

# Few-Body Systems Group (Sector 11) at BLTP, JINR

## 1999 Annual Activity Report

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## I. MAIN RESULTS

The scattering length for the  $\eta$ -meson collision with deuteron is calculated on the basis of rigorous few-body equations (AGS) for various  $\eta - N$  input. The results obtained strongly support the existence of a resonance or quasibound state close to the  $\eta d$  threshold [N. V. Shevchenko, V. B. Belyaev, S. A. Rakityansky, S. A. Sofianos, and W. Sandhas, LANL e-print nucl-th/9908035].

It has been shown that the recent measurements for electromagnetic production of pions can be explained in a dynamical and unitary isobar models, together with a simple scaling assumption for the bare  $\gamma^* N \Delta$  form factors [S.S. Kamalov and S.N. Yang, nucl-th/9904072; D. Drechsel, O. Hanstein, S.S. Kamalov, and L. Tiator, Nucl. Phys. A **645** (1999) 145]. Within these models, it was found that the bare  $\Delta$  is almost spherical and the electric E2 and Coulomb C2 quadrupole excitations of the physical  $\Delta$  are nearly saturated by pion cloud contribution in  $Q^2 \leq 4.0 \text{ GeV}^2$ . Our results well agree with the experimental data, but deviate strongly from the predictions of perturbative QCD (pQCD). This remains an intriguing question, both theoretically and experimentally, to find the region of  $Q^2$  which will signal the onset of pQCD.

All terms of the system of coupled hyperradial equations are obtained analytically in the asymptotic domain of large hyperradius  $\rho$  for three-body system with the short-range interactions [O. I. Kartavtsev, Few-Body Systems Suppl. **10** (1999) 199]. The solution of this system reveals universal description for the low-energy scattering cross sections.

Spectrum of the three-electron quantum dot has been calculated in the framework of the Faddeev approach for the lowest doublet ( $S = 1/2$ ) and quartet ( $S = 3/2$ ) states for a range of angular momenta [M. Braun, O.I. Kartavtsev, Contributed paper to 16th Intern. Conf. on Few-body Problems in Physics, 6–10.03.2000, Taipei, Taiwan].

The recently suggested hyperradial-adiabatic approach to the solution of a rotational three-body problem has been formulated in details [A.V. Matveenko, Report at the APAC'99 Conference, 19–24.09.1999, Mainz, Germany]. Rotational degrees of freedom can be done analytically so that rotational states can be treated no more complicated as non-rotational ones. The computer code, allowing to calculate symmetry-adapted adiabatic potentials for physical problems, has been developed and checked.

In the framework of adiabatic and Born-approximation approaches the reaction of nonradiative production of deuteron was considered under primordial nucleosynthesis condition [D.E. Monakhov, L.M. Lekala, S.A. Sofianos, S.A. Rakityansky, and V.B. Belyaev, Contributed paper to 16th Intern. Conf. on Few-Body problems in Physics, Taipei, Taiwan, 6–10.03.2000]. The rate of this reaction was compared with its corresponding binary radiative capture reaction of neutron and proton. The contributions of three particle reactions are obtained to be much less than binary one.

The  ${}^4\text{He}_3$  bound states and the scattering of a  ${}^4\text{He}$  atom off a  ${}^4\text{He}$  dimer at ultra-low energies have been investigated using the Faddeev differential equations. Various realistic  ${}^4\text{He}$ – ${}^4\text{He}$  interactions were employed, among them the recent TTY potential by Tang, Toennies and Yiu [A. K. Motovilov, W. Sandhas, S. A. Sofianos, and E. A. Kolganova, LANL e-print physics/9910016].

Some general properties of the spectral shift function  $\xi(\lambda, H_0, H_0 + V(s))$  corresponding to selfadjoint Hamiltonian  $H_0$  and selfadjoint potential  $V(s)$ ,  $s \in (s_1, s_2) \subset$

$\mathbb{R}$ , have been studied under the assumption that both functions  $V(s)$  and  $V'(s)$  are continuously differentiable with respect to the trace-norm topology and  $V''(s) \geq 0$  [F. Gesztesy, K.A. Makarov, and A.K. Motovilov, LANL e-print math.SP/9909076]. The main result of this investigation is that for given  $\mu \in \mathbb{R}$  the mapping  $s \mapsto \text{Tr}(V'(s)E_{H(s)}((-\infty, \mu)))$  is a nonincreasing function with respect to  $s$ . Here,  $\{E_{H(s)}(\lambda)\}_{\lambda \in \mathbb{R}}$  denotes the family of spectral projections of  $H(s) = H_0 + V(s)$ . Moreover, the integrated spectral shift function  $\zeta(\mu, s) = \int_{-\infty}^{\mu} d\lambda \xi(\lambda, H_0, H(s))$  for the pair  $(H_0, H(s))$  is concave with respect to  $s$ . Notice that the spectral shift function  $\xi(\lambda, H_0, H_0 + V)$  is a generalization of the scattering phase shift.

It was shown that the life times of actual physical systems “two atoms + electron” ( $\geq 10^6$  s) allow to consider these systems as bound ones for any processes in gases. On the basis of results of a previous research a new class of diatomic negative molecular ions having the states with anomalously large characteristic sizes predicted [F.M. Pen'kov, Phys. Rev. **A60**, 3756 (1999); JETP **88**, 1079 (1999)].

Functional dependence of the Raynal-Revai coefficients on the kinematical angle is studied by the methods of the angular momentum theory. For those functions various identities and the sets of differential and linear equations are derived [V.V. Pupyshchev, Phys. Atom. Nucl. **62**, 1955 (1999)]. The obtained relations are used to build economic algorithms for calculation the Raynal-Revai coefficients in general case and in the limits of zero and large mass of one of the particles.

Peculiarities of the multichannel periodic structures, multichannel resonance tunneling and the degeneracy of bound states have been described. The effect of the concentration of quantum waves in a chosen partial channel with their spatial localization in the place under control has been shown. Exact solutions for classical few-body systems derived from the multichannel quantum inverse problem have been found. [B.N. Zakhariev and V.M. Chabanov, Part. & Nucl. **30**, 277, (1999); Phys. Lett. **A255**, 123, (1999)]

## II. LIST OF PUBLICATIONS

### A. JOURNAL PUBLICATIONS

1. Belyaev V.B., D.E. Monakhov, D.V. Naumov, and F.M. Pen'kov, "The fate of  ${}^7\text{Be}$  in the Sun. Triple collisions", *Few-Body Systems Suppl.* **10**, 215-218 (1999).
2. V.B. Belyaev, D.E. Monakhov, S.A. Sofianos, and W. Sandhas, "Existence and transition properties of the three-deuteron muonic molecule  $3d2e^- \mu^-$ ", *Hyperfine Interactions* **118**, 243–246 (1999).
3. V.M. Bystritsky, M. Filipowicz, and F.M. Pen'kov, "Medium density variation as a method for investigating properties of mesomolecular resonances", *Hyperfine Interactions* **119**, 369–371 (1999).
4. V.M. Bystritsky, M. Filipowicz, and F.M. Pen'kov, "Method of investigation of nuclear reactions in charge-nonsymmetrical muonic complexes", *Nuclear Instruments & Methods in Physics Research* **A432**, 188–194 (1999).
5. V.M. Bystritsky and F.M. Pen'kov, "Method for experimental determining the features of nuclear fusion from  $\mu$ -molecular resonance states" *Phys. Atom. Nucl.* **62**, 281–290 (1999).
6. V.M. Chabanov and B.N. Zakhariev, "Coexistence of confinement and propagating waves: a quantum paradox", *Phys. Lett.* **A255**, 123-128, (1999).
7. D. Drechsel, O. Hanstein, S.S. Kamalov, and L. Tiator, "A Unitary isobar model for pion photo- and electroproduction on the proton up to 1 GeV", *Nucl. Phys.* **A 645**, 145–174 (1999).
8. D. Drechsel, S.S. Kamalov, G. Krein, and L. Tiator, "The generalized GDH integrals and the spin structure of the nucleon", *Phys. Rev.* **D 59**, 094021 (1999).
9. S.S. Kamalov, D. Drechsel, O. Hanstein, and L. Tiator, "Pion Photo- and Electroproduction on the Proton", *Few-Body Systems Suppl.* **11**, 169–172 (1999).
10. O.I. Kartavtsev, "Universal description of the  $\text{He}_3$  system at low energy", *Few-Body Systems Suppl.* **10**, 199–202 (1999).
11. O.I. Kartavtsev, V.I. Kochkin, and E.A. Kolganova, "Resonances and near-threshold scattering in  $\text{HeH}\mu$  systems" *Hyperfine Interactions* **118**, 235 (1999).
12. O.I. Kartavtsev, D.E. Monakhov, and S.I. Fedotov, "Auger decay rates of antiprotonic helium", *Hyperfine Interactions* **119**, 207 (1999).
13. E.A. Kolganova and A.K. Motovilov, "Mechanism of the emergence of Efimov states in the  ${}^4\text{He}$  trimer", *Phys. Atom. Nucl.* **62** No. 7, 1179–1192 (1999).
14. F.X. Lee, C. Bennhold, S.S. Kamalov, and L.E. Wright, "Higher Nucleon Resonances in Exclusive ( $\gamma, \pi$ ) Reactions", *Phys. Rev.* **C 60**, 034605 (1999).
15. A.V. Matveenko, "The character of the Atomcule", *Hyperfine Interactions* **119**, 241–243 (1999).

16. A.V. Matveenko, “Three-body angular basis and simple expression for Wigner  $d(\beta)$  matrices”, *Phys. Rev. A* **59**, 1034–1037 (1999).
17. R. Mennicken and A.K. Motovilov, “Operator interpretation of resonances arising in spectral problems for  $2 \times 2$  matrix Hamiltonians”, *Operator Theory: Advances and Applications* **108**, 316–322 (1999).
18. R. Mennicken and A.K. Motovilov, “Operator interpretation of resonances arising in spectral problems for  $2 \times 2$  operator matrices”, *Math. Nachr.* **201**, 117–181 (1999).
19. A.K. Motovilov and E.A. Kolganova, “Structure of T– and S– matrices in unphysical sheets and resonances in three– body systems”, *Few–Body Systems Suppl.* **10**, 75–84 (1999).
20. E. Oset, J.A. Gomes-Tejedor, F. Cano, J.C. Nacher, S. Kamalov, L. Alvarez-Ruso, and E. Hernandez, “Double Pion Production Reactions”, *Few Body Suppl.* **11**, 275–283 (1999).
21. F.M. Pen’kov, “Lifetime of Efimov states of negative two-atom ions” *Phys. Rev.* **A60**, 3756–3763 (1999).
22. F.M. Pen’kov, “Subthreshold resonances in three-particle molecular systems”, *JETP* **88**, 1079–1086 (1999).
23. V.V. Pupyshev, “Raynal-Revai coefficients as functions of kinematical angle”, *Phys. Atom. Nucl.* **62**, 1955–1965 (1999).
24. V.V. Pupyshev, “Some methods and results of analytical investigation of the problem of three nuclear particles” *Part. & Nucl.* **30**, 1562–1649 (1999).
25. N.V. Shevchenko, S.A. Rakityansky, S.A. Sofianos, and V.B. Belyaev, “Non-radiative synthesis of  ${}^7\text{Be}$  in solar plasma”, *Journal of Physics* **G25**, 95–106 (1999).
26. B.N. Zakhariev and V.M. Chabanov, “The qualitative theory of elementary transformations of one- and multichannel quantum systems in the inverse scattering problem approach. The construction of transformations with given spectral parameters”, *Part. & Nucl.* **30**, 277-320, (1999).
27. B.N. Zakhariev and V.M. Chabanov, “The elements of quantum design”, *Vest. Sec. Fiz. RAEN* **5**, 58-77, (1999) (Russian).

## B. ARTICLES ACCEPTED FOR PUBLICATIONS

1. D. Drechsel, L. Tiator, S.S. Kamalov, and S.N. Yang, “Medium effects in coherent pion photo- and electroproduction on  ${}^4\text{He}$  and  ${}^{12}\text{C}$ ”, *Nucl. Phys. A* (LANL e-print nucl-th/9906019)
2. D. Drechsel, S.S. Kamalov, G. Krein, B. Pasquini, and L. Tiator, “The generalized polarizabilities and electroexcitation of the nucleon”, *Nucl. Phys. A* (LANL e-print nucl-th/9907056)

3. S.S. Kamalov and S.N. Yang, “Pion cloud and the  $Q^2$  dependence of  $\gamma^* \rightarrow \Delta$  transition form factors”, Phys. Rev. Lett. (LANL e-print nucl-th/9904072)  
O.I. Kartavtsev, D.E. Monakhov, and S.I. Fedotov, “Auger decay rates of antiprotonic helium”, Phys. Rev. A
4. E.A. Kolganova, A.K. Motovilov, “Scattering and resonances in the  $^4\text{He}$  three-atomic system”, Comp. Phys. Commun.
5. A.V. Matveenkov and E. Alt, “Semianalytic wave-function for highly rotational states of antiprotonic He”, Hyperfine Interactions.
6. F. Rambo, S.S. Kamalov, *et al.*, “Coherent  $\pi^0$  photoproduction from  $^4\text{He}$ ”, Nucl. Phys. A (LANL e-print nucl-th/9907020.)

### C. PREPRINTS AND DATA BASES

1. V.M. Bystritsky, ..., F.M. Pen'kov *et al.*, “The astrophysical S-factor for the  $dd$ -reaction at ultralow energy” *Preprint JINR, D15-99-163, Dubna 1999*
2. F. Gesztesy, K.A. Makarov, and A.K. Motovilov, Monotonicity and concavity properties of the spectral shift function, *LANL e-print math.SP/9909076*
3. A.K. Motovilov, W. Sandhas, and V.B. Belyaev, “Enhancement of the fusion probability in molecular structures due to nuclear threshold resonances”, *LANL e-print cond-mat/9909414*
4. A.K. Motovilov, W. Sandhas, S.A. Sofianos, and E.A. Kolganova, “Binding energies and scattering observables in the  $^4\text{He}_3$  atomic system”, *LANL e-print physics/9910016*
5. F.M. Pen'kov, “Underthreshold long-range resonances in three-particle systems”, *LANL e-print physics/9903048*.
6. N.V. Shevchenko, V.B. Belyaev, S.A. Rakityansky, S.A. Sofianos, and W. Sandhas, “Low-energy  $\eta d$  resonance”, *LANL e-print nucl-th/9908035*.
7. L. Tiator, D. Drechsel, and S.S. Kamalov, “Pion electroproduction on the nucleon and the GDH sum rules”, *LANL e-print nucl-th/9909068*.

### D. CONFERENCE CONTRIBUTIONS

1. F. Gesztesy, K.A. Makarov, and A.K. Motovilov, “Monotonicity and concavity properties of the spectral shift function”, Contribution to Proceedings of the International Conference on Infinite Dimensional (Stochastic) Analysis and Quantum Physics, January 18–22, 1999, Leipzig (Germany).
2. S.S. Kamalov and S.N. Yang, “ $Q^2$  dependence of the  $\gamma N \Delta$  form factors”, Invited talk in PANIC99, Uppsala (Sweden), June 10–16, 1999 (to be published in Nucl. Phys. A).

3. M.Kh. Khankhasaev, "R&D needs of chemical separation technologies for nuclear wastes from the perspective of federal governmental programs of Russia", In: *Chemical Separation Technologies and Related Methods of Nuclear Waste Management Applications, Problems and Research Needs, Proc. of Intern. Workshop, Dubna, Russia, May 18–28, 1998*, Eds. G. Choppin and M. Khankhasaev, Kluwer Acad. Publishers, 1999, pp. 169–186.
4. A.V. Matveenko, "Symmetry-invariant adiabatic approach to the three-body collisions", Contribution to Proc. of the 21 st Int. Conf. on the Physics of Electronic and Atomic Collisions, Sendai, Japan, July 22–27, 1999.
5. A.V. Matveenko and E. Alt, "Semianalytic wave-function for highly rotational states of antiprotonic He", Contribution to Proc. of the 1 st Euroconference on Atomic Physics at Accelerators, Laser Spectroscopy and Applications, APAC 99, September 19–24, 1999, Mainz, Germany.
6. D.E. Monakhov, L.M. Lekala, S.A. Sofianos, S.A. Rakityansky, and V.B. Belyaev, "*Primordial formation of deuterons via triple collisions*", Contributed paper to 16 th Intern. Conf. on Few-Body problems in Physics, Taipei, Taiwan, 6.03–10.03.2000.
7. A.K. Motovilov, W. Sandhas, S.A. Sofianos, and E.A. Kolganova, "Binding energies and scattering observables in the  $^4\text{He}_3$  atomic system", Contributed paper to 16 th Intern. Conf. on Few-Body problems in Physics, Taipei, Taiwan, 6.03–10.03.2000.

### III. VISITS

#### A. CONFERENCES, SCHOOLS

1. V.B. Belyaev, ICT\* International Workshop “Nuclear Reactions in Stars and in the Laboratory”, Trento, Italy, 8.02–19.02.1999
2. V.M. Chabanov, International Conference on Supersymmetry, Dubna, Russia, 26.07–31.07.1999
3. A.V. Matveenکو, The 1st Euroconference on Atomic Physics at Accelerators Laser Spectroscopy and Applications (APAC 99), Mainz, Germany, 19.09–24.09.1999
4. A.K. Motovilov, ICT\* International Workshop “Nuclear Reactions in Stars and in the Laboratory”, Trento, Italy, 8.02–19.02.1999
5. A.K. Motovilov, 1999 UAB-GIT International Conference on Differential Equations and Mathematical Physics, Birmingham, Alabama, USA, 16.03–20.03.1999
6. B.N. Zakhariev, International Conference on Supersymmetry, Dubna, Russia, 26.07–31.07.1999
7. B.N. Zakhariev, Inter-University Conference, Izhevsk, Russia, 21.04–24.04.1999

#### B. COLLABORATION VISITS

1. V.B. Belyaev, Department of Physics, UNISA, Pretoria, South Africa, 1.04–30.04.1999
2. V.B. Belyaev, Institute of Astrophysics, Cambridge University, Cambridge, England, 1.05–5.05.1999
3. V.B. Belyaev, Physikalisches Institut, Universität Bonn, Bonn, Germany, 1.11–15.12.1999
4. M.Kh. Khankhasaev, Institute for International Cooperative Environmental Research of Florida State University, Tallahassee, Florida, USA, 01.01–31.12.1999
5. S.S. Kamalov, National Taiwan University, Taipei, Republic of China, 01.11.1998–01.05.1999
6. S.S. Kamalov, Institut für Kerphysik, University of Mainz, Mainz, Germany, 01.09.1999–01.11.1999
7. O.I. Kartavtsev, Department of Physics, UNISA, Pretoria, South Africa, 18.10–16.11.1999
8. O.I. Kartavtsev, Research Institute for Particle and Nuclear Physics, Budapest, Hungary, 21.11–29.11.1999
9. O.I. Kartavtsev, Nuclear Physics Institute, Řež near Prague, Czech Republic, 30.11–20.12.1999



10. A.V. Matveenko, Saclay, France, 03.05–31.05.1999
11. A.V. Matveenko, Universität Mainz, Mainz, Germany, 03.09-25.09.1999
12. D.E. Monakhov, Department of Physics, UNISA, Pretoria, South Africa, 4.10–3.12.1999
13. A.K. Motovilov, Physikalisches Institut, Universität Bonn, Bonn, Germany, 10.02–10.08.1999
14. A.K. Motovilov, Department of Mathematics, University of Missouri, Columbia, Missouri, 21.03–28.03.1999
15. A.K. Motovilov, Institut für Analysis, Technische Mathematik und Versicherungsmathematik, Technische Universität Wien, Vienna, Austria, 17.10–27.10.1999
16. N.V. Shevchenko, Physikalisches Institut, Universität Bonn, Bonn, Germany, 01.06.99–30.06.99
17. B.N. Zakhariiev, Milton-Keynes University, England, 28.09–30.09.1999
18. B.N. Zakhariiev, Universität Gissen, Gissen, Germany, 4.10–6.10.1999
19. B.N. Zakhariiev, Universität Siegen, Siegen, Germany, October 7.10–9.10.1999

#### IV. VISITORS

1. L.M. Berkovich, Samara University, Samara, Russia, 17.05–27.05.1999
2. O. Hanstein, Institut für Kerphysik, University of Mainz, Mainz, Germany, 28.06.1999–08.08.1999
3. L. Lekala, Department of Physics, UNISA, Pretoria, South Africa, 1.09–1.10.1999
4. J. Revai, Central Institute of Physics (KFKI), Budapest, Hungary, July 1999
5. S. Wycech, Warsaw University, Warsaw, Poland, June 1999

## V. GRANTS

1. V.B. Belyaev, “Eta-meson production on light nuclei”, NATO 970110 (Principal Investigators V.B. Belyaev and W. Sandhas, Universität Bonn)
2. V.B. Belyaev and A.K. Motovilov, “Theoretical and experimental study of influence of the near-threshold nuclear resonances on molecular properties”, RFBR 98-02-16884, 01.1998–12.1999 (Principal Investigator V.B. Belyaev)
3. V.B. Belyaev, A.K. Motovilov, and N.V. Shevchenko, “Scattering and photoproduction of  $\eta$ -mesons on light nuclei”, RFBR–DFG 98-02-04093, RUS 113/425/0 (R), 04.1998–04.2000 (Principal Investigators S.A. Rakityansky, JINR, and W. Sandhas, Universität Bonn)
4. V.M. Chabanov, Fellowship for young researchers INTAS–ICFPM–96–0457, 1998–1999.
5. A.V. Matveenko, “Three-body Coulomb problem: Extended adiabatic approach”, Heisenberg-Landau Program, 01.1999–12.1999 (Principal Investigators A.V. Matveenko and E. Alt, Universität Mainz).
6. A.K. Motovilov, “Operator models in problems of mathematical physics and their spectral analysis”, RFBR 98-01-01000, 01.1998–12.2000 (Principal Investigator A.A. Shkalikov, Moscow State University)
7. A.K. Motovilov, “Resonance states and scattering in few-body quantum systems: development of the cluster-reduction method and representations for the scattering matrices in unphysical sheets”, RFBR 98-02-18190, 01.1998–12.1999 (Principal Investigator S.L. Yakovlev, St. Petersburg State University)
8. N.V. Shevchenko, International Soros Science Education Program (ISSEP), Postgraduate Student grant a99–966, 1999.
9. N.V. Shevchenko, Fellowship for young researchers INTAS–ICFPM–96–0457, 1998–1999.

## VI. TEACHING

V.B. Belyaev, Supervisor of Ph. D. Thesis of D.E. Monakhov (BLTP, JINR); the thesis has been successfully defended in June 1999

V.B. Belyaev, Ph. D. Thesis supervisor of N.V. Shevchenko (Irkutsk University)

A.K. Motovilov, Diploma Thesis supervisor of M.V. Agaverdyev (Irkutsk University)

B.N. Zakhariiev: lectures in Moscow State University, Moscow Physics Engineering Institute and Moscow Physics and Technology Institute

B.N. Zakhariiev, Diploma Theses supervisor of V. Torchinov and A. Perelstein A. (both of Moscow Physics and Technology Institute)

B.N. Zakhariiev, Ph. D. Thesis supervisor of M. Mineev (LCTA, JINR)

## VII. ORGANIZATION ACTIVITY

V.B. Belyaev, Co-Chairman of the ECT\* International Workshop “Nuclear Reactions in Stars and in the Laboratory”, Trento, Italy, 8.02–19.02.1999

V.B. Belyaev, Member of the Organizing Committee of the International Workshop “Resonances in Few-Body Systems” to be held in Debrecen, Hungary, in September 2000

V.B. Belyaev, Member of Editorial Board of the journal “Few–Body Systems”

M.Kh. Khankhasaev, Member of the Executive Committee of the 5th International Symposium and Exhibition on Environmental Contamination in Central and Eastern Europe, Prague, Czech Republics, 12.09–14.09.2000

M.Kh. Khankhasaev, Associate Director of the Institute for International Cooperative Environmental Research (IICER) of Florida State University, Tallahassee, Florida, and Director of the Center for Russian-American Cooperative Environmental Research of IICER.

B.N. Zakhariev, Member of Governing Body of the Moscow Physical Society

B.N. Zakhariev: Member of the Editorial Board of the Journal of Moscow Physical Society.

B.N. Zakhariev: Member of the Dr. Sc. panel in BLTP, JINR