BOGOLIUBOV LABORATORY OF THEORETICAL PHYSICS

At the Bogoliubov Laboratory of Theoretical Physics (BLTP), studies were 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. An important component of the BLTP activities is theoretical support of experimental research to be carried out within major international projects with the participation of JINR as well as Dubna based experimental programmes of JINR Laboratories. The research resulted in more than 400 publications in peer-reviewed journals and proceedings of international conferences. Most of the results were obtained in cooperation with scientists from the JINR Member States, Brazil, China, Egypt, Germany, Italy, France, Serbia, Spain, and other countries. The Laboratory has become a site for organization of international conferences, workshops, schools for young scientists in various fields of theoretical physics. In 2013, more than 900 scientists participated in 13 international conferences, workshops and schools organized at the Laboratory. In 2013, 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 Armenia, on Smorodinsky–Ter-Martirosyan Programme; with Polish theorists, on the Bogoliubov–Infeld Programme; with Czech theorists, on the Blokhintsev–Votruba Programme; and Romanian theorists, on the Titeica–Markov Programme. Collaboration with scientists from Western Europe was carried out in the framework of the JINR–INFN, JINR–IN2P3 agreements and was also supported by RFBR–CNSF, RFBR–DFG, RFBR–CNRS. The agreements for collaboration between the Bogoliubov Laboratory and CERN TH, KEK, APCTP (South Korea), ITP CAN (Beijing) are functioning. Much attention was paid to recruiting young researchers, students, and post-graduate students to the Laboratory within the research and education project "Dubna International Advanced School of Theoretical Physics" (DIAS-TH), in particular. More than 80 PhD students and young scientists from the JINR Member States participated in the DIAS-TH schools. The Laboratory plays the role of the training center for young scientists and students from many countries. Currently, about one third of the scientific personnel are young scientists and PhD students. Within the JINR fellowship programme for nonmember states several young researchers from Argentina, China, India, Japan, Mexica, South Korea, Tajikistan and Turkey have been working at BLTP on the long-term basis.

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.

In the Yang–Mills theory with $N = (1,1)$ supersymmetry in $D = 6$ dimensions within the spinor helicity and on-shell superspace formalism, the scattering amplitudes on mass shell were studied. This formalism

leads to an effective and straightforward technique reducing the calculation to a set of scalar master-integrals. The four-point amplitude was calculated in one and two loops in the planar limit. All integrals are UV and IR finite and expressed in terms of logs and polylogs of transcendentality level 2 at one loop, and 3 and 4 at two loops. The all-loop asymptotical limit at high energy was obtained which exhibits the Regge-type behaviour. The exact expression for the intercept is obtained in the planar case [1].

A new formalism for computing and including both the perturbative and nonperturbative QCD contributions to the scale evolution of average gluon and quark jet multiplicities was developed. The new method is motivated by recent progress in timelike small-x resummation obtained in the MS-bar factorization scheme. The next-to-next-to-leading-logarithmic (NNLL) resummed expressions, which represent generalizations of previous analytical results, were obtained. It was shown that a global fit of gluon and quark jet multiplicities to all available experimental data sets results in the statistical and theoretical uncertainties both not exceeding 5% for scales above 10 GeV. It was finally proposed to use the jet multiplicity data as a new way to extract the strong-coupling constant. Including all the available theoretical input within our approach, $\alpha_s(M_Z) = 0.1199 \pm 0.0026$ was obtained in the MS-bar scheme for 5 active quarks in an approximation equivalent to next-to-next-to-leading order enhanced by the resummations of $\ln(x)$ terms through the NNLL level and of $\ln(Q^2)$ terms by the renormalization group, in excellent agreement with the present world average [2].

In a series of papers [3], the three-loop beta-functions for fundamental parameters of the Standard Model were calculated. The obtained results allowed one to analyze the behaivoir of the SM in the region of Plank energies and stimulated the research dedicated to the problem of vacuum stability. In addition, the beta-functions for the gauge constants and the parameters of the Higgs field potential are generalized to the case of matrix Yukawa couplings.

The polarized Bjorken sum rule at low momentum transfers in the range $Q = 0.22-1.73$ GeV up to the four-loop level was analyzed in the framework of the QCD perturbation theory and the singularity-free analytic perturbation theory (APT). It was shown that the usage of the two-loop APT allowed one to describe the precise low-energy JLab data down to $Q \sim 300$ GeV and extract the higher twist corrections in a reliable way [4].

A regularization procedure for the integral curvature invariants on manifolds with conical singularities in the presence of squashed cones was proposed. This allows one to calculate the entanglement entropy for the entangling surfaces which have extrinsic curvatures. A case of invariants which are quadratic polynomials of the Riemann curvature is elaborated in different dimensions and applied to several problems related to the entanglement entropy. The results are in complete agreement with computations of the logarithmic terms in the entanglement entropy of 4D conformal field theories [5].

The rare decays of heavy hadrons containing b-quark attract increasing attention in connection with the search for new physics effects at the LHC. In a series of papers [6, 7], a systematic analysis of rare decays of λ_b-baryon was carried out. Within the covariant quark model developed in Dubna, all possible form factors characterizing the b-quark transitions to s-quark in the entire kinematic region of the momentum transfer squared were calculated. The differential rates, the asymmetry parameters and the widths of rare and nonleptonic decays were calculated by means of the obtained form factors. Using the model-independent helicity methods we have written down a three-fold joint angular decay distribution for the cascade decay $\lambda_b \to \lambda(\to p\pi) + J/\psi(\to l^+l^-)$. The given formula is already used by experimentalists in the analysis of the angular distributions in the rare decays of λ_b-baryon.

The complete contribution of corrections of an order of $m\alpha^7$ and the contribution of the leading corrections of an order of $m\alpha^8$ to the energies of ρ-vibrational transitions in the molecular ions of hydrogen H_2^+ and HD^+, and in the antiprotonic helium atoms were calculated [8]. That allows one to infer the atomic mass of the electron and electron-to-(anti)proton mass ratio with fractional uncertainty of $(1-0.8) \cdot 10^{-10}$. For comparison, the CODATA recommended value for the atomic mass of electron has fractional uncertainty of $4.1 \cdot 10^{-10}$.

The applicability domain was studied for a QTF based approach with covariant wave packets as the in- and out-states, which describes the neutrino flavor transitions. The approach incorporates the so-called Grimus-Stockinger (GS) theorem which defines the asymptotics of the generalized neutrino propagator at large distances. The extended GS theorem was formulated and proved. It was shown that the preasymptotic corrections could lead to the observable effects of breakdown of the classical inverse-square law (ISL) at short but macroscopic distances. A statistical analysis of available reactor data suggests that the ISL violation could be fully or partially responsible for the reactor anomaly observed in SBL experiments [9].

Transition form factors of pseudoscalar mesons in the space- and time-like regions are studied by means of the anomaly sum rule (ASR) — an exact nonperturbative relation which is a consequence of the dispersive representation of axial anomaly. The analytical continuation of ASR to the time-like region allows one to link the axial anomaly with the vector meson dominance model [10].

Within the factorized handbag model, the transversity effects in the light-vector-mesons production were analyzed. It was shown that transversity Generalized Parton distributions H_T and E_T are extremely important in the description of the spin density matrix elements (SDMEs) and spin asymmetries in a transversely

polarized target for the ρ-meson production. The obtained results are in good agreement with the data of HERMES and COMPASS experiments [11].

Within the QCD analysis of the COMPASS and HERMES data on the pion and kaon multiple production, the new parameterizations of the fragmentation functions were obtained, which can eliminate differences in the results of analysis of the polarized DIS and SIDIS data [12].

It was demonstrated that the ligh-by-light hadronic corrections to the muon anomalous magnetic moments due to the contributions of light pseudoscalar and scalar mesons and dynamical quark loop cannot explain the sharp disagreement between experimental observations and theoretical prediction of the Standard Model [13].

It was shown that large anomalous chromomagnetic moment of quarks, induced by complex topological structure of QCD vacuum, plays an important role in the different high-energy reactions. In particular, this interaction should lead to large spin effects in the reactions with polarized hadrons [14].

The light-cone QCD sum rules for the electromagnetic nucleon form factor were derived including the next-to-leading-order corrections for the contribution of twist-three and twist-four operators and the self-consistent treatment of the nucleon mass corrections [15].

The dynamics of color fields as generated by configurations of relativistic particles with Abelian and non-Abelian ($SU(2)$) charges was studied in the classical limit. Though the chromodynamic (non-Abelian) systems generally show Coulomb-like features in analogy with electrodynamics, a very peculiar feature in the non-Abelian case is that the presence of the non-Abelian additional term in the chromoelectric and chromomagnetic fields creates a kind of "color charge glow", which is manifested as a distinct color wave disturbance. The phenomenon may be relevant to the hadronization phase in ultrarelativistic heavy-ion collisions, where the partonic state is governed by strong local color fluctuations [16].

It was shown that within the lattice QCD, the large-scale topological gluon configurations play a major role in the change of thermal gauge field ensembles at the deconfinement phase transition in gluodynamics as well as at the crossover phenomenon in full QCD. It was demonstrated that the topological susceptibility can be used as an indicator for deconfinement phase transition [17].

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 R-matrix acting in the tensor product of two spinor representation spaces of Lie algebra $so(d)$ was thoroughly studied. The corresponding Yang–Baxter relation was proved and the underlying local Yang–Baxter equation was established [18].

A new method of searching for the integrals of motion in dilaton gravity was developed; some additional integrals of motion in affine gravity were found, and static/cosmological states were investigated. The possibility of cosmological inflation driven by the homogeneous and isotropic Yang-Mills field $SU(2)$ was investigated in different models [19].

A possible connection between two second-order theories of gravity, Galilean gravity, and teleparallel gravity was studied. By using the conformal transformation method, we constructed from the third-order Galilean action some auxiliary action, which can be covariantly generalized only in theories with torsion. On this way, a new second-order phenomenological Lagrangian was obtained, which may be useful for cosmological applications and for construction of a new second-order theory of gravity [20].

A number of integrable one-scalar spatially flat cosmologies were built. Their behavior was examined in several cases, and some general lessons on this type of systems, whose potentials involved combinations of exponential functions, and on similar nonintegrable ones were drawn. These include the need for the scalar to emerge from the initial singularity while climbing up sufficiently steep exponential potentials ("climbing phenomenon") and the inevitable collapse in a Big Crunch whenever the scalar tries to settle at negative extrema of the potential. The links between these types of potentials and "brane supersymmetry breaking" were elaborated on — a mechanism that ties together string scale and scale of supersymmetry breaking in a class of orientifold models. Under some assumptions, the extended objects of these vacua can inject inflationary phases with discrete values of the spectral index that are determined by the number of unwrapped dimensions of the branes and by the inverse power with which the string coupling g_s enters into their world-volume actions. An NS fivebrane, which is interestingly unstable in this class of models, when wrapped on a small internal cycle would yield a spectral index that is amusingly close to the experimentally favored PLANCK value $n_s \sim 0.96$ [21].

The electromagnetic vacuum energy was considered in the presence of perfectly conducting plane and a ball with dielectric permittivity ε and with magnetic permeability $\mu, \mu \neq 1$. The Casimir repulsion in the system is caused by the magnetic permeability of the ball. In the case of a perfectly permeable sphere, $\mu \to \infty$, the vacuum energy was estimated numerically. The short- and long-distance asymptotes corresponding to the repulsive force and respective low-temperature corrections and high-temperature limits were found for a wide range of μ. The constraints on the Casimir repulsion in this geometry were established [22].

A method to construct the on-shell component actions for the theories with $1/2$ partial breaking of global

supersymmetry within the nonlinear realization (coset) approach was proposed. An example of the component action of $N = 1$ supermembrane in $D = 4$ constructed within our procedure was examined in detail [23].

A class of $d = 1$ sigma models of the Wess–Zumino type on the $SU(n|1)/U(n)$ fermionic cosets was constructed. Both classical and quantum models were considered. The unitarity of the quantum models was poven by introducing the metric operator on the Hilbert space of the quantum states, so that all their norms became positive-definite. It was shown that the quantum $n = 2$ model exhibited hidden $SU(2|2)$ symmetry [24].

The general formulation of $N = 1$ supersymmetric self-dual Abelian gauge theory involving auxiliary chiral spinor superfields was constructed. Self-duality in this context was just $U(N)$ invariance of the nonlinear interaction of the auxiliary superfields. A few instructive examples of a procedure to generate self-dual $N = 1$ models with higher derivatives in this approach were considered [25].

Based on the nonlinear realization method, we proposed a method for construction of component actions on the mass surface for supersymmetric fields with half violated global supersymmetry [26].

The relations between minimal dilatonic gravity and $f(R)$ gravity theories were established, and strict conditions for their global equivalence were studied [27].

In the studies of quantum integrable models with $GL(3)$ trigonometric R-matrix, it was proved that the set of nested Bethe vectors was closed under the action of the elements of the monodromy matrix [28].

The existence of pseudotoric structures on any toric symplectic manifold was proved and the conjecture was presented which states that given by this construction exotic monotone Lagrangian tori are Hamiltonian non-isotopic to the standard Liouville tori [29].

Nuclear Structure and Dynamics

In 2013, 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.

Within the QRPA, the partial restoration of the isospin symmetry was achieved. This was accomplished by separating the renormalization parameter g_{pp} of the particle–particle proton–neutron interaction into the isovector and isoscalar parts. The isovector parameter needs to be chosen to be essentially equal to the pairing constant $g_{\rm pair}$, so no new parameter is needed. For the $0\nu\beta\beta$ decay, the Fermi matrix element M_f is substantially reduced, while the full matrix element M^{ov} is reduced by $\sim 10\%$. Moreover, the fulfillment of the requirement that the $2\nu\beta\beta$ Fermi matrix element vanishes is also achieved unlike in the previous version of the method [30].

The action of the long-range residual force on the expectation value of observables in the nuclear ground states was evaluated by finding optimal values for the coefficients of the canonical transformation which connects the phonon vacuum state with the (quasi)particle ground state. We compare the ground-state wave functions, obtained using the presented approach, with those obtained using the conventional random phase approximation (RPA) and its extended version ERPA. The problem with overbinding of the nuclear ground state calculated by using the RPA was shown to be removed if one sticks to the prescriptions of the present approach. The reason being that the latter conforms to the original variational formulation. Calculations were performed within the two-level Lipkin–Meshkov–Glick model [31].

The influence of the coupling between one- and two-phonon terms in the wave functions and the tensor force effects on properties of Gamow–Teller states has been studied [32]. It was found that the beta-decay half-lives are decreased by these effects. Calculations are in good agreement with the available experimental data for the $N = 50$ isotones. A prediction for the beta-decay half-life of ^{76}Fe that is important for stellar nucleosynthesis has been done.

The nature of $E1$ low-energy strength (LES), often denoted as a "pygmy" dipole resonance, was analyzed within the random phase approximation (RPA) in ^{208}Pb by using Skyrme forces in a fully self-consistent manner. The first overview is given by the strength functions for the dipole, compressional, and toroidal operators. A more detailed insight is gained by averaged transition densities and currents where the latter provide a very illustrative flow pattern. The analysis revealed a clear isoscalar toroidal flow in the low-energy bin 6.0–8.8 MeV of the LES and a mixed isoscalar/isovector toroidal/compression flow in the higher bin 8.8–10.5 MeV. Thus the modes covered by LES embrace both a vertical and an irrotational motion. The simple collective picture of LES as oscillations of the neutron excess against the nuclear core is not confirmed [33].

A collective model able to describe the chiral rotation and vibration was proposed and applied to the system of one $h_{11/2}$ proton particle and one $h_{11/2}$ neutron hole coupled to triaxial rigid rotor. It goes beyond the mean-field approximation, includes quantum fluctuations in the chiral degree of freedom, and restores the chiral symmetry. The potential energy and the mass coefficients are obtained and included in the collective Hamiltonian. It is shown that for chiral rotations, the partner states become more degenerate with increasing angular momentum [34].

The isotopic dependence of the complete fusion (capture) cross section was analyzed in the reactions $^{130,132,134,136,138,140,142,144,146,148,150}\mathrm{Xe} + {}^{48}\mathrm{Ca}$ with stable and radioactive beams. It was shown for the first time that the neutron-rich nuclei $^{186-191}\mathrm{W}$ can be reached with relatively large cross sections by complete fusion reactions with radioactive ion beams at incident energies near the Coulomb barrier. A comparison between the complete fusion and fragmentation reactions for the production of neutron-rich W and neutron-deficient Rn isotopes was performed [35].

Using an improved scission-point model, the mass distributions were calculated for induced fission of even Hg isotopes with mass numbers from $A = 174$ to 196. With increasing A of a fissioning $^{A}\mathrm{Hg}$ nucleus, the mass distribution evolves from the symmetric one for $^{174}\mathrm{Hg}$ to the asymmetric for isotopes close to $^{180}\mathrm{Hg}$ and back to a more symmetric for $^{192,194,196}\mathrm{Hg}$. In the fissioning Hg isotopes their excitation energy weakly influences the shape of the mass distribution. In $^{180,184}\mathrm{Hg}$, the mass distributions of fission fragments remain asymmetric even at high excitation energies [36].

The concept of dynamical adiabatic states, originally proposed to describe one-electron atom(ion)–ion collision systems was developed and the properties of the corresponding dynamical adiabatic potential energy curves were studied for a complete range of internuclear distances R. The advantages of a dynamical adiabatic basis are threefold. First, it is compatible with the boundary conditions. Second, rotational transitions are transformed into radial transitions via a type of hidden crossings in contrast with the standard adiabatic basis. And third, the ionization process can be described by using a basis of the complete discrete orthogonal wave packets, which is much more satisfactory for the process compared with the standard adiabatic approach [37].

A nonperturbative theoretical approach to treat collisions with generic anisotropic interactions in quasi-one-dimensional geometries was developed. This approach avoids the limitations of pseudopotential theory and allows one to include accurately long-range anisotropic interactions. For ultracold dipolar collisions in a harmonic waveguide, it predicts dipolar confinement-induced resonances (DCIRs) which are attributed to different angular momentum states. The analytically derived resonance condition reveals in detail the interplay of the confinement with the anisotropic nature of the dipole-dipole interactions. The results obtained are in excellent agreement with *ab initio* numerical calculations confirming the robustness of the presented approach. The exact knowledge of the positions of DCIRs may pave the way for the experimental realization of, e.g., Tonks-Girardeau-like or super-Tonks-Girardeau-like phases in effective one-dimensional dipolar gases [38].

A new, essentially stronger bound on the rotation of a spectral subspace of a self-adjoint Hamiltonian under generic additive perturbations was found. The proof of this bound is based on using a new $\sin 2\theta$ theorem that provides a local estimate on the maximal angle between unperturbed and perturbed spectral subspaces. Another ingredient of the proof is the triangle inequality for maximal angles between arbitrary subspaces of the Hilbert space [39].

The results of analysis of elastic scattering and breakup processes in interactions of the $^{11}\mathrm{Li}$ nucleus with protons are presented. The hybrid model of the microscopic optical potential (OP) was applied. This OP includes the single-folding real part, while its imaginary part was derived within the high-energy approximation theory. For $^{11}\mathrm{Li} + p$ elastic scattering, the microscopic large-scale shell model (LSSM) density of $^{11}\mathrm{Li}$ was used. The depths of the real and imaginary parts of OP were fitted to the elastic scattering data at 62, 68.4, and 75 MeV/nucleon, being simultaneously adjusted to reproduce the true energy dependence of the corresponding volume integrals. The role of the spin-orbit potential was studied and predictions for the total reaction cross sections were made. Also, the cluster model, in which $^{11}\mathrm{Li}$ consists of a $2n$-halo and the $^{9}\mathrm{Li}$ core having its own LSSM form of density, was adopted. The respective microscopic proton-cluster OPs were calculated and folded with the density probability of the relative motion of both clusters to get the whole $^{11}\mathrm{Li} + p$ OP. The breakup cross sections of $^{11}\mathrm{Li}$ at 62 MeV/nucleon and momentum distributions of the cluster fragments were calculated. The analysis of the single-particle density of $^{11}\mathrm{Li}$ within the same cluster model accounting for the possible geometric forms of the halo-cluster density distribution was performed [40].

The generalized Breit–Wheeler process, i.e., the emission of e^+e^- pairs off a probe photon propagating through a polarized short-pulsed electromagnetic (e.g., laser) wave field, was analyzed. We showed that the production probability was determined by the interplay of two dynamical effects. The first one was related to the shape and duration of the pulse and the second one is the nonlinear dynamics of the interaction of $e^{\pm}$ with the strong electromagnetic field. The first effect manifests itself most clearly in the weak-field regime, where the small field intensity is compensated by the rapid variation of the electromagnetic field in a limited space–time region, which intensified the few-photon events and could enhance the production probability by orders of magnitude compared to an infinitely long pulse. Therefore, short pulses may be considered as a powerful amplifier. The nonlinear dynamics in the multiphoton Breit–Wheeler regime plays decisive role at large field intensities, where effects of the pulse shape and duration are less important. In the transition regime, both effects must be taken into account simultaneously. We provide suitable expressions for the e^+e^- production probability for kinematic regions which can be used in transport codes [41].

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.

A microscopic theory of high-temperature superconductivity in cuprates was formulated within the extended Hubbard model in the limit of strong correlations ($U \gg t$). It was shown that the kinematic spin-fluctuation interaction played the major role in the d-wave superconducting pairing while the intersite Coulomb repulsion and electron-phonon interactions are small [42].

The peculiarities of symmetry breaking, symmetry transformations and the related physical effects in finite quantum systems were investigated. It was shown that for finite systems with a sufficiently large number of particles, crossover transitions became sharp, so that symmetry breaking happened similarly to that in macroscopic systems. These concerns, in particular, global gauge symmetry breaking, related to the Bose–Einstein condensation and superconductivity, or isotropy breaking, related to the generation of quantum vortices, and the stratification in multicomponent mixtures [43].

A detailed analysis of the problem of possible magnetic behavior of the carbon-based structures was fulfilled to elucidate and resolve some unclear and disputable issues, in particular, the peculiar and contradictory experimental results. It was concluded that the results of the previous studies, where the "ferromagnetism" was detected in pure graphene, were incorrect. Rather, graphene was strongly diamagnetic, similarly to graphite. It was shown that the traces of a quasi-magnetic behavior, which some authors observed in their samples, should be attributed to induced magnetism due to the impurities, defects, etc. This conclusion was confirmed in the most recent experiments by the Geim–Novoselov group [44].

The critical exponents of the model of polymer chains were derived for the case when the ends of chains were located in local areas separated by a large distance exceeding the persistence length [45].

A new solution of the Yang–Baxter equation, the most complicated among known ones, was constructed, which was determined by an integral operator with an elliptic hypergeometric kernel. This led to new solvable models of spin chains with continuous values of spins [46].

A three-parametric family of integrable totally asymmetric models of interacting particles with factorized steady state was proposed. The Bethe equations were obtained for the model on the periodic lattice, and the expression for the Green function of the Markov equation was conjectured for the model on the infinite lattice [47].

The phase behavior in a double-strand DNA was considered. It was shown that T_c is the point of the infinite order phase transition. The specific behavior of the order parameter, free energy, and correlation functions was addressed [48].

A survey is given of the theory and applications of a new class of special functions of mathematical physics — elliptic hypergeometric functions [49].

The book is devoted to the review of the original results of the author in the theory of integrable $s = 1/2$ quantum spin chains with the exchange constants proportional to the inverse square hyperbolic sine (infinite chains) and the Weierstrass elliptic function with a real period which equals the number of lattice sites (chains with periodic boundary conditions) [50].

Tunnel current was calculated in a contact made of both graphene monolayers and bilayers with two possible packings and orientations of the crystal lattice. For zigzag termination, it was found that the tunnel current exhibits characteristic peaks due to localized edge states, which leads to a pronounced ON/OFF effect under the influence of the gate voltage. The switching effect was found to be absent in the case of graphene contacts with armchair termination, and increasing bias voltage provokes only an increase in the conductivity [51].

The auxiliary lattice spin and itinerant dopon degrees of freedom of the spin-dopon formulation of the $t-J$ model were shown to be confined in the emergent $U(1)$ gauge theory generated by the electron no double occupancy constraint. This constraint is enforced by the requirement of an infinitely large spin-dopon coupling. As a result, the $t-J$ model is equivalent to a Kondo–Heisenberg lattice model of itinerant dopons and localized lattice spins at infinite Kondo coupling at all dopings. We show that a Fermi-liquid treatment of the large vs. small Fermi surface crossing in the cuprates, which heavily relies on the Luttinger count, leads to inconsistencies and it is automatically excluded form the $t-J$ model framework [52].

The presence of a charge density wave (CDW) along a stack of coupled Josephson junctions (JJs) in layered superconductors was demonstrated. The transformation of a longitudinal plasma wave to CDW and transitions between different types of CDWs were described. The effect of the external electromagnetic radiation on the states corresponding to CDW differs crucially from the case of the single JJ. Shapiro steps in JJ along the stack does not correspond directly to the frequency of external radiation but demonstrates different voltages reflecting the voltage distribution of rotating and oscillating Josephson junctions in the stack [53].

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

In 2013, the research and education project DIAS-TH was successfully continued. There were the following activities in the framework of DIAS-TH:

- XI Winter School on Theoretical Physics (January 28 – February 3);
- XVII Research Workshop "Nucleation Theory and Applications" (April 1–30);
- Helmholtz International Summer School–Workshop "Physics of Heavy Quarks and Hadrons" (July 15–28);
- Helmholtz International School "Cosmology, Strings and New Physics" (September 2–14);
- Regular seminars for students and postgraduates were organized;
- Computer processing of videorecords of lectures was continued;
- Web-site of DIAS-TH was supported.

Preliminary Plans for 2014

- XII Winter School on Theoretical Physics (February 2–8);
- XVIII Research Workshop "Nucleation Theory and Applications" (April 1–30);
- Helmholtz International Summer School "Nuclear Theory and Astrophysical Applications" (July 21 – August 1);
- Helmholtz International School "Lattice QCD, Hadron Structure and Hadronic Matter" (August 25 – September 6).

CONFERENCES AND MEETINGS

- XXI International Colloquium "Integrable Systems and Quantum Symmetries", June 12–16, Prague, Czech Republic;
- III International School "Symmetry in Integrable Systems and Nuclear Physics", July 7–13, Tsakhadzor, Armenia;
- Advanced Study Institute "Symmetries and Spin", July 7–13, Prague, Czech Republic;
- VII APCTP–BLTP/JINR Joint Workshop "Modern Problems in Nuclear and Elementary Particle Physics", July 14–19, Bolshye Koty, Irkutsk region;
- IN2P3–BLTP Workshop "Recent Achievements in Nuclear Theory", July 22–27, Dubna;
- International Workshop "Supersymmetries and Quantum Symmetries (SQS'2013)", July 29 – August 3, Dubna;
- KLFTP/CAS–BLTP/JINR Workshop "Nuclear Problems", August 26–30, Beijing;
- XV International Workshop "High-Energy Spin Physics (DSPIN2012)", October 8–12, Dubna;
- Armenia–Dubna Workshop "Problems of Integrable (Supersymmetric) Systems", December 25–26, Dubna.

COMPUTER FACILITIES

In 2013, two high-performance servers have been purchased for replacement of the aged servers theor.jinr.ru and thproxy.jinr.ru. To accelerate the data transfer between BLTP servers, the technology of 10 Gbit/s Ethernet has been introduced. Forty high-performance PCs were purchased. Several packages of licensed software have been acquired: network licenses for Intel Cluster Studio for Linux, additional network licenses for Wolfram Mathematica, large pools of software from Adobe, ABBYY, Design Science. The wireless WiFi network comprised of 20 access points covering the whole main BLTP building has been constructed.

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