex lines formation, controlled by the amplitude and time duration of the excitation produced by an external oscillating field. A simple model was suggested to account for the experimental observations. The transition from the nonturbulent to the turbulent regime is a rather gradual crossover. But it takes place in a sharp enough way, allowing for the definition of an effective critical line separating the regimes [50].

A two-dimensional directed stochastic sandpile model was studied analytically with the use of directed Abelian algebras recently introduced by Alcaraz and Rittenberg. Exact expressions for the probabilities of all possible toppling events involved in the transfer of an arbitrary number of particles to a site in the stationary state were derived. A description of the virtual-time evolution of directed avalanches on two dimensional lattices was suggested. Due to intractability of the general problem, the algebraic approach was applied to the solution of the special cases of directed deterministic avalanches and trivial stochastic avalanches describing simple random walks of two particles. In the general case of the quadratic directed algebra, the maximum possible values of the current of particles at any given moment of virtual time and the occupation number («height») of each site at any moment of time were obtained exactly [51].

Size effects on nanoscale were considered. By analyzing a series of examples, it was shown that various intensive macroscopic characteristics of nanoobjects exhibited nontrivial size dependences on the scale of 200 to 40 Å. Drastic variations take place for sizes in the region 50 Å for ordinary systems, and 60–200 Å in the case of magnetic systems. It was argued that X-ray and neutron scattering gives an excellent metrological support in the domain from 100 to 10 Å [52].

The $su(2{-}1)$ coherent-state path-integral representation of the partition function of the $t{-}J$ model of strongly correlated electrons was derived at finite doping. The emergent effective action was compared to the one proposed earlier on phenomenological grounds by Shankar to describe holes in an antiferromagnet (Nucl. Phys. B. 1990. V. 330. P 433). The $t{-}J$ model effective action was found to have an important «extra» factor with no analogue in Shankar's action. It represents the local constraint of no double electron occupancy and reflects the rearrangement of the underlying phase-space manifold due to the presence of strong electron correlation. This important ingredient was shown to be essential to describe the physics of strongly correlated electron systems [53].

Manifestation of a resonance-type hysteresis related to the parametric resonance in the system of coupled Josephson junctions was demonstrated. In contrast with the McCumber and Steward hysteresis, it was found that the width of this hysteresis was inversely proportional to the McCumber parameter and it also depends on the coupling between junctions and the boundary conditions. Investigation of the time dependence of the electric charge in superconducting layers allowd us to explain the origin of this hysteresis by different charge dynamics for increasing and decreasing bias current processes. The effect of the wavelength of the longitudinal plasma wave created at the resonance on the charging of superconducting layers was demonstrated. A strong effect of the dissipation in the system on the amplitude of the charge oscillations at the resonance was found [54].

Intrinsic Josephson junctions in high-temperature superconductors have a good perspective for different electronic devices (in particular, for the quantum voltage standard) operated at relatively high temperature and over a wide frequency range. The parametric resonance in the intrinsic Josephson junctions and creation of the longitudinal plasma wave was investigated. The charge oscillations in the superconducting layers at different values of bias current were studied. It was demonstrated that the resonance characteristics might be used for the determination of the parameters of the system [55].

The mathematical modeling of static distributions of the magnetic flow in long Josephson junctions (JJ) was performed taking into account the second harmonic in the decomposition of the Josephson current and the sequential comparison of the results with the conventional model. For the analysis of stability, each concrete distribution of magnetic current in the junction was put into relationship with the Sturm–Liouville spectral problem; the nullification of its minimal eigenvalue indicates the bifurcation distribution by one of the problem parameters. The corresponding nonlinear boundary problem was numerically solved by a continuous analog of the Newtonian method with the spline-collocation scheme for linearized problems at each Newtonian iteration. The main distributions of the magnetic flow were found and their stability against changes of model parameters investigated. The obtained results were compared with the results of the JJ conventional model of the superconductor-insulator-superconductor type [56].

The decrease of the barrier transparency in superconductor-insulator-superconductor (SIS) Josephson junctions leads to the deviations of the current-phase relation from the sinusoidal form. The sign of second harmonics is important for many applications, in particular, in junctions with a more complex structure like SNINS or SFIFS, where N is a normal metal and F is a weak metallic ferromagnet. The static magnetic flux distributions in long Josephson junctions were studied taking into account the higher harmonics in the Fourier-decomposition of the Josephson current. Stability analysis was based on numerical solution of a spectral Sturm–Liouville problem formulated for each distribution. In this approach the nullification of the minimal eigenvalue of this problem indicates a bifurcation point in one of the parameters. At each step of a numerical continuation in parameters of the model, the corresponding nonlinear boundary problem was solved on the basis of the continuous analog of Newton's method. The solutions which do not exist in the traditional model were found. The influence of the second harmonic on stability of magnetic flux distributions for main solutions was investigated [57].

The determinant formula for the generalized Green function of the Totally Asymmetric Exclusion Process was proved. The function describes transitions between particle positions at different moments of time. The current correlation function was calculated and its convergence to the process Airy-2 was proved [58].

Single site height probabilities in the Abelian sandpile model are directly related to the probability $P_{\rm ret}$ that a loop erased random walk passes through the nearest neighbour of the starting site (return probability). The exact values of these quantities on the square lattice were conjectured, in particular $P_{\rm ret} = 5/16$. A rigorous proof of this conjecture was provided by using a local monomer-dimer formulation of these questions [59].

Predictions of the conformal field theory for the Potts model were used for derivation of the asymptotic value of the visiting probability of a remote point of the two-dimensional lattice by the loop erased random walk [60].

For the first time the equality of superconformal indices in three-dimensional theories with $U(1)$-gauge group for the theories related by mirror symmetry was established. Partition functions of supersymmetric field theories on three-dimensional manifold S^3 were deduced as limits from superconformal indices of four-dimensional theories on $S^3 \times S^1$. It was shown that superconformal indices of four-dimensional $N = 4$ super-Yang-Mills theories were reduced in a certain limit to measure for Macdonald polynomials and, therefore, can be computed exactly [61].

A general scheme for construction of q-differential operators over a quantum matrix algebra was given. A particular case of the $GL(n)$ type reflection equation algebra was considered in detail. In this case a subalgebra of adjoint vector fields is specified inside the algebra of one-sided fields. The adjoint fields are tangent to quantum analogs of the coadjoint $GL(n)$ orbits. Explicit formulae for restrictions of the corresponding q-differential operators on the orbits were given [62].

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

In 2011, the research and education project DIAS-TH was successfully continued. The following activities in the framework of DIAS-TH were:

• 9th Winter School on Theoretical Physics (January 30 – February 6);

• XV Research Workshop «Nucleation Theory and Applications» (April 1–30);

• Helmholtz International Summer School «Nuclear Theory and Astrophysical Applications» (July 24 – August 2);

• II Helmholtz International Summer School «Lattice QCD, Hadron Structure and Hadronic Matter» (September 5–17);

• Regular seminars for students and postgraduates were organized;

• Computer processing of video records of lectures was continued;

• Web-site of DIAS-TH was supported.

Preliminary Plans for 2012

• 10th Winter School on Theoretical Physics (January 30 – February 6);

• XVI Research Workshop «Nucleation Theory and Applications» (April 1–30);

• Helmholtz International Summer School — Workshop «Calculations for Modern and Future Colliders (CALC-2012)» (July 23 – August 2);

• Helmholtz International School «Dense Matter in Heavy-Ion Collisions and Astrophysics» (August 28 – September 8).

COMPUTER FACILITIES

In 2011, the computer hall KRAST went through major improvements. The old TFS file server was moved to a more efficient equipment and free software. The PC-based computational servers were put into operation. They were equipped with i7 processors, overclocked to 4 GHz. In order to provide reliable printing facilities the additional Printer HP LaserJet P4015x was acquired. For renewal of the desktop park 11 PCs based on Intel i5 CPU was purchased. This figure doesn't include notebooks and PCs purchased individually using grants.

CONFERENCES AND MEETINGS

• International Conference «Classical and Quantum Integrable Systems» (January 24–27, Protvino);

• Symposium «JINR at the Centenary of Atomic Nucleus» (March 10–11);

• International Conference on Physics in Memoriam of Acad. Prof. Matey Mateev (April 11, Sofia, Bulgaria);

• Advanced Study Institute «Symmetries and Spin» (May 2–9, Prague, Czech Republic);

• The 5th APCTP-BLTP JINR Joint Workshop «Frontiers in Nuclear Physics at Dubna» (May 15–20);

• XV International Conference «Symmetry Methods in Physics» (July 12–16, Dubna and July 25–29, Yerevan, Armenia);

• International Workshop «Supersymmetries and Quantum Symmetries» (July 18–23);

• 7 International Conference «Quantum Theory and Symmetries» (August 7–13, Prague, Czech Republic);

• XIV International Workshop «High-Energy Spin Physics» (September 20–24);

• International Conference «Advances of QFT» (October 4–7);

• International Workshop «Bogoliubov Readings» (October 11–15);

• 4th Workshop «Precision Physics and Fundamental Physical Constants» (December 5–9);

• Round Table «Italy — Russia» (December 10–18, Dubna).

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Roumanian theorists — on the Titeica–Markov Programme.

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