Laboratory "Elementary Particle Theory" - Annual Report 2013

Prof. Dr.Sc. Emil Nissimov (Head)

The scope of science research in the Laboratory embraces various major and actively developing research branches in modern theoretical and mathematical physics. Our research is executed within the framework of a broad international collaboration with world renown science centers such as CERN (Geneva), ICTP and SISSA (Trieste), JINR (Dubna), as well as with numerous leading universities and academic research institutions from abroad, including Austria, Belgium, France, Germany, Israel, Japan, Italy, Romania, Russia, Serbia, Switzerland, United Kingdom, United States of America.

In 2013 the members of the Laboratory (co)authored **63 scientific works** altogether, among them - 44 published and 17 pending publication papers in international journals and international conference series. Throughout 2013 scientific papers of Laboratory's members have received **406 independent citations** in international science journals and conference proceedings worldwide.

Members of the Laboratory have participated in several large projects funded by Bulgarian National Science Foundation (DMU-03/6 6 (2011-2014); DCVP-02/1 (2009-2014)), Bulgarian Ministry of Science and Education, as well as in various prestigious internationally funded projects - supported through bi-national academic cooperation agreements and/or funded by the European Commission programs:

(a) COST action MP-1210 "The String Theory Universe" (2013-2017);

(b) COST action MP-1304 "Exploring fundamental physics with compact stars" (2013-2017);

(c) European Commision PRACE Projects: PRACE-1IP-Ext - Project RI-261557 (2010-2013); PRACE-2IP - Project RI-283493 (2011-2014); PRACE-3IP - Project RI-312763 (2012-2014)

(d) Academic exchange agreement between Ben-Gurion University (Israel) and Bulgarian Academy of Sciences (2009-2016);

(e) Scientific cooperation France - Bulgaria: project Rila 01/6 (2013-2016);

(f) Joint Institute for Nuclear Research, Dubna (Russia) – two priority projects 01-3-1070-2009/2013;

(g) Alexander von Humboldt Foundation Fellowship (2012-2015) - Univ. Tübingen (Germany).

Principal Research Areas

Area 1: Algebraic and geometric methods in quantum theory. Quantum informatics

(*L. Hadjiivanov, I. Todorov, T. Palev, A. Ganchev, L. Georgiev, N. Nikolov, N. Stoilova, T. Popov, V. Molotkov, D. Nedanovski*)

A general notion of residue of massless Feynman amplitude (or more precisely, Feynman integrand) in configuration space was introduced based on a scaling analysis of the renormalization in a joint collaboration of N.M. Nikolov, R.Stora and I. Todorov. The introduced residue is a renormalization invariant for the case of an amplitude without subdivergences - i.e. for a Feynman distribution that is homogeneous off the full (small) diagonal. Its vanishing is a necessary and sufficient condition for the convergence of such an amplitude. It extends to arbitrary - not necessarily primitively divergent - Feynman

amplitudes. This notion of convergence is finer than the usual power counting criterion and includes cancellation of divergences.

An algebraic formalism for quantum superfields with extended superconformal symmetry analogous to the vertex algebras has been developed. It can be applied to the cohomological analysis of anomalies in perturbative models possessing the corresponding symmetry and provides a framework for building on-shell models.

The Fock spaces *V(p)* of *m* parafermions and *n* parabosons with relative parafermion relations among them which are the unitary irreducible representations of $osp(2m+1|2n)$ with lowest weight $(-p/2,\ldots,-p/2|p/2,\ldots,p/2)$ have been investigated. Despite their importance, these representations have never been constructed (even in the simplest case $m=n=1$) due to computational difficulties. The problem was partially solved in the general case, and an explicit and elegant construction of the representation as well the action of the generators was given for $osp(3|2)$.

A homological proof of the identities between Schur polynomials found by N. Stoilova and J. Van der Jeugt related to the characters of the Fock spaces of the parastatistics algebra has been obtained. It turns out that these identities appear as Euler characteristics of minimal free resolvents of parastatistical Fock spaces.

A study of the algebra of the quantum group invariant combinations of left and right chiral *SU(n)* WZNW zero modes was started generalizing known so far *n=2* results. The Fock space representation of a particular quotient of this "two-dimensional zero mode's" algebra provides a finite dimensional analog of the covariant quantization of gauge theories, the quantum group playing the role of a generalized symmetry. The quotient algebra and its representation seem to be new and hence of interest also from algebraic and combinatorial point of view.

Lecture courses have been delivered at the Sofia University by N. Nikolov (45h, "Quantum Field Theory and Elementary Particles", Faculty of Mathematics and Informatics) and I. Todorov ("Conformal Feynman amplitudes and single valued polylogarithms", Faculty of Physics).

Area 2: Conformal and Superconformal Symmetry in Gauge, Field and String Theory (*V.K. Dobrev, V.B. Petkova, L.K. Anguelova, M. Stanishkov, S. Stoimenov, S.G. Mikhov, O. Stoychev,*)

(2a) Strongly-interacting gauge fields (*L.K. Anguelova)*

We obtained new results for the meson spectrum of a certain type of strongly-coupled gauge theories. We also introduced a new method for studying (in)stabilities in holographic models of such theories. I presented these results at the Conference Strongly-Coupled Dynamics Beyond the Standard Model (Edinburgh, UK) and in arXiv:1306.1981, 1309.6678. I also presented current research and previous results in the area of moduli stabilization in string compactifications (which is crucial for extracting phenomenological predictions from string theory) at seminars in the Institute for Basic Sciences in Pohang, South Korea, and Queen Mary University of London, UK.

(2b) ***Conformal and Superconformal Symmetry in Field and String Theory*** (V.B. Petkova, M. Stanishkov, O. Stoychev)

In work in progress are calculated a class of multiple integrals in conformal sl (4) Toda theory. They define the 3-point functions which determine the coefficients of operator product expansions of scalar fields. This is the first step in the calculation of similar

amplitudes in sl(4) WZW model. These calculations are important in the context of two-dimensional conformal theories – due to the very few results so far for algebras of higher rank, but also because of their possible applications in the gauge-gravity (AdS_5/CFT_4) correspondence.

During the past 2013 an important topic was the duality between string theories in three-dimensional anti- de Sitter space and certain two-dimensional conformal theories. There was an attempt to construct excited states of the corresponding quantum spin chain. It was shown that, unfortunately, even in leading order in the chain length, the chain does not correspond to interaction of nearest neighbours, unlike the analogous case in higher dimensions. Another topic of research was the problem of finding the beta functions and anomalous dimensions in perturbed two-dimensional conformal theories. The problem is to find non-trivial corrections in second order, which are in general non-universal and depend on the renormalization scheme. In this case we found the mixing matrices for certain fields in two-dimensional supersymmetric theories.

(2c) Invariant (Deformed) Differential Equations and Non-Standard Quantum Groups (V.K. Dobrev, S. Stoimenov, S.G. Mikhov)

We continue the project of systematic construction of invariant differential operators for non-compact semisimple algebras. We applied our new idea for parabolic relation between different real forms of a complex Lie algebra, in particular, to algebras that are parabolically related to the so-called 'conformal Lie algebras. For the groups Sp(n,R) (and Sp(n/2,n/2) when n is even) is given the multiplet classification of the special multiplets, giving the necessary data for all relevant invariant differential operators. We have also classified also the minimal representations. Further, we obtained the classification of invariant differential operators for the cases SU(3,3) and SL(6,R). Invited review on "Non-relativistic holography" was prepared for Int. J. Mod. Phys. A. A system undergoing ageing is characterized by dynamical scaling with dynamical exponent z and braking of time-translation invariance in its observables. For z = 2, the dynamical scaling can be extended to invariance under local representation of ageing algebra. From this, the two-point function can be derived and simply related to linear response and correlation functions of given stochastic system.

Our efforts are directed towards generalization of this method for arbitrary integer dynamical exponent z. For these purposes we have constructed non-local representations of the ageing algebra for arbitrary dynamical exponent z and spatial dimensions d> 1. The closure of the algebra is on the space of functions, solutions of a Schrödinger type equation. The generators are realized by higher order differential operators for z-even or by Riesz fractional derivatives for z-odd. We derive the two-point covariant functions for arbitrary z and for z = 4 relate this to results for certain exactly solvable models: spherical and Mullins-Herring models with conserved order parameter.

Area 3: New Aspects in String Theory and Gravitation (*E. Nissimov, S. Pacheva, B. Ivanov, P. Bozhilov, D. Doneva, D. Staicova, B. Damyanov*)

(3a) *Generalized Gravity and Nonlinear Gauge Theories with Applications to Elementary Particle Physics and Cosmology* (E. Nissimov. S. Pacheva)

Our principal results in 2013 in close collaboration with our colleagues from Ben-Gurion University (Israel) are as follows:

(i) We derive a physically interesting new type of gravitational waves - ***charge-confining electro-vacuum gravitational shock waves***. This is achieved via applying an Aichelburg-Sexl-type ultra-relativistic boost procedure to the static spherically symmetric solutions of non-standard Reissner-Nordström type obtained from gravity coupled to a special kind of nonlinear gauge field system containing a "square-root" Maxwell term (the latter is known to produce charge confinement in flat space-time). The resulting gravitational waves possess the remarkable property of confining (trapping) charged test particles (both massive and massless) within finite distance from their wave front.

(ii) We have found a ***new mechanism of dynamical spontaneous breaking of supersymmetry***. Namely, we construct a modified version of standard minimal N=1 supergravity. The modification is based on an idea worked out in detail in previous papers by our Israeli collaborators, where a new class of (non-supersymmetric) gravity theories has been proposed, which appear to be promising candidates for resolution of the dark energy and dark matter problems, the fifth force problem, etc. The idea is to employ an alternative volume form (volume element, or generally-covariant integration measure on the space-time manifold) in the pertinent Lagrangian action, defined in terms of auxiliary (pure-gauge) fields instead of the standard Riemannian metric volume form. Invariance under supersymmetry of the new modified N=1 supergravity action is preserved due to the addition of an appropriate compensating antisymmetric tensor gauge field. This new formalism naturally triggers the appearance of a *dynamically generated cosmological constant* as an arbitrary integration constant which signifies a *spontaneous (dynamical) breaking of supersymmetry*. Furthermore, applying the same formalism to anti-de Sitter supergravity allows us to appropriately choose the above mentioned arbitrary integration constant so as to obtain simultaneously a very small effective observable cosmological constant as well as a large gravitino mass as required by modern cosmological scenarios for slowly expanding universe of today.

(3b) ***Gauge/gravity duality and integrability in string theory relevant for the Anti-de-Sitter/conformal-field-theory correspondence*** (P. Bozhilov)

In the last three years an interesting subject of research became the investigation of the properties of the correlation functions arising in the semi-classical limit in the framework of the AdS/CFT correspondence. Working in this area, we found the leading finite-size effects on the normalized structure constants in semi-classical three-point correlation functions of two finite-size giant magnon “heavy” string states and three different types of "light" states - primary scalar operators, dilaton operator with nonzero momentum and singlet scalar operators on higher string levels. This is done for the case of AdS_5 x S^5 string theory background, dual to N = 4 super Yang-Mills theory in four dimensions and its gamma-deformation dual to N=1 super Yang-Mills.

(3c) ***Relativistic gravity and astrophysics – exact solutions of Einstein’s equations*** (B. Ivanov)

The investigation of collapsing spheres of perfect fluids with heat flow, representing models of collapsing and radiating stars in astrophysics, has continued. The collapse of anisotropic fluid spheres has also been studied.The gravitational effects of the electromagnetic field were discussed. Additional arguments were given that the respective term in the gravitational force does not vanish.

(3d) ***Models and dynamics of rapidly rotating neutron stars*** (D. Doneva). We construct models of rapidly rotating neutron stars in scalar-tensor theories of gravity. It turns out that the fast rotation magnifies the nontrivial scalar field and as a result the neutron star solutions can deviate much stronger from the pure general relativistic solutions, compared to the static case. This opens a new window towards testing the scalar-tensor theories of gravity. We study also the oscillations of rapidly rotating neutron stars in pure general relativity and the gravitational wave driven instabilities. We derive relations that can be used directly in the future gravitational wave observations. Equation of state independent relations are also derived for rotating neutron stars. These relations can serve as a tool to circumvent the uncertainties in the nuclear matter equation of state in various astrophysical scenarios.

(3e) ***Electromagnetic spectra of the Kerr black hole*** (D. Staicova). The differential equations governing the late-time ring-down of the linear perturbations of the Kerr metric have been solved analytically in terms of confluent Heun functions and the electromagnetic quasinormal spectra of the Kerr black hole has been obtained. This is done by imposing the appropriate boundary conditions on the exact solutions and solving numerically the so-obtained two-dimensional transcendental system. This new method allows for fuller examination of the system and demonstrates new aspects of this problem, important for the multi-messenger approach in the search of gravitational signal from compact objects. It also emphasizes on the need of further development of the theory and the numerical implementations of the Heun functions. An important step in this direction was the establishing in 2013 of "the Heun project".

(3f) ***Applications of generalized functions of Colombeau for modeling of singularities*** (B. Damyanov). Modeling of singularities given by distributions or discontinuous functions by means of the generalized functions of Colombeau has proved useful in many physical problems such as geodesics for impulsive gravitational waves, jump conditions in hyperbolic systems and others. Methods based on algebra of generalized Colombeau functions are applied to obtain results for singular products of Schwartz distributions.

Area 4: Theory and Phenomenology of Elementary Particles and Their Bound States (*E. Christova, D. Bakalov, D. Stamenov, M. Stoilov, B. Obreshkov, E. Ginina*)

(4a) ***Partonic content of the nucleon and QCD*** (E. Christova, D. Stamenov)

In order to determine correctly the polarized sea quark parton densities (PDFs) a good knowledge of the fragmentation functions (FFs) (that describe the fragmentation of the quarks into hadrons) is needed. A new set of FFs is obtained from a NLO QCD fit to the HERMES data on pion multiplicities (D. Stamenov in a collaboration with E. Leader, Imperial College, London and A. Sidorov, JINR, Dubna). It is shown that the new pion FFs are different from the existing ones obtained from other experiments. It is found that the different presentations of the HERMES data on multiplicities are not equivalent and lead to different results for the same physical quantities. An additional study of this puzzle is needed.

The axial form factor (FF) of the nucleon is a fundamental quantity, whose knowledge is crucial for the current neutrino experiments. The axial FF is extracted from experiment and at present it is highly controversial. As an alternative for its determination we suggest measurement of the polarization of the final nucleon in elastic and quasi-elastic neutrino-

nucleon scattering. We have calculated the longitudinal and transverse polarizations and shown that their sensitivity to the axial FF is much stronger than the cross section. Such measurements could be performed at the high-statistics neutrino experiments. The results are obtained by E. Christova in collaboration with S.M.Bilenky, JINR, Dubna.

(4b) ***Physics beyond the Standard Model*** (E. Christova, E. Ginina)

If Supersymmetry is to be realized in Nature, a large number of scalar quarks and scalar gluons will be generated at the LHC in CERN. It is shown that the effects of flavour violation in the corresponding cross sections could be essential at the LHC at 14 TeV energies. The results are obtained by E.Ginina in collaboration with the Vienna SUSY group.

Area5: Interdisciplinary research - ***Modeling of biomolecule interactions Molecular-dynamics investigations of immunoproteins*** (N. Ilieva)

A MD-based methodology was developed for quantitative estimates of the binding affinity of HLA-complexes upon point mutations in the presented peptide in the context of a specific drug design. The importance of these investigations is in their role as a training example for the analysis of the KIR-HLA:peptide complex, which is attractive with its ability for selecting T-cells, active towards a HLA:peptide complex with a HIV peptide. The prognostic estimate there would be extremely valuable because of the lack of experimental data. The comparison between the predicted and experimentally obtained values (from the Medical Faculty of Imperial College in London) shows 0.68% coincidence, which is comparable with the best prediction software results (0.69% coincidence). The preparation of an article on these results is in progress. On the side of novel HPC tools and libraries, two libraries were developed, optimized for Intel Xeon Phi coprocessor native execution – the AGBNP2 (Analytical Generalized Born plus Nonpolar model 2) implicit solvent model and a grid-based Poisson solver. An on-line Best-Practice Guide on Intel Xeon Phi was co-authored.