BOGOLIUBOV LABORATORY OF THEORETICAL PHYSICS

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

FIELDS AND PARTICLES

Theoretical investigations in the *Theory of Fields and Particles* 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.

Last year, considerable progress was achieved in several directions. Below, one can find a short description of the selected results obtained at BLTP in 2006.

On the eve of launching of the LHC and within the preparation for SUSY search the parameter space of the Minimal Supersymmetric Standard Model was reanalysed with taking account of recent astrophysical data on the amount of dark matter. The interpretation of the flux of diffuse gamma rays was given as a signal of annihilation of dark matter in the halo of our galaxy. It was shown that this interpretation was consistent with supersymmetry and an estimate on the mass of the lightest supersymmetric particle of the order of 60 GeV was obtained. The region of parameter space which was consistent with this interpretation was found. In this region the cross sections of superpartner production were calculated. The most probable and low background processes were considered. The missing momentum distributions which were the main tools for the identification of supersymmetric particles were constructed [1].

In MS-like renormalization schemes, the Appequist–Carrazzone decoupling theorem does not in general apply to quantities that do no physical observables, such as coupling constants, i.e., quarks with large masses do not authomatically decouple. The contributions of heavy quarks to the strong coupling constant $\alpha_s^{n_f}(\mu)$ were studied: the four-loop corrections at the flavor thresholds were calculated in the modified minimal subtraction scheme. Taking into account the present knowledge of the coefficient β_4 of the Callan–Symanzik β-function of Quantum Chromodynamics, appropriate relationships between the asymptotic scale parameters Λ^{n_f} were derived for different numbers of flavors n_f [2].

The Collins fragmentation function was extracted from HERMES data on azimuthal single-spin asymmetries in semi-inclusive deeply inelastic scattering, and BELLE data on azimuthal asymmetries in electron–positron annihilations [3]. We found that the HERMES and BELLE data yielded a consistent picture of the Collins fragmentation function which was compatible with COMPASS data (Fig. 1) and with the information previously obtained from analysis of DELPHI data. Estimates for future experiments were made.

On the basis of a fit to the Sivers effect in deep inelastic scattering, we made predictions for single-spin asymmetries in the Drell–Yan process at RHIC [4].

The possibility of direct extraction of the transversity and its accompanying T-odd parton distribution function

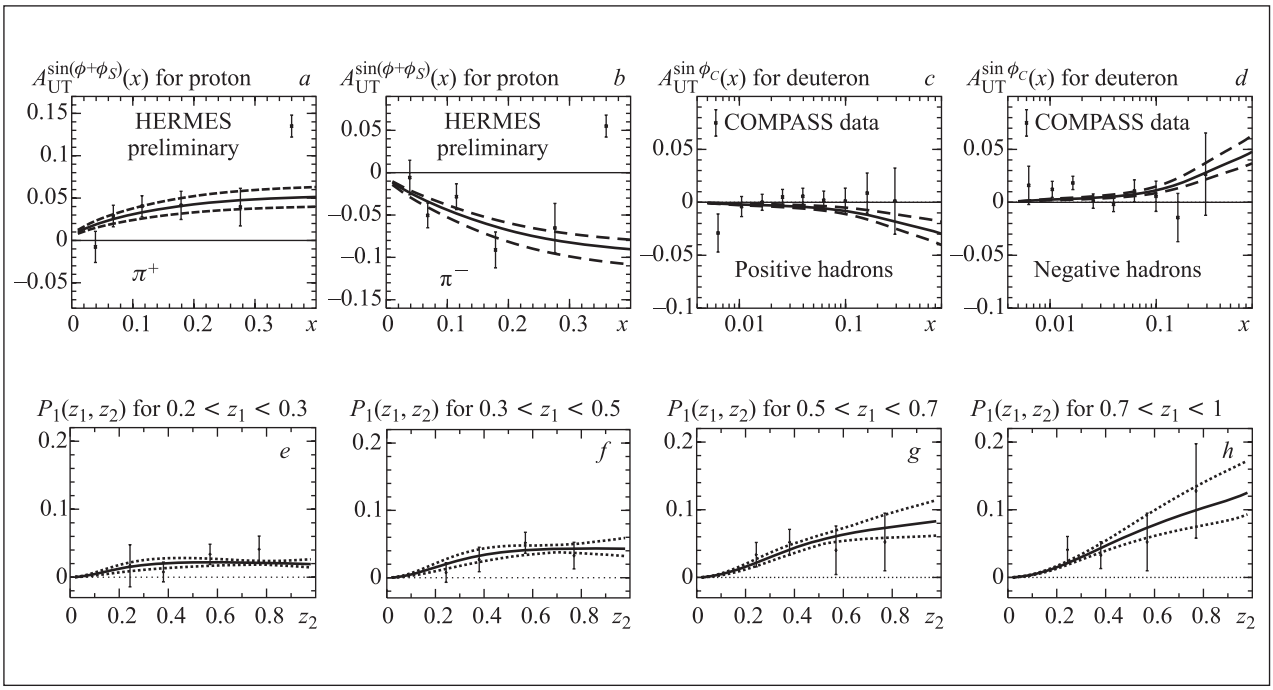

Fig. 1. *a–d*) the HERMES (*a*, *b*) and COMPASS (*c*, *d*) data on Collins asymmetry; *e–h*) the BELLE data on Collins effect

from Drell–Yan processes with unpolarized pion beam and with both unpolarized and transversely polarized proton targets was shown [5]. At present, such a measurement can be performed in the COMPASS experiment at CERN. The preliminary estimations performed for COMPASS kinematic region demonstrate that it is quite real to extract both transversity and its accompanying T-odd PDF in the COMPASS conditions.

The new method of polarized semi-inclusive deep inelastic scattering (SIDIS) data analysis in the next-to-leading order (NLO) QCD was proposed and developed [6]. Within the method, one, first, directly extracts in NLO a few first truncated (available to measurement) Mellin moments of the quark helicity distributions. Second, using these moments as an input to the proposed modification of the Jacobi polynomial expansion method (MJEM), one eventually reconstructs the local quark helicity distributions themselves. The analysis of HERMES data on pion production was performed. The LO results of the valence distribution reconstruction are in good accordance with the respective leading order SMC and HERMES results, while the NLO results are in agreement with the existing NLO parametrizations on these quantities.

Investigations of hard exclusive processes are essential for our understanding of the internal quark–gluon dynamics of hadrons. Theoretically, such studies are based on the assumption of factorization of dynamics at long and short distances. The short-distance physics is well elaborated by perturbative methods of QCD and depends on particular hard subprocesses. The long-distance dynamics is essentially nonperturbative and within the factorization formalism becomes parametrized in terms of hadronic *distribution amplitudes*. These nonperturbative quantities are universal and are defined as vacuum-to-hadron matrix elements of particular nonlocal light-cone quark or quark–gluon operators. In the present study, we found that the leading- and higher-twist distribution amplitudes of pion, ρ-meson, and real and virtual photons were analyzed in the instanton liquid model [7]. The first experiments measuring the photon DA in the photon dissociation to two pions via two-gluon (Pomeron) exchange were carried out at HERA.

New integral representations for the Adler D-function and the R-ratio of the electron–positron annihilation into hadrons were derived in the general framework of the Shirkov–Solovtsov analytic approach to QCD. These representations capture both the effects due to the interrelation between space-like and time-like domains and the effects due to the nonvanishing pion mass. The latter played a crucial role in this analysis, forcing the Adler D-function to vanish in the infrared limit. Within the developed approach the Adler D-function was calculated by employing its perturbative approximation as the only additional input. The obtained result was found to be in reasonable agreement with the experimental prediction for the Adler D-function in the entire energy range [8].

The constraints on the pion distribution amplitude (DA) available from perturbative QCD, nonperturbative QCD (nonlocal QCD sum rules and light cone sum rules) with the analysis of current data on $F_{\pi\gamma\gamma^*}(Q^2)$, including recent high-precision lattice calculations of the second moment of the pion's DA, were combined. Good agreement between our results and these lattice estimates was

established. The above constraints were supplemented with those extracted from the renormalon approach by means of the twist-four contributions to the pion distribution amplitude in order to further increase stability with respect to related theoretical uncertainties. It was shown which regions in the space of the first two nontrivial Gegenbauer coefficients a_2 and a_4 of all these constraints overlap, thus tagging the pion structure to the highest degree possible at present [9].

The investigations of the production of exotic hadrons in hard reaction, allowing one to apply the QCD factorization and reduce the uncertainties related to model inputs, were continued [10]. The production of exotic hybrid mesons in the collisions of real and virtual photons was analyzed [11].

Recent experiments on measurements of proton electromagnetic form factors $G_{E,M}(q^2)$ in the space-like region, which were carried out at JLab and SLAC, found the discrepancy in the results of two measurement methods. One method is based on measurement of unpolarized electron–proton method, and the other one uses the electron–proton scattering with polarization transfer. One of the possible solutions of this problem consists in taking into account the radiative corrections. The calculation of radiative corrections to initial and final particle bremsstrahlung, using the structure function approach and the two-photon contribution, was performed. As a result, it was estimated that the two-photon contribution was small, less than a per cent, in the whole kinematically reachable region. However, the initial electron bremsstrahlung contribution was large, of an order of ten per cent, and gave a significant contribution to the unpolarized scattering method of G_E/G_M measurement. In the polarized method this radiative corrections were also seen, but they canceled out in the ratio G_E/G_M and the remaining contribution was of an order of 0.1%. After applying these radiative corrections to known experimental data the results of these two measurement methods coincided within error-bars [12].

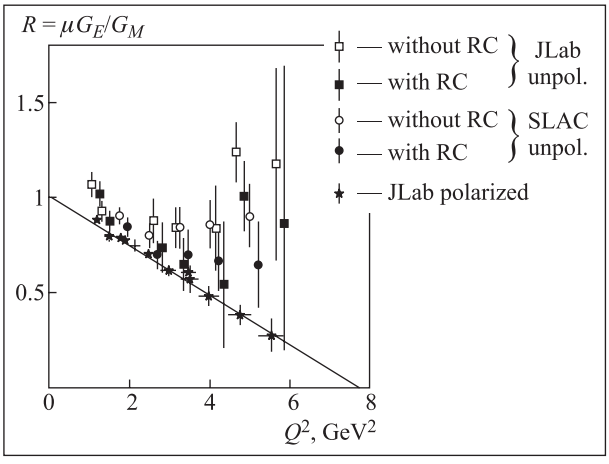

Fig. 2. Experimental data with radiative corrections (RC) applied

Taking into account recent results of CDF collaboration on decay $B_c \to J/\psi + \pi$ with $J/\psi \to \mu^+\mu^-$ (*Abulencia A. et al.* (*CDF Collab.*) // Phys. Rev. Lett. 2006. V. 96. P. 082002), the analysis of almost all accessible low-lying exclusive nonleptonic two-body and semileptonic three-body modes of the B_c-decays was performed in [13] within the relativistic constituent quark model. A set of numerical values for the leptonic, semileptonic and nonleptonic partial decay widths of B_c-meson was given. Explicit formulae for the angular decay distributions of the cascade decays $B_c^- \to J/\psi(\to l^+l^-) + \rho^-(\to \pi^-\pi^0)$ and $B_c^- \to J/\psi(\to l^+l^-) + W^-_{\text{off-shell}}(\to l^- + \bar{\nu}_l)$ were provided. For the nonleptonic decay $B_c^- \to J/\psi + \rho^-$ lepton mass and T-odd effects were included in our analysis. These angular decay distributions may be of help in analyzing the cascade decay data. Also, by analyzing the cascade angular decay distributions, one can learn more details about the spin dynamics of the decay process than from the rate analysis alone.

The world data on inclusive polarized DIS, in both NLO and LO QCD, including the new HERMES and COMPASS data on g_1 structure function were analyzed. The updated NLO polarized densities were given in both the $\overline{\text{MS}}$ and JET schemes and presented at HEPDATA web site http://durpdg.dur.ac.uk/hepdata. The size of higher twist corrections to the spin proton and neutron g_1 structure functions and their role in determining the polarized parton densities in the nucleon were discussed [14].

An effective nonlocal four-quark interaction of the Nambu–Jona-Lasinio type was derived in the framework of QCD. In doing so, the Bogoliubov compensation equations were used to determine the form factors of the four-quark vertices. The model has no ultraviolet divergences, and all its parameters are expressed via QCD parameters α_s and m_0 (current quark mass). The masses of decay widths of the pions and scalar meson were described [15].

The origin of the lightest scalar mesons was studied in the framework of the instanton liquid model of the QCD vacuum. The impact of vacuum excitations on the sigma-meson features was analyzed in detail. In particular, it was noticed that the changes produced in the scalar sector might unexpectedly become quite considerable in spite of insignificant values of corrections to the dynamical quark masses and then the medley of sigma-meson and those excitations might reveal themselves as broad resonance states of vitally different masses [16].

The high-precision spectroscopy of ro-vibrational transitions in molecules opens up interesting possibilities for the metrology of the fundamental constants (electron-to-nucleus mass ratios). In the framework of this program the leading relativistic and radiative corrections were obtained for the ro-vibrational states of H_2^+ and HD^+ with a *numerical uncertainty* below 1 kHz [17]. The hyperfine splitting of the states of H_2^+ and HD^+ was calculated with accuracy of an order of $m\alpha^6(m_e/M_N)$ [18]. The results of the research will be published as a chapter in «Precision Physics of Simple Atomic Systems» (Lecture Notes

in Physics. Springer, 2007). The data on the antiprotonic helium atom spectroscopy and determination of the $m_{\bar{p}}/m_e$ ratio will be included in the 2006 year adjustment of CODATA recommended values for fundamental constants.

In order to increase the efficiency of laser-stimulated recombination of antihydrogen in cold antiproton–positron plasma in a trap it was proposed to use a new resonance mechanism involving quasistationary states of the positron that arose due to the joint action of the Coulomb field of the antiproton and the strong magnetic field of the trap under conditions of the ATHENA and ALPHA antihydrogen atom formation experiments (CERN). The recombination rate was expressed via the cross section of the laser-induced ionization of the atom, possessing nonmonotonic frequency dependence due to the presence of the quasistationary states against the continuum background. The estimates based on the calculated ionization cross-section values demonstrated the possibility to increase the efficiency of the laser-induced recombination by an optimal choice of the laser frequency [19].

Electron–positron pair creation in the quasi-periodic electric field of a standing wave was investigated using a quantum kinetic equation with a non-Markovian source term. For field strengths and frequencies corresponding to modern optical lasers, with intensities of the order of 10^{20} W/cm^2, an electron–positron plasma was created with a maximum density of the order of 10^{20} cm^{-3}. As an observable signal of e^+e^- vacuum pair creation in experiments with counter-propagating optical laser beams 5–10 two-photon annihilation events per laser pulse were estimated, to be detected as coincident γ-quanta [20].

MODERN MATHEMATICAL PHYSICS

The topics of main focus in the theme were:

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

Below, we present some results obtained in 2006 on these subjects.

The «master» higher-spin (HS) particle system incorporating all the previously known models of this type as particular gauges was proposed. Quantization of the master system gives rise to a new form of the massless HS equations in an extended space involving, besides extra spinorial coordinates, also a complex scalar coordinate. These equations contain, among their solutions, the customary massless higher-spin multiplet with fields of all integer and half-integer helicities and new multiplets with a non-zero minimal helicity. A twistorial formulation of the master system was also constructed [21].

The three-string vertex coefficients in light-cone open string field theory was found to satisfy the Hirota equations for the dispersionless Toda lattice hierarchy. The Hirota equations allow one to calculate the correlators of an associated quantum system where the Neumann coefficients represent the two-point functions. The three-string vertex coefficients of the light-cone string field theory on a maximally supersymmetric pp-wave background were also considered. These Neumann coefficients were shown to satisfy the Hirota equations for the full Toda lattice hierarchy at least up to the second order in the «string mass» mu. Asymptotic expansions in the «string mass» for deformed Γ-functions and Neumann coefficients were constructed [22].

It was proved that the field equations of supergravity for purely time-dependent backgrounds, which reduced to those of a one-dimensional sigma model, admited a Lax pair representation and were fully integrable. In the case where the effective sigma model was on a maximally split non-compact coset U/H (maximal supergravity or subsectors of lower supersymmetry supergravities), a completely explicit analytic integration algorithm could also be constructed. At asymptotically early and asymptotically late times the Lax operator was always in the Cartan subalgebra of the algebra U and due to the isospectral property the two limits differed only by the action of some element of the Weyl group. Hence, the entire cosmic evolution could be seen as a billiard scattering with quantized angles defined by the Weyl group. The solution algorithm realized a map from H/W into W [23].

The origin of off-shell dualities between $d = 1$ supermultiplets with different sets of physical bosonic components and the same number of fermionic ones was revealed, using the manifestly supersymmetric superfield approach. These dualities were shown to arise as a result of gauging some symmetries in the actions of the supermultiplets with maximal sets of physical bosons. As a by-product, there was found a new nonlinear version of the $N = 4$ multiplet (4,4,0), such that its simplest superfield action produced the most general 4-dim hyper-Kähler metric with one triholomorphic isometry as the bosonic target metric [24].

Nonpolynomial Baxterized solutions of reflection equations, associated with affine Hecke and affine Birman–Murakami–Wenzl algebras, were found. These solutions were used for a new algebraic formulation of integrable spin chain models with nontrivial boundary conditions [25].

The method of separation of variables was adapted for spin Z_N-symmetric integrable models. The problem of constructing eigen-vectors for commuting inte-

grals of motion was reduced to a difference Baxter equation and in the simplest case of the generalized Ising model was solved completely. In the general case, the obtained Baxter equation was shown to be equivalent to the functional relations for quantum transfer matrix in the Baxter–Bazhanov–Stroganov model [26].

Explicit solutions of the Hermitian Yang–Mills equations on the noncommutative space $\mathbf{C}^n_\theta$ were constructed. In the commutative limit they coincided with the standard instantons on $\mathbf{C}P^n$ written in local coordinates [27].

Various versions of dimensional reduction of gravity theories to two-dimensional and one-dimensional dilaton gravity models were studied. An unusual dimensional reduction of an integrable $(1+1)$-dimensional dilaton gravity coupled to matter was found, which worked in the moduli space and reduced the general states to one-dimensional static states, cosmological models, and waves. An unusual feature of this reduction was that the wave solutions depended on two variables — space and time. It was shown that these waves could also be derived by a generalized separation of variables (applicable also to nonintegrable models and to higher dimensional theories). These results clearly demonstrated a nontrivial and close relation between static states, cosmologies, and waves.

Using the generalized separation of variables the one-dimensional states depending on both the space and time variables were also found in the spherically symmetric higher-dimensional gravity coupled to scalar matter fields. This procedure was more general than the usual reduction and apparently more general than the reductions that employed group theoretical methods. In this way, unusual generalizations of the spherical static states and cosmologies were constructed that were related by a simple duality transformation. Even more interesting new static states, cosmologies and waves possibly exist in cylindrical and axial theories. A generalization of the standard cylindrical four-dimensional gravity was proposed, which reduced to a $(1+1)$-dimensional dilaton gravity with nontrivial cosmological potentials produced by a four-dimensional Kaluza–Klein mechanism. Such potentials do not exist in the spherical theory but may be present in any axially symmetric theory even if it is almost spherical. This means that any axial, almost spherical universe, can be qualitatively different from the exactly spherical one. In particular, in the almost spherical universe, geometry may generate weak cosmological potentials that possibly could imitate dark energy effects [28].

Geometrical structure of the entanglement entropy associated with a spatial division of quantum many-body systems near a critical point (corresponding to a second order phase transition) was established. Such systems can be described in terms of quantum field theory. The subleading terms in the entropy in 2 and 3 space dimensions were found for the first time. The terms take into account the geometrical structure of the dividing surface as well as boundary effects.

The hypothesis was formulated and justified that in quantum gravity the surface density of the entanglement entropy of fundamental microscopic degrees of freedom equaled $1/(4G)$, where G was the gravity coupling in the low-energy gravity sector of the theory.

A «holographic formula» for entanglement entropy in conformal field theories admitting a dual description in terms of anti-de Sitter gravity theory was proven. The given formula, which was «guessed» in the works of other authors, was a concrete confirmation of the hypothesis about the relationship between the gravity and the entanglement of the fundamental microscopic degrees of freedom. The formula enabled one to reduce complicated calculations of the entanglement entropy to a pure classical geometrical problem of finding minimal surfaces in anti-de Sitter space [29].

The cosmological perturbation theory was developed in the framework of the Hamiltonian description of the General Relativity which was considered in a finite space-time volume. The role of the evolution parameter invariant under space-time transformations was played here by the cosmological scale factor which was extracted from the metric tensor by space averaging of its determinant. As a result, the Dirac reduction of the Hamiltonian works well and the potential perturbations of the Friedman metric turn out to be expressed in terms of the scale invariant Lichneroviz variables. In this approach, the corrections to the Schwarzschild metric were obtained, in particular, and a new approach was proposed to the solution of the problem concerning the large scale structure of the Universe [30].

NUCLEAR THEORY

In 2006, investigations within the area «Nuclear Theory» were carried out in accordance with the four projects:

- Theory of Nuclear Excitations;
- Dynamics and Manifestation of Structure in Nuclear and Mesoscopic Systems;
- Few-Body Physics;
- Relativistic Nuclear Dynamics.

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

In the framework of the relativistic mean field approach a pseudospin dependence of the residual forces in nuclei was studied. It was shown that this dependence is relatively weak. As a consequence, a pseudospin dependence of the particle-core coupling is weak as well. This leads to a small splitting of the pseudospin doublets pro-

duced by a vector coupling of an odd particle pseudospin and a pseudo-orbital momentum of the core. Some possibilities for experimental investigations of the pseudospin symmetry manifestations in the spectra of heavy odd nuclei with $Z \geqslant 100$ were indicated [31].

The properties of alternating parity bands in heavy nuclei ^{234}Th, $^{239-242}$U, $^{241-245}$Pu, $^{243-248}$Cm, $^{245-250}$Cf,$^{248-251}$Fm, $^{249-254}$No, $^{253-256}$Rf, and ^{258}Sg were analyzed within the dinuclear system model. The model is based on the assumption that the cluster type shapes are produced by a motion of a nuclear system in the mass-asymmetry coordinate. The energies of low-lying states, whose parity is opposite to the parity of the ground state, were predicted for the first time [32].

A way of a detailed investigation of weak ΛN interaction in the $^{10}_{\Lambda}$Be and $^{10}_{\Lambda}$B hypernuclei, which stand out owing to their $\alpha\alpha N\Lambda$ cluster structure, was proposed and discussed. The detection of a few groups of correlated $\alpha\alpha$ pairs would furnish information about decays to specific states of product nuclei (^{8}Be*, ^{8}Li, ^{8}B), thereby paving the way to a phenomenological analysis of the weak decays of p-shell hypernuclei. The ratios of the intensities of individual α-particle groups to be measured in experiments at the JINR nuclotron will provide a useful criterion for choosing an appropriate model of weak ΛN interaction [33].

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

Within the scission point model the bimodality in fission of actinides was demonstrated to be related to different neighboring charge and mass splittings. It was shown that for fixed charge and mass numbers of fragments the potential energy of the prescission configuration as a function of deformation parameters of the fragments has several minima. The scission at these minima leads to a relative enhancement of the yields of the fragments that have the corresponding values of the total kinetic energy and to the appearance of a fine structure in the mass-energy distribution. This phenomenon is peculiar not only to the fission of heavy nuclei like ^{256,258}Fm and ^{256,258,262}No, but also to that of lighter actinides like ^{236}U, ^{240}Pu and ^{252}Cf [34].

Energy- and angular-correlation distributions of the three fragments in ^{6}He breakup on ^{208}Pb at collision energy 240 MeV/nucleon were investigated within the microscopic four-body distorted wave model and compared with experimental data. The calculations described the experimental data for fragment correlations near the breakup threshold rather well and the physics is contained in a few elementary modes. However, with increasing excitation energy of ^{6}He, some striking deviations from experimental distributions are encountered [35].

In the field of *few-body physics* the following results were obtained:

The scattering lengths and phase shifts of ^{4}He–^{4}He$_2$ and ^{3}He–^{4}He$_2$ collisions were calculated. Moreover, under the assumption that weakening of the two-body potential mimics the behavior of the scattering length in a magnetic field, it was shown how the low-energy three-body scattering properties depend on the two-body scattering length. A magnetic field is an appropriate tool in modeling the Efimov effect, which occurs in the case of infinite two-body scattering lengths, manifesting itself in an infinite number of three-body bound states. It has already been shown that the excited state of the ^{4}He$_3$ trimer is of Efimov nature. To get the complete Efimov effect it suffices to weaken the He–He interatomic potential only by about 3%. Also, it was demonstrated how a new Efimov level appears from a virtual state [36].

It was shown that the atom–atom interaction or the scattering of an electron off a fixed impurity can be virtually switched off by the impact of geometrical confinement. By tuning the width $a_\perp$ of optical or magnetic trap one can turn off the ultracold atom–atom scattering in the confining trap. This happens if the fundamental atom–atom two-body interaction is rather strong and the two-body s- and p- scattering lengths $a_s \sim -a_p$ reach the order of the confinement width $a_\perp = 1.45a_s$. It could improve the sensitivity of guided atom interferometers, manipulate the properties of quasi-1D quantum gases or even help to decrease heat dissipation in tiny electronic devices [37].

The main results of the project *«Nuclear Structure and Dynamics at Relativistic Energies»* are:

A 3-fluid hydrodynamic model for simulating relativistic heavy-ion collisions was introduced. Alongside with two baryon-rich fluids, the new model considers the time-delayed evolution of the third, baryon-free (i.e., with the zero net baryonic charge) fluid of newly produced particles. With pure hadronic equation of state a great body of experimental data in the incident energy range of $E_{\rm lab} \simeq 1 - 160A$ GeV was reasonably reproduced [38].

The possibility to produce an intermediate Θ^+ via a $KN \to \Theta^+$ formation process in $\gamma D \to pK^-X$ ($X = nK^+, pK^0$) reactions at some specific kinematic conditions was considered. In particular, it was assumed that a pK^- pair was knocked out in the forward direction and its invariant mass was close to the mass of Λ^* ($\Lambda^* \equiv \Lambda(1520)$). The recent CLAS search for the Θ^+ in the $\gamma D \to pK^-nK^+$ reaction was analyzed and it was shown that the conditions of this experiment greatly reduce the Θ^+ formation process [39].

Invariant mass spectra of di-electrons stemming from bremsstrahlung processes were calculated in a covariant diagrammatical approach for the exclusive reaction $Dp \to p_{\rm sp}\, np\, e^+e^-$ with detection of a forward spectator proton, $p_{\rm sp}$. The effective nucleon–meson interactions were adjusted to the process $pp \to pp\, e^+e^-$ at energies below the vector meson production threshold. Subthreshold di-electron production in Dp collisions at low spectator momenta was investigated. Calculations were performed for kinematic conditions envisaged for forthcoming experiments at HADES [40].

Moreover, a new result was obtained in theoretical investigations of *atomic clusters*.

A simple scheme of population and detection of low-lying electronic quadrupole modes in free small deformed metal clusters was proposed. The scheme was analyzed in terms of the time-dependent local density approximation calculations. Long-lived quadrupole oscillations can be generated via resonant two-photon (two-dipole) excitation and then detected through the appearance of satellites in photoelectron spectra generated by a probe pulse. The energies of these modes being combined with the photoelectron data for hole states allow one to gather full mean-field spectra of valence electrons near the Fermi energy. Besides, the scheme allows one to estimate the lifetime of electron-hole pairs and hence the relaxation time of electronic energy into ionic heat [41].

THEORY OF CONDENSED MATTER

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

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

A number of important new results were obtained in the field of *physical properties of complex materials and nanostructures* among which are the following:

For the first time, a microscopic theory of electronic spectrum in the cuprate high-temperature superconductor, which had no fitting parameters for an electron-boson interaction, was developed within the Hubbard model. The Dyson equation is derived in the noncrossing approximation for the self-energy. Doping and temperature dependence calculated for electron dispersions, spectral functions and the Fermi surface agree with recent photoemission experiments [42].

The low-energy electronic structure of icosahedral fullerenes was studied within the field-theory model. The exact analytical solution of the problem (both for the eigenfunctions and the energy spectrum) was found [43].

The electronic states near the Fermi energy in spheroidal fullerenes were studied. The appearance of a fine structure in the electronic energy spectrum was found due to spheroidal deformation. In particular, two quasi-zero modes in addition to the true zero mode were predicted to emerge in spheroidal fullerenes [44].

A cluster model for the dissolution of C60 fullerenes in a nonpolar solvent was proposed. The model provides the explanation of a maximum experimentally observed in the time dependence of solution concentration during dissolution. The model is based on the kinetic equations of nucleation theory and involves a balance between the flux of fullerene molecules from the solid phase and the sedimentation of large clusters from the solution. The formation of clusters was described using the drop model. Analysis of the numerical calculations of the equations revealed four qualitatively different dissolution regimes depending on the relation between the model parameters [45].

In the investigations of *mathematical problems of many-particle systems* the following main results were obtained:

The totally asymmetric exclusion process was considered in discrete time with the parallel update. Constructing an appropriate transformation of the evolution operator, the problem was reduced to that solvable by the Bethe ansatz. The nonstationary solution of the master equation for the infinite 1D lattice was obtained in a determinant form. Using a modified combinatorial treatment of the Bethe ansatz, an alternative derivation of the resulting determinant expression was obtained [46].

An elliptic analogue of the Gauss hypergeometric function was built and its relation to the elliptic Calogero–Sutherland type models was revealed. Sequences of spectral transformations for the Frobenius–Stickelberger–Thiele polynomials was defined, leading to a new $(1+1)$-dimensional integrable discrete time chain. Two classes of Stiltjes functions were investigated in detail with explicit elliptic or hypergeometric dependence on time leading to equations of motion of the Toda chain [47].

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

In 2006, the research-educational project DIAS-TH was successfully continued. The following activities in the framework of DIAS-TH were: 4th Winter School on Theoretical Physics (January 29 – February 7); X Research Workshop «Nucleation Theory and Applications» (April 1–30); Helmholtz International School on Calculations for Modern and Future Colliders (July 15–25); International School on Few-Body Problems in Physics (August 7–17); Helmholtz International School «Dense Matter in Heavy-Ion Collisions and Astrophysics» (August 21 – September 1); Advanced Summer School on Modern Mathematical Physics (September 3–12); the regular seminars for students and postgraduates were organized; computer processing of video records of lectures was continued; Web-site of DIAS-TH was supported.

COMPUTER FACILITIES

For the purpose of supporting resource-demanding calculations the server based on two dual-core Xeon 5160 processors was purchased. These processors belong to the newest Intel Core microarchitecture. The server is equipped with 16 GB of high-speed memory DDR2-667 MHz and two SATA disks with capacity of 300 GB each.

The pool of personal computers at BLTP was upgraded by installing 20 new machines. The new multimedia projector from Toshiba will make it possible to improve the quality of presentations at seminars and conferences.

MEETINGS, SCIENTIFIC COLLABORATION

In 2006, besides the Schools organized in the framework of DIAS-TH, the Laboratory participated in the organization of 7 International Conferences and Workshops held in Dubna, Moscow, Prague, Protvino, and Yerevan: International Workshop «Classical and Quantum Integrable Systems» (January 23–26, Protvino, Russia); «Nuclear Structure and Related Topics» (June 13–17, Dubna); XV International Colloquium «Integrable Systems and Quantum Groups» (June 15–7); XII International Conference «Symmetry Methods in Physics» (July 3–8, Yerevan, Armenia); Rochester Conference — XXXIII International Conference on High Energy Physics (July 26 – August 2, Moscow); XVIII International Baldin Seminar «Relativistic Nuclear Physics and Quantum Chromodynamics» (September 25–30, Dubna) — jointly with Veksler and Baldin Laboratory of High Energies; Round Table Discussion II «Serching for the Mixed Phase of Strongly Interacting Matter at the JINR Nuclotron: Nuclotron Facility Development» (October 6–7, Dubna).

In 2006, the international collaboration was supported by grants of the plenipotentiaries of Bulgaria, the Czech Republic, Poland, the Slovak Republic, Hungary, Romania and the JINR Directorate; the collaboration with German theorists was based on the Heisenberg–Landau Programme; with Polish theorists, on the Bogoliubov–Infeld Programme; with Czech theorists, on the Blokhintsev–Votruba Programme; and Roumanian theorists on the Ţiţeica–Markov Programme.

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

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

REFERENCES

1. *de Boer W. et al.* // Phys. Lett. B. 2006. V. 636. P. 13;
   Bogachev D. Yu. et al. // Intern. J. Mod. Phys. A. 2006. V. 21. P. 5221;
   Bednyakov V. A. et al. hep-ex/0608060.
2. *Kniehl B. A. et al.* // Phys. Rev. Lett. 2006. V. 97. P. 042001.
3. *Efremov A. V., Goeke K., Schweitzer P.* // Phys. Rev. D. 2006. V. 73. P. 094025; hep-ph/060305.
4. *Collins J. C. et al.* // Phys. Rev. D. 2006. V. 73. P. 094023; hep-ph/0511272.
5. *Sissakian A. et al.* // Eur. Phys. J. C. 2006. V. 46. P. 147.
6. *Sissakian A., Shevchenko O., Ivanov O.* // Phys. Rev. D. 2006. V. 73. P. 094026.
7. *Dorokhov A. E., Broniowski W., Ruiz Arriola E.* // Phys. Rev. D. 2006. V. 74. P. 054023;
   Dorokhov A. E. hep-ph/0610212; Based on the talks given at XVIII Conf. Few Body Problems in Physics, Santos, Brazil, Aug. 21–26, 2006 and ISMD-2006, Paraty, Rio de Janeiro, Brazil, Sept. 2–8, 2006.
8. *Nesterenko A. V., Papavassiliou J.* // J. Phys. G. 2006. V. 32. P. 1025–1034.
9. *Bakulev A. P., Mikhailov S. V., Stefanis N. G.* // Phys. Rev. D. 2006. V. 73. P. 056002.
10. *Anikin I. V. et al.* hep-ph/0610177; Proc. of the 33rd Intern. Conf. on High Energy Physics (ICHEP 06) (submitted).
11. *Anikin I. V. et al.* // Eur. Phys. J. C. 2006. V. 47. P. 71; hep-ph/0601176.
12. *Kuraev E. A., Bystritskiy Yu. M., Tomasi-Gustafsson E.* hep-ph/0603132; Phys. Rev. C (submitted).
13. *Ivanov M. A., Körner J. G., Santorelli P.* // Phys. Rev. D. 2006. V. 73. P. 054024.
14. *Leader E., Sidorov A. V., Stamenov D. B.* // Ibid. P. 034023.
15. *Arbuzov B. A., Volkov M. K., Zaitsev I. V.* // Intern. J. Mod. Phys. A. 2006. V. 21. P. 5721.
16. *Molodtsov S. V. et al.* hep-ph/0611203.
17. *Korobov V. I.* // Phys. Rev. A. 2006. V. 74. P. 052506.
18. *Korobov V. I., Hilico L., Karr J.-Ph.* // Ibid. P. 040502(R); *Bakalov D., Korobov V. I., Schiller S.* // Phys. Rev. Lett. 2006. V. 97.
19. *Serov V. V., Derbov V. L., Vinitsky S. I.* // Optika i Spektroskopiya. 2007. V. 102 (submitted) (in Russian);
   Chuluunbaatar O. et al. // Proc. SPIE. 2007. V. 6537 (submitted).
20. *Blaschke D. B. et al.* // Phys. Rev. Lett. 2006. V. 94. P. 140402.
21. *Fedoruk S., Ivanov E.* // Class. Quant. Grav. 2006. V. 23. P. 5195–5214; hep-th/0604111.
22. *Bonora L. et al.* // Class. Quant. Grav. 2006. V. 23. P. 799; *Kadyshevsky V. G., Sorin A. S.* // Theor. Math. Phys. 2006. V. 149(3). P. 1627.
23. *Fre P., Sorin A. S.* // Nucl. Phys. B. 2006. V. 733. P. 334.

24. *Delduc F., Ivanov E.* // Ibid. V. 753. P. 211–241; hep-th/0605211.
25. *Isaev A. P., Ogievetsky O. V.* // Nucl. Phys. B. 2007. V. 760. [PM]. P. 167–183.
26. *von Gehlen G. et al.* // J. Phys. A: Math. Gen. 2006. V. 39. P. 7257–7282; nlin.SI/0603028.
27. *Ivanova T. A., Lechtenfeld O.* // Phys. Lett. B. 2006. V. 639. P. 407.
28. *Filippov A. T.* // Teor. Mat. Fiz. 2006. V. 146. P. 115; hep-th/0605276.
29. *Fursaev D. V.* // Phys. Rev. D. 2006. V. 73. P. 124025; hep-th/0602134; JHEP. 2006. 0609. 018; hep-th/0606184.
30. *Barbashov B. M. et al.* // Phys. Lett. B. 2006. V. 633. P. 458–462; Intern. J. Mod. Phys. A. 2006. V. 21. P. 5957.
31. *Jolos R. V., Voronov V. V.* nucl-th/0610079.
32. *Shneidman T. M. et al.* // Phys. Rev. C. 2006. V. 74. P. 034316.
33. *Majling L., Kuz'min V.A., Tetereva T.V.* // Phys. At. Nucl. 2006. V. 69. P. 810.
34. *Andreev A. V. et al.* // Ibid. P. 197.
35. *Ershov S. N., Danilin B. V., Vaagen J. S.* // Phys. Rev. C. 2006. V. 74. P. 014603.
36. *Kolganova E. A., Motovilov A. K., Sandhas W.* // Few-Body Syst. 2006. V. 38. P. 205.
37. *Kim J. I., Melezhik V. S., Schmelcher P.* // Phys. Rev. Lett. 2006. V. 97. P. 193203.
38. *Ivanov Yu. B., Russkikh V. N., Toneev V. D.* // Phys. Rev. C. 2006. V. 73. P. 044904.
39. *Titov A. I. et al.* // Phys. Rev. C. 2006. V. 74. P. 055206.
40. *Kaptari L. P., Kämpfer B.* // Nucl. Phys. A. 2006. V. 764. P. 338.
41. *Nesterenko V. O. et al.* // Phys. Rev. A. 2006. V. 73. P. 021201.
42. *Plakida N. M., Oudovenko V. S.* JINR Preprint E17-2006-96. Dubna, 2006; JETP. 2007. V. 131, No. 1.
43. *Kolesnikov D. V., Osipov V. A.* // Eur. Phys. J. B. 2006. V. 49. P. 465.
44. *Pudlak M., Pincak R., Osipov V. A.* // Phys. Rev. B. 2006. V. 74.
45. *Tropin T. V. et al.* // JETP Lett. 2006. V. 83. P. 467.
46. *Povolotsky A. M., Priezzhev V. B.* // J. Stat. Mech. 2006. P. 07002.
47. *Spiridonov V. P., Warnaar S. O.* // Adv. in Math. 2006. P. 207. P. 91–132.