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; Modern Mathematical Physics: Gravity, Supersymmetry, Integrability; Nuclear Structure and Dynamics; Theory of Condensed Matter and New Materials. Important components of the BLTP activities are theoretical support of experimental research to be carried out at JINR Laboratories as well as other research centers with JINR participation (CERN, GSI, BNL, FNAL, etc.). and recruiting of young researchers, students, and postgraduate students to the Laboratory.

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.

Among the theories beyond the Standard Model (SM) of particle physics, Supersymmetry (SUSY) provides an excellent dark matter (DM) candidate, the neutralino. One clear prediction of cosmology is the annihilation cross section of DM particles, assuming them to be a thermal relic from the Early Universe. In most of the parameter space of Supersymmetry the annihilation cross section is too small compared with the prediction of cosmology. However, for large values of the tan OI parameter, the annihilation through s-channel pseudoscalar Higgs exchange yields the correct relic density in practically the whole range of possible SUSY masses up to the few TeV range. The required values of tan OI are typically around 50, i.e., of the order of the top and bottom mass ratio, which happens to be also the range allowing for Yukawa unification in a Grand Unified Theory with gauge coupling unification. For such large values of tan OI, the associated production of the heavier Higgses is enhanced by three orders of magnitude and might be observable as one of the first hints of new physics at the LHC [1].

The form factors for the half-BPS operators O_I^n and $N = 4$ stress tensor supermultiplet current $T^{\rm AB}$ are studied at the second order of perturbation theory; and for the Konishi operator K, at the first order of perturbation theory in $N = 4$ SYM theory at weak coupling. For all the objects we observe the exponentiation of the IR divergences with two anomalous dimensions: the cusp anomalous dimension and the collinear anomalous dimension. The IR finite parts are expressed in terms of logarithms, polylogarithms, and the generalized Goncharov polylogarithms of several variables. All the answers are expressed in terms of the integrals which can be obtained from the dual conformal ones appearing in the amplitude calculations via special procedure [2].

Deep-inelastic scattering data on F_2 structure function from various fixed-target experiments were analyzed in the nonsinglet approximation with a next-to-next-to-leading-order accuracy. The study of high statistics deep inelastic scattering data provided by BCDMS, SLAC, NMC, and BFP collaborations was carried out. For the coupling constant, the value $\alpha_s(M_Z) = 0.1167 +/- 0.0021$ was found, which in this approximation turns out to be slightly less than that obtained at the next-to-leading order, as was generally anticipated. The application of the analytic and "frozen" modifications of the strong coupling constant, featuring no unphysical singularity (the Landau pole), leads to the further improvement of agreement between

theory and experiment and the behavior of the higher twist terms in the next-to-next-to-leading order is found to confirm earlier studies of the subject [3, 4].

A nonperturbative model for the QCD invariant charge, which contains no low-energy unphysical singularities and possesses elevated higher loop correction stability, was developed in the framework of potential approach [5]. The static quark–antiquark potential is constructed by making use of the proposed model for the strong running coupling. The obtained result coincides with the perturbative potential at small distances and agrees with the relevant lattice simulation data in the nonperturbative physically relevant region. The model yields a reasonable value of the QCD scale parameter, which is consistent with its previous estimations obtained within a potential approach .

A supersymmetric extension of the Standard Model with neutrino Yukawa interactions and R-parity violation was considered. It was found that R-parity breaking term $\lambda\nu H_u H_d$ leads to an additional F-type contribution to the Higgs scalar potential, and thus to the masses of supersymmetric Higgs bosons. The most interesting consequence is the modification of the tree-level expression for the lightest neutral supersymmetric Higgs boson mass. It appears that due to this contribution the bound on the lightest Higgs mass may be shifted upwards, thus slightly opening the part of the model parameter space excluded by nonobservation of the light Higgs boson at LEP in the framework of the Minimal Supersymmetric Standard Model [6].

The consequences of treating the $X(3872)$-meson as a tetraquark bound state were explored within a relativistic constituent quark model with infrared confinement. The decay widths of the observed channels $X \to J/\psi + 2\pi(3\pi)$ and $X \to \underline{D}^0 + D^0 + \pi^0$ were calculated. For reasonable values of the size parameter of $X(3872)$, the consistency of the theoretical results with the available experimental data was found [7].

Explanation of the unexpected behavior of the pion transition form factor at large momentum transfer, discovered by the BaBar collaboration in 2009, was proposed. It is found that the logarithmic enhancement of the form factor is possible due to the specific properties of the pion wave function. In particular, it leads to an almost flat distribution amplitude of the pion in accordance with earlier suggestions by A. E. Dorokhov, A. V. Radyushkin, and M. V. Polyakov. An additional contribution to the pion transition form factor can be related to an admixture of gluons in the pion wave function due to isotopic symmetry violation [8, 9].

A combined NLO QCD analysis of the polarized inclusive and semi-inclusive DIS data was presented. In contrast to the previous combined analysis, the $1/Q^2$ terms (kinematic — target mass corrections, and dynamic — higher twist corrections) in the expression for the nucleon spin structure function g_1 were taken into account. The impact of the semi-inclusive data on the polarized parton densities and on the higher twist corrections was demonstrated. The controversial behavior of the polarized strange quark density obtained from the fit to the DIS data alone, and from a combined analysis of DIS and SIDIS data was revealed [10].

A new framework for transverse-momentum dependent parton distribution functions based on a generalized concept of gauge invariance was proposed. The spin-dependent (Pauli) term was included into the Wilson lines. It is shown that while the Pauli term preserves the probabilistic interpretation of twist-two distributions (unpolarized and polarized), it gives rise to additional pole contributions to the twist-three distributions. The Feynman rules for the calculation with gauge links containing the Pauli term were presented, and the phenomenological implications of the approach were discussed [11].

It was shown that in the two-photon decays of scalar mesons $f_0(600)$, $a_0(980)$, and $f_0(980)$, an important role was played by both quark and meson loops ($1/N_c$ approximation). Taking into account the meson loops leads to good agreement of the NJL model predictions with experimental data [12].

The detailed analysis of sum rules for the spin structure function at low momentum transfers was performed. By applying the APT and QCD motivated model for the transition to real photon limit, the good description of high precision JLAB data was achieved [13].

The investigation of pion transition form factor related to BaBar data questioning QCD factorization was continued. The QCD Sum Rules for the pion distribution amplitude (DA) derivative at the end-point and its average slope were obtained. It is shown that the high-Q^2 BaBar data manifesting the significant growth of the pion transition form factor between 10 and 40 GeV^2 cannot be explained in terms of the input DA, higher-order perturbative corrections at the NNLO or higher twist [14].

An exact nonperturbative method relying on the anomaly and valid even in the case breakdown of the QCD factorization was applied to analyze the pion transition form factor. The axial anomaly in the virtual photon case was found to be a collective effect of the meson spectrum. The small correction to the continuum could lead to the enhanced (by the factor about 30 for BaBar kinematics) corrections to pion transition form factor [15].

The manifestations of axial anomaly in heavy ion collisions were considered. They result in the so-called Chiral Vortaic Effect, leading to observable correlations of neutron pair [16].

The consistent quantum field theory approach to neutrino flavor transitions in vacuum was developed. The approach is based on the technique of macroscopic Feynman diagrams [17].

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 2010 on these subjects are described below.

An integral representation for the scalar products of nested Bethe vectors for the quantum integrable models associated with the quantum affine algebra $U_q(gl_3)$ was given. This result was obtained in the framework of the universal Bethe ansatz, using the representation of the universal Bethe vectors in terms of the total currents of a new realization of the quantum affine algebra $U_q(gl_3)$ [18].

It was shown that all primitive idempotents for the Brauer algebra can be found by evaluating a rational function of several variables which had the form of a product of R-matrix type factors [19].

The continuum limit and finite (physical) volume effects as well as the Gribov copy dependence of the $SU(2)$ Landau gauge gluon propagator on the lattice were studied. In the case of lattices, with decreasing lattice spacing but fixed physical volume (nonperturbative), the renormalizability and the approach to the continuum limit for the renormalized gluon propagator at the momenta $p \geqslant 0.6$ GeV were confirmed. The finite-volume effects and the Gribov copy influence turned out to be small in this region. On the contrary, the Gribov copy influence becomes stronger and finite-volume effects still require special attention in the deep infrared regime [20].

Previous results for the superplane Landau model were generalized to exhibit explicit worldline $N = 2$ supersymmetry for an arbitrary magnetic field on any two-dimensional manifold. The quantization procedure in the general case is characterized by two independent potentials on the manifold, and the relevant Hamiltonians prove to be factorizable. In the restricted case when both the Gauss curvature and the magnetic field are constant over the manifold and, as a consequence, the underlying potentials are related, the Hamiltonians admit an infinite series of factorization chains implying the integrability of the associated systems. The spectrum and eigenvectors for the particular model with CP^1 as the bosonic manifold were explicitly determined [21].

Using the harmonic superspace approach, the three-dimensional $N = 4$ supersymmetric quantum mechanics of the supermultiplet $(3, 4, 1)$ coupled to an external $SU(2)$ gauge field was constructed. The off-shell $N = 4$ supersymmetry requires the gauge field to be a static form of the 't Hooft ansatz for the 4D self-dual $SU(2)$ gauge fields, that is a particular solution of Bogomolny equations for BPS monopoles. The explicit form of the corresponding superfield and component actions as well as of the quantum Hamiltonian and $N = 4$ supercharges was presented. The latter can be used to describe a more general $N = 4$ mechanics system, with an arbitrary BPS monopole background and on-shell $N = 4$ supersymmetry. The essential feature of the construction is the use of semidynamical spin $(4, 4, 0)$ multiplet with the Wess–Zumino type action [22].

The map of three-dimensional $N = 4$ superfields to $N = 3$ harmonic superspace was considered. The left and right representations of the $N = 4$ superconformal group were constructed on $N = 3$ analytic superfields. These representations are convenient for the description of $N = 4$ superconformal couplings of the Abelian gauge superfields with hypermultiplets. The $N = 4$ invariance in the non-Abelian $N = 3$ Yang–Mills theory was analyzed [23].

The Lagrangian and Hamiltonian formulations of N=4 supersymmetric systems describing the motion of an isospin particle on a conformally flat four-manifold with $SO(4)$ isometry carrying the non-Abelian field of a BPST instanton, were constructed. The conformal factor can be specified to yield various particular systems, such as superconformally invariant mechanics as well as a particle on the four-sphere, the pseudosphere or on $R \times S^3$. The isospin degrees of freedom arise as bosonic components of an additional fermionic $N = 4$ supermultiplet, whose other components are rendered auxiliary by a nonlocal redefinition [24].

New models of an «affine» theory of gravity in D-dimensional space-times with symmetric connections were proposed. They are based on ideas of Weyl, Eddington, and Einstein and, in particular, on Einstein's proposal to specify the space-time geometry by making use of the Hamilton principle. The connection coefficients are derived by varying a «geometric» Lagrangian that is supposed to be an arbitrary function of the generalized (nonsymmetric) Ricci curvature tensor expressed in terms of the connection coefficients regarded as independent variables. In addition to the standard Einstein gravity, such a theory predicts dark energy (the cosmological constant, in the first approximation), a neutral massive (or tachyonic) vector field, and massive (or tachyonic) scalar fields. These fields couple only to gravity and may generate dark matter and/or inflation. The masses have geometric origin and one cannot avoid their appearance in any concrete model [25].

The integration of Lax equations with both generic Lax operators and generic initial conditions was analyzed in full. A complete general formula for pertinent solution is derived which holds true for any (diagonalizable or nondiagonalizable) initial Lax matrix and gives an original rigorous mathematical proof of its validity. These results are important for diverse physical applications of Lax equation with generic Lax matrices and generic initial conditions [26].

The Hermitian–Yang–Mills (HYM) equations were investigated for gauge potentials on a complex vector bundle E over an almost complex manifold X^6. This manifold is the twistor space of an oriented Riemannian manifold M^4. Each solution of the HYM equations on such X^6 defines a pseudoholomorphic structure on the bundle E. It is shown that the pull-back to $X^6$of any anti-self-dual gauge field on M^4 is a solution of the HYM equations on X^6. This correspondence allows one to introduce new twistor actions for bosonic and supersymmetric Yang–Mills theories. As examples of X^6, the homogeneous nearly Kaehler and nearly Calabi–Yau manifolds were considered which are twistor spaces of S^4, CP^2 and B_4, CB_2 (real 4-ball and complex 2-ball), respectively. Various explicit examples of solutions to the HYM equations on these spaces are provided. Applications in flux compactifications of heterotic strings are briefly discussed [27].

The methods of spectral geometry are proved to be effective for construction of quantum field theory with allowance for the space-time curvature and geometry of the boundaries. In this approach, the possibility of violation of the third law of thermodynamics in some Casimir calculations was investigated. The material boundaries of two types were considered: the metals described by the Drude model and dielectrics with finite direct current conductivity. In these cases the violation of the third law of thermodynamics manifests itself as nonvanishing of the entropy for vanishing temperature. The relevant calculations for plane surfaces were analyzed, and the corresponding contributions for a ball in front of a plane were calculated. It is argued that the violation of the 3rd law is not related to the infinite size of the planes [28].

NUCLEAR STRUCTURE AND DYNAMICS

In 2010, 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.

A refined version of the quasiparticle–phonon model for odd–even spherical nuclei was elaborated. Specifically, the random phase approximation was used to describe one-phonon excitations of even–even core, and backward-going amplitudes were included in a trial wave function of the corresponding odd–even nucleus. In this way, the core-particle equations couple with the generalized equations describing the pairing correlations and the vibrational states of the even–even core. The spectroscopic factors and transition probabilities between states in selected Te, Xe, and Ba nuclides with $A \approx 130$ were calculated [29].

A new method of calculations of stellar weak-interaction rates based on the thermofield dynamics and allowing calculations of the weak-interaction response of nuclei at finite temperatures in a thermodynamically consistent way, was proposed. The method enables a transparent treatment of excitation and de-excitation processes in a hot nucleus. The thermal evolution of the GT_+ distributions as well as the strength distributions of first-forbidden transitions was presented for the sample nuclei from Fe and Ge isotopic chains. The results were used to calculate electron capture rates at finite temperatures and are relevant to supernovae collapse simulations [30].

A systematic analysis was performed of the description of odd nuclei by the Skyrme–Hartree–Fock approach augmented with pairing in the BCS approximation and blocking of the odd nucleon. Current and spin densities in the Skyrme functional produce time-odd mean fields (TOMF) for odd nuclei. Their effect on binding energies, odd–even staggering, separation energies and spectra was investigated for the three Skyrme parameterizations SkI3, SLy6, and SV-bas. About 1300 spherical and axially deformed odd nuclei with $16\mu \leqslant Z \leqslant \mu 92$ were considered. The calculations demonstrate that the TOMF effect is generally small, although not fully negligible. The influence of the Skyrme parameterization and the consistency of the calculations are much more important [31]

A microscopic state-of-the-art calculation of nuclear matrix element (NME) for neutrinoless double β-decay of ^{150}Nd with an account for nuclear deformation was performed. The proton-neutron QRPA with the Brückner G matrix derived from the charge-dependent Bonn (Bonn-CD) nucleon–nucleon potential was used as the underlying nuclear structure model. The present calculated NME is suppressed by about 40% as compared with the previous QRPA result obtained with neglect of deformation of ^{150}Nd. By making use of this newest NME, one may conclude that neutrinoless double β-decay of ^{150}Nd, to be measured soon by the SNO+ collaboration, provides one of the best probes of the Majorana neutrino mass [32].

The possibility of producing the still nonidentified very neutron-rich nuclei ^{84,86}Zn and ^{90,92}Ge in the multinucleon transfer actinide-based reactions with a ^{48}Ca beam at incident energies near the Coulomb barrier was demonstrated. The dynamics of the binary reaction was considered within the dinuclear system model as the diffusive multinucleon transfer between the interacting nuclei in the collisions when the excitation energy of the produced exotic isotope is lower than the threshold for the neutron emission. The predicted cross sections are in the range (0.1–5) pb. The current experimental technology allows one to reach the cross section of 1 pb in about one week of beam time [33].

The hyperdeformed nuclei treated as dinuclear or quasimolecular configurations were suggested to be directly produced in heavy-ion reactions. At bombarding energies near the Coulomb barrier the excited dinuclear system formed in the entrance channel of the heavy-ion collision can be cooled down by neutron emission and to be transformed into the hyperdeformed nuclear system. The transition from the excited dinuclear system to a hyperdeformed configuration was described within the statistical approach. At subbarrier energies, tunneling through the Coulomb barrier was considered using the quantum diffusion approach based on the formalism of reduced density matrix. The appropriate pairs of projectile-target for the beams of ^{40}Ca, ^{48}Ca and ^{58}Ni were proposed to populate hyperdeformed states. The production cross sections and some characteristics of the corresponding hyperdeformed states were calculated. Optimal conditions of experimental identification of this type of states were found. At subburrier beam energies, the partial production and identification cross sections were calculated as functions of bombarding energy [34].

A cause of the observed difference between the ratio of the evaporation residue (ER) cross section $\sigma_{\rm ER}$ to the fusion cross section $\sigma_{\rm fus}$ in the ^{19}F$+^{181}$Ta and ^{16}O$+^{184}$W reactions at high excitation energies, was analyzed. The analysis performed in the framework of the dinuclear system and advanced statistical models showed that the observed difference is caused by the unintentional inclusion of the quasifission and fast fission contributions in the fission-like fragment yields. The different yields of ER and fusion–fission fragments for the two reactions are caused by different capture cross sections formed at the first stage of the reacting nuclei [35].

The current status of studies of the information content in the Borromean halo continuum and other open system phenomena was demonstrated. The microscopic four-body distorted wave theory for two-neutron halo breakup reactions leading to low-lying halo excitations was developed. The theory accounts for both elastic and inelastic breakup. The Coulomb and nuclear dissociation was included in a consistent way. It was noted that the studies of two-proton decay were a powerful complimentary tool for understanding the nuclear three-body structures. The calculations described the experimental data for fragment correlations near the breakup threshold rather well. Experimental data were called for on exclusive cross sections — theory now provides correlation cross sections from fully inclusive (spectrum) to fully exclusive [36].

The ^{6}He$+^{12}$C elastic scattering data at beam energies of 3, 38.3, and 41.6 MeV/nucleon were studied utilizing the microscopic optical potentials (OPs) obtained by a double-folding procedure and also by using those inherent in the high-energy approximation. The calculated OPs were based on the neutron and proton density distributions of colliding nuclei established in an appropriate model for ^{6}He and obtained from the electron scattering form factors for ^{12}C. The depths of the real and imaginary parts of the microscopic OPs were considered as fitting parameters. At low energy, the volume OPs reproduce sufficiently well the experimental data. At higher energies, generally, additional surface terms having the form of a derivative of the imaginary part of the microscopic OP are needed. The problem of ambiguity of adjusted OP was resolved requiring the respective volume integrals to obey the determined dependence on the collision energy [37].

In the experiment performed at Innsbruck University in collaboration with theoreticians from BLTP, JINR and Hamburg University, confinement-induced resonances (CIRs) were observed in strongly interacting quantum-gas systems with tunable interactions for 1D- and 2D-geometry of confining optical potentials. In 1D-system with transverse confinement, CIRs are caused by a coupling between the incident channel of two colliding atoms and the closed channel with a transversally excited molecular state. It was observed by characteristic atomic loss and heating signatures that atom–atom scattering modified substantially under the condition of the CIR appearance. The prediction of V. Melezhik that introducing an anisotropy in the transversal confinement leads to the CIR splitting was confirmed. The effect is a consequence of lifting, in an anisotropic trap, the degeneracy of the threshold of the closed channel with a transversally excited molecular state [38].

Within the previously developed Dubna–Mainz–Taipei meson-exchange model, the singularity structure of the πN scattering amplitudes was investigated. For all partial waves up to F waves and c.m. energies up to $W \sim 2$ GeV, the T-matrix poles were calculated by three different techniques: analytic continuation into the complex energy plane and speed-plot and regularization method. For all the four-star resonances except the $S_{11}(1535)$, a very good agreement between the analytic continuation and the regularization method was found. Moreover, the resonance poles for resonances that are not so well established were also found, but in these cases the pole positions and residues obtained by analytic continuation can substantially differ from the results predicted by the speed-plot and regularization methods [39].

The shear (η) and bulk (ς) viscosities were calculated for the hadron and the quark–gluon phases as well as for the pure gluon matter in a quasiparticle relaxation time approximation. General expressions for η and ς were derived for a system described by the quasiparticle relativistic mean-field theory with the scaling of hadron masses and couplings. A two-phase model allowing for the first-order phase transition from the hadron phase to the strongly coupled quark–gluon plasma was constructed by means of the Gibbs conditions. The EoS of the model fairly well reproduces global properties of hot and dense hadron matter including the temperature region near critical temperature. The first-order phase transition for the glue matter is reproduced as well. Temperature and baryon density dependence of the calculated viscosity-to-entropy ratios (η/s, ς/s) were analyzed and compared with those obtained in other models. Effects of resonance widths on viscosities and viscosity-to-entropy ratios were estimated and found to be important at low temperatures [40].

Within a covariant Bethe–Salpeter approach, a rank-six separable neutron–proton interaction kernel for the triplet coupled ${}^3S_1$–${}^3D_1$ partial-wave state was constructed. Two different methods of relativistic generalization of initially nonrelativistic form factors parametrizing the kernel were considered. The model parameters were determined by fitting the elastic ${}^3S_1$ and ${}^3D_1$ phase shifts and the triplet scattering length as well as the asymptotic D/S ratio of the deuteron wave functions and the deuteron binding energy. The constructed rank-six interaction kernels are successfully used for the description of the on-shell and off-shell characteristics of the triplet ${}^3S_1$–${}^3D_1$ partial-wave state of the np system and the deuteron. The constructed separable model of NN interaction can be used in calculations of deuteron photo- and electrodisintegration, etc. [41].

THEORY OF CONDENSED MATTER AND NEW MATERIALS

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.

A new theory of spin-excitation spectrum in strongly correlated electronic systems, such as high-temperature cuprate superconductors, was developed. Using the Mori-type projection technique for the thermodynamic Green function, an exact representation for the dynamical spin susceptibility was obtained which was calculated for the t-J model in the superconducting state. For the first time, an explanation of a weak temperature dependence of the magnetic resonance mode observed in neutron-scattering experiments in the cuprate superconductors was given [42].

The reorientation temperature in an antiferromagnetic square lattice was studied within the framework of many-body Green function theory. The model Hamiltonian includes a Heisenberg term, second order single ion anisotropy, and a transverse external magnetic field in the x-direction. The orientation temperature as a function of the single-ion anisotropic parameter was evaluated for different transverse magnetic fields. Within the same method, a model of ultrathin ferromagnetic films which takes into account different surface and bulk exchange couplings was studied. The reorientation magnetic field as a function of the surface single-ion anisotropy parameter was evaluated for different film thicknesses, surface exchange coupling enhancements, and temperatures [43].

The intensity profile of small-angle scattering from a generalized Cantor fractal in three dimensions was calculated analytically. The variable fractal dimension is controlled using a scaling factor and can vary from zero to one in one dimension and from zero to three in three dimensions. Small-angle scattering from monodispersive sets, which were randomly oriented and placed, was calculated. The scattering intensities displayed minima and maxima superimposed on a power law decay, with the exponent equal to the fractal dimension of the scatterer. The minima and maxima were damped out with increasing polydispersity of the fractal sets. It was established that, for a finite generation of the fractal, the power exponent changes at sufficiently large wave vectors from the fractal dimension to four, the value given by the usual Porod law. It was shown that the number of particles of which the fractal is composed can be estimated from the value of the boundary between the fractal and Porod regions [44].

A statistical model is advanced for describing quantum turbulence in a superfluid system with Bose–Einstein condensate. Such a turbulent superfluid can be realized for trapped Bose atoms subject to either an alternating trapping potential or to an alternating magnetic field modulating the atomic scattering length by means of Feshbach resonance. The turbulent system is represented as a continuous mixture of states each of which is characterized by its own vorticity corresponding to a particular vortex [45].

Ab initio quantum-chemical cluster calculations, with the structural data taken from experiment, were performed for the perovskite LaCoO3. The calculated

energy level ordering of different spin states of Co3+, for the trigonal lattice structure, at $T = 5$ K and 300 K indicated that the low-spin (LS, $S = 0$) ground state was separated from the first excited high-spin (HS, $S = 2$) state by a gap < 100 meV, while the intermediate-spin (IS, $S = 1$) state is located at much higher energy $\gg 0.5$ eV. It was suggested that the local lattice relaxation around the Co3+ ion excited to the HS state and the spin-orbit coupling reduce the spin gap to a value near 10 MeV. Coupling of the IS state to the Jahn–Teller local lattice distortion was found to be rather strong and reduces its energy position to a value of 200–300 MeV [46].

It was shown that the origin of anomalous isotopic effect for tunneling states in NbTi-H/D could be explained by large-scale fluctuations in the thermal expansion which are able to generate anomalous two-level systems [47].

A gauge-theory approach to describe Dirac fermions on a disclinated flexible membrane beyond the inextensional limit is formulated. The elastic membrane is considered as an embedding of a 2D surface into R3. The disclination is incorporated through an $SO(2)$ gauge vortex located at the origin, which results in a metric with a conical singularity. A smoothing of the conical singularity is accounted for by replacing a disclinated rigid plane membrane with a hyperboloid of near-zero curvature pierced at the tip by the $SO(2)$ vortex. The embedding parameters are chosen to match the solution to the von Karman equations. A homogeneous part of that solution is shown to stabilize the theory. The modification of the Landau states and density of electronic states of the graphene membrane due to elasticity is discussed [48].

The detailed investigation of the phase dynamics and the IV curves in the system of coupled Josephson junctions was carried out. The superconducting, quasiparticle, diffusion, and displacement currents were calculated as functions of the total current through the system. The role of the diffusion current in the formation of the IV curves was studied and the influence of this quantity on the IV curve branching and the magnitude of the return current was revealed. The calculation results agree qualitatively with the experimental data [49].

A complete adiabatic transport of the Bose–Einstein condensate in a double-well trap was investigated within the Landau–Zener (LZ) and Gaussian Landau–Zener (GLZ) schemes for small nonlinearity when the atomic interaction is weaker than the coupling. The schemes use the constant (LZ) and time-dependent Gaussian (GLZ) couplings. The mean field calculations show that LZ and GLZ suggest essentially different transport dynamics. Significant deviations from the case of strong coupling were discussed [50].

The asymptotics of two-site correlation functions for height variables in the two-dimensional Abelian sandpile model were computed exactly. By using combinatorial methods for the enumeration of spanning trees, the well-known result for the correlation of minimal heights $(1, 1)$ was extended to the case $(1, h)$ for height values $h = 2, 3, 4$. These results confirm the dominant logarithmic behaviour for large distances predicted by logarithmic conformal field theory based on field identifications, obtained previously. From lattice calculations, the explicit values for the coefficients of logarithmic and power terms were derived [51].

Simplified models of charged matter coupling to the radiation resonance modes generalizing the well-known Jaynes–Cummings and Dicke models were considered. It is shown that these new models are integrable for arbitrary numbers of dipole sources and resonance modes of the radiation field. The integrals of motion for Sutherland hyperbolic quantum systems of particles with internal degrees of freedom ($su(n)$ spins) interacting with an external field of the Morse potential of arbitrary strength were constructed. These systems are confined if certain constraints are imposed on their parameters and the number of particles. The ground state was described by a wave function of the Jastrow form [52].

A generalization of the electric–magnetic duality from electrodynamics to non-Abelian gauge theories was investigated in $N = 1, 2, 4$ supersymmetric field theories since the end of the 70s. Transition from the ultraviolet to the infrared region in $N = 1$ theories was performed by the Seiberg duality transformations which were believed to exist only for the conformal window $3N_c/2 < N_f < 3N_c$ for SQCD with SU(N_c) gauge group and N_f flavors. Using the superconformal indice techniques, it was shown that there were nontrivial dualities lying beyond this conformal window. They have a more complicated structure and exist for dual gauge group SU(N_c) and either $N_f = 4$ (for arbitrary even N_c) or $N_f = N_c+2$ (for arbitrary N_c). Similar dualities outside the conformal window were discovered for the gauge group SP($2N_c$). The corresponding theories are physically distinguished by the presence of chiral superfields with small or negative R-charges. For $N = 4$ theories for all simple gauge groups explicit forms of the superconformal indices were derived in terms of the elliptic hypergeometric integrals. For some particular parameter values these indices have been computed exactly [53].

Infinite sets of inequalities which provide upper bounds on the difference between the quadratic fluctuations of intensive observables of an N-particle system and the corresponding Bogoliubov–Duhamel inner product were derived. They generalize all the known inequalities that can be used in the majorization step of the Approximating Hamiltonian method. The novel feature is that, under sufficiently mild conditions, the upper bounds have the same form and order of magnitude with respect to N for all the quantities derived by a finite number of commutations of an original intensive observable with the Hamiltonian of the system [54].

In 2010, the research and education project DIAS-TH was successfully continued. The following activities in the framework of DIAS-TH were:

- 8th Winter School on Theoretical Physics (January 31 – February 7);
- XIV Research Workshop «Nucleation Theory and Applications» (April 1–30);
- International School «Dense QCD Phases in Heavy-Ion Collisions» (August 21 – September 4);
- International Advanced School on Modern Mathematical Physics (September 5–15);
- 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.

More than 90 PhD students and young scientists from the JINR Member States participated in the DIAS-TH schools.

COMPUTER FACILITIES

In the year 2010, total of 14 computers were purchased. Two most powerful computers were equipped with four-core processors, 24 GB RAM and solid state disks. These two computers will be used as computational servers to support most demanding tasks. During several conferences which took place at BLTP in 2010, the live audio-video broadcast over Internet was performed for the first time with the use of Vidicor system. The video camera purchased in 2010 gives the possibility to broadcast in high-definition as well as in the standard format. The new network equipment will allow one to extend the Gigabit Ethernet (wired) as well as wireless networks at BLTP. Due to an increased number of portable computers getting access to BLTP network especially during meetings, more attention was paid to improvement of network management. Several database tables were created and appropriate applications to collect and display data were developed. This will allow for more detailed accounting of network activity and planing future modifications of network infrastructure.

MEETINGS, SCIENTIFIC COLLABORATION

In 2010, besides the Schools organized in the framework of DIAS-TH, the Laboratory participated in the organization of 11 international conferences and workshops:

- XIX International Colloquium «Integrable Systems and Quantum Symmetries» (June 17–19, Prague, Czech Republic);
- CAS–BLTP JINR Joint Workshop on Nuclear Theory (June 28 – July 4, Dubna, Russia);
- International Conference «Dubna-Nano2010» (July 5–10, Dubna, Russia);
- Advanced Study Institute «Symmetries and Spin» (July 18–25, Prague, Czech Republic);
- XIV International Conference «Symmetry Methods in Physics» (August 16–22, Tsakhkadzor, Armenia);
- International Conference «Critical Point and Onset of Deconfinement (CPOD)» (August 23–29, Dubna, Russia);
- 2nd South Africa–JINR Symposium «Models and Methods in Few- and Many-Body Systems» (September 8–10, Dubna, Russia);
- International Workshop «Bogoliubov Readings» (September 22–25, Dubna, Russia);
- XX International Baldin Seminar «Relativistic Nuclear Physics & Quantum Chromodynamics» (October 4–9, Dubna, Russia);
- International Workshop «Nuclear Structure: Recent Developments» (dedicated to the 85th anniversary of V. G. Soloviev's birth) (October 14–16, Dubna, Russia);
- Round Table 2 Discussion Italy–Russia, Dubna «Space Physics and Biology» (December 19–22, Dubna, Russia).

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