Laboratory "Elementary Particle Theory" - Annual Report 2012

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The current scope of science research in the Laboratory includes several principal areas listed below, which are centered around the major trends in modern theoretical and mathematical physics and are executed within the framework of a broad international collaboration with leading international 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 2012 the members of the Laboratory (co)authored **56 scientific works** altogether, among them - 26 published and 23 pending publication papers in international journals and international conference series. Throughout 2012 scientific papers of Laboratory's members have received **320 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 (02-257/2008, 02-288/2008, 02-115/2008 (center of excellence), 02-183/2008, DMU-03/6), 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 MP1210 "The String Theory Universe" (approved Nov. 2012);

(b) Academic exchange agreement between Ben-Gurion University (Israel) and Bulgarian Academy of Sciences (2009-2015);

(c) Scientific cooperation France - Bulgaria: project "Rila-4" No.112;

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

(e) Alexander von Humboldt Foundation (2010-2012).

Principal Research Areas

Area 1: Quantum Field Theory, Quantum Groups and Quantum Statistics (*L. Hadjiivanov, I. Todorov, T. Palev, A. Ganchev, L. Georgiev, N. Nikolov, N. Stoilova, T. Popov, V. Molotkov, D. Nedanovski*)

The canonically quantized monodromy matrices in the chiral WZNW model acquire additional quantum numerical factors which could be considered as a result of non-perturbative renormalization. Both the quantum field theoretical and algebraic aspects of this phenomenon are studied and it is shown that the renormalization factors are compatible with the natural definitions of determinants of the involved matrices with non-commuting entries.

An axiomatic approach to the renormalization of configuration space Feynman amplitudes and the determination of their residues is developed. The residues provide the correct criterion for the presence of divergences in any perturbative quantum field theory (the cancellation of divergences in supersymmetric models is due to their vanishing). The obtained structures involve operads, combinatorics and number theory and are of interest for pure mathematics.

The high-temperature properties of arbitrary quantum Hall liquids in Fabri-Pérot interferometers are studied with the help of the modular transformations in the rational CFT for the boundary states. The Coulomb blockade and the peaks in the conductivity are analyzed for the Z_4-parafermion Read-Rezayi fluid. The connection between the number of electrons on the Coulomb island and the u(1) current in the twisted CFT for the boundary states is determined in the presence of Aharonov-Bohm flux or of an external potential on the gate in single-electron transistors working in the quantum Hall effect regime.

It is shown that the Lie algebra su(1,1) can be deformed by a reflection operator in such a way that its positive discrete series representations extend to representations of the deformed algebra $su(1,1)_\gamma$. The constructed representations of $su(1,1)_\gamma$ are used in a model of a quantum oscillator. The corresponding wave functions are expressed in terms of continuous dual Hahn polynomials. Interesting limits and special cases of the obtained models are also discussed.

The study of certain classes of commutative homotopic algebras related to graded Lie algebras is continued. Their higher products are expressed explicitly with the help of Kontsevich's tree formulae. Applications to the parastatistics Fock spaces are considered.

Area 2: Conformal and Superconformal Symmetry in Field and String Theory, Non-Standard Quantum Groups and Invariant Equations (*V. Dobrev, V. Petkova, O. Stoychev, M. Stanishkov, S. Mikhov, S. Stoimenov*)

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

A semiclassical 3-point function of vertex operators on the Euclidean AdS_3 Wess-Zumino-Witten model is constructed as a solution of classical Knizhnik-Zamolodchikov equations in the presence of sources. This result is related to the string realization of dual conformal field theory models. The paper was presented (invited talk by V.B. Petkova) at 20th Colloquium `Integrable Systems and Quantum Symmetries', Prague, 17-23.6.2012.

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

We continue the project of systematic construction of invariant differential operators for non-compact semisimple algebras. We formulated a new idea for parabolic relation between different real forms of a complex Lie algebra – the condition is that the corresponding parabolic subalgebras have the same complexification. This idea is applied to algebras that are parabolically related to the so-called 'conformal Lie algebras. For the groups Sp(n,R) is given the multiplet classification of the main multiplets and 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 all possible first order invariant differential operators, i.e., the conservation laws, for so(p,q). We constructed explicitly the character formula of the positive nergy UIRs of the conformal superalgebra su(2,2/N) for all cases when N=1 and some cases when N=2,4.

The ageing Lie algebra *age*(d) and especially its local representations for a dynamical exponent z=2 has played an important rôle in the description of systems undergoing

simple ageing, after a quench from a disordered state to the low-temperature phase. The construction of representations of ageing algebra for generic values of z is described for any space dimension d>1, generalising upon earlier results for d=1. The mechanism for the closure of the Lie algebra, namely only over the functions from the solution space of the equations of Scrödinger type is extended to the case d>1. The Lie algebra generators contain higher-order differential operators (if z is even) or the Riesz fractional derivative (z arbitrary), which in general case leads to *non-local* group(finite) transformations. Co-variant two-time response functions are derived. Some simple applications to exactly solvable models of phase separation or interface growth with conserved dynamics are discussed.

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

(3a) ***Lightlike branes in the physics of black holes, elementary particle physics and cosmology*** (E. Nissimov. S. Pacheva)

Lightlike branes are if substantial interest both in general relativity as well as in modern non-perturbative string theory. Within the context of bulk gravity-matter systems interacting self-consistently with one or more lightlike branes we have obtained several explicit classes of solutions with different physical interpretation as wormhole-like space-times with one or more ``throats", singularity-free black holes, *lightlike brane worlds* and space-times undergoing a sequence of spontaneous compactification-decompactification transitions.

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

We compute 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.

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

We studied a new type of system containing "nonlinear" R^2 gravity coupled to a special kind of a non-canonical nonlinear electrodynamics known to produce in flat space-time a QCD-like *confining potential* between charged fermions. We found several new physically interesting features: (i) appearance of a constant vacuum radial electric field in charged black holes; (ii) novel mechanism of dynamical generation of cosmological constant through the nonlinear gauge field; (iii) phase transition "confinement-deconfinement" triggered by the effective dilaton potential; (iv) effective variable gauge coupling constants (in particular - a variable strength of confinement) as well as effective variable cosmological constant, both depending on the strength of the dynamically generated dilaton vacuum expectation value.

A global view is given upon the study of collapsing shear-free perfect fluid spheres with heat flow which represent models of collapsing and radiationg star in astrophysics. The main equations are the isotropy condition (equality of radial and tangential pressures) and the junction condition on the surface dividing the interior and the exterior solutions. A compact formalism is proposed, which simplifies these equations. Six generating

functions are given for the general solution of the isotropy equation. A general formula for separable solutions is presented, incorporating collapse to a black hole or to a naked singularity.

(3d) ***Structure and properties of compact objects in relativistic astrophysics*** (D. Doneva). The spectrum of the non-radial oscillations of neutron stars containing both ordinary matter and dark energy in different proportions is studied. We show that the oscillation frequencies of the mixed dark energy-neutron stars can differ significantly from the pure neutron stars case. These results can be used to limit the amount of dark energy in neutron stars and also to impose constrains on the dark energy models. We also study the non-radial oscillations of anisotropic neutron stars.

(3e) ***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 spin 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 fragmentation functions is obtained from a NLO QCD fit to the *preliminary* COMPASS (CERN) data on pion and kaon multiplicities (D. Stamenov in a collaboration with E. Leader, Imperial College, London and A. Sidorov, JINR, Dubna). It is shown that the new kaon FFs are very different from the existing ones. The sensitivity of the polarized PDFs to the FFs is discussed, and a solution of the strange quark polarization puzzle is suggested.

(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. The cross section for production of scalar gluons and their subsequent decays into squarks and neutral Higgs has been calculated. Quark flavour violation and the existing constraints from B-decays have been taken into account. The results are obtained in collaboration with the Vienna SUSY group.