Laboratory "Elementary Particle Theory" - Annual Report 2015

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The science research in the Laboratory is focused on various major actively developing research areas in modern theoretical and mathematical physics.The research is conducted 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

In 2015 the members of the Laboratory (co)authored **45 scientific works** altogether, among them - 34 published and 11 pending publication papers in international journals and international conference series. Throughout 2015 scientific papers of Laboratory's members have received **453 independent citations** in international science journals and conference proceedings worldwide.

In 2015 members of the Laboratory have organized the ***XI- th International Workshop "Lie Theory and Its Applications in Physics"*** in Varna.

Members of the Laboratory have participated in several large projects funded by Bulgarian National Science Foundation (DFNI T02/6), 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, among them **COST action MP-1210, COST action MP-1304** and **COST action MP-1405**.

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*)

The thermoelectric characteristics, such as the electric and thermal conductances, thermo-power and thermoelectric power factor, of Coulomb-blockaded fractional quantum Hall islands with filling factors $\nu_H = 5/2$ and $\nu_H = 2 + k/(k+2)$ with $k = 3, 4, \ldots$ have been investigated theoretically. Their dependence on the temperature, magnetic flux and gate potential have been analyzed numerically in order to be eventually compared to the results of future experiments suggested to detect the non-Abelian statistics of the corresponding quasiparticles in these islands.

The Fock representation of a dynamical quantum group (at even roots of unity) naturally arising in the canonical quantization of the two-dimensional $su(n)_k$ Wess-Zumino-Novikov-Witten model has been studied. It is finite dimensional and has a basis that can be conveniently labeled by the subset of su(n) Young diagrams of "spread" (a term introduced for the sum of the number of rows and columns) not exceeding h=k+n.

An orthogonal basis of weight vectors for a class of infinite-dimensional representations of the orthosymplectic Lie superalgebra osp(2m+1|2n) is introduced. These representations are particular lowest weight representations V(p), with a lowest weight of the form [-p/2,…, -p/2 | p/2,…,p/2], p being a positive integer. Explicit expressions for the transformation of the basis under the action of algebra generators are found. Since the relations of algebra generators correspond to the defining relations of m pairs of parafermion operators and n pairs of paraboson operators with relative parafermion relations, the parastatistics Fock space of order p is also explicitly constructed. Furthermore, the representations V(p) are shown to have interesting characters in terms of supersymmetric Schur functions, and a simple character formula is also obtained.

The celebrated Robinson-Schensted-Knuth correspondence between matrices and pairs of Young tableaux has been put in a larger context showing its quantum group symmetries through the quantum Schur-Weyl duality. We report on a new bijection between Young tableaux and braids in knot theory which allows to give a proof of the long standing conjecture on quantum pseudo-plactic algebras.

We examine new algebraic structures which are common for both the theory of vertex algebras and the renormalization theory. The discovered operadic structure in these theories extracts their main mathematical problems and at the same time proposes a powerful solution method. The so-called compact picture gives a very convenient coordinate description of the conformal field theories.

We consider a geometric generalization of the compact picture for the case of field theories with extended superconformal symmetry as an important step towards solving the problem of constructing a Hilbert space for such theories.

The problem of integration over the internal vertices has been solved which is related to the causal factorization condition in (classically) conformal invariant quantum field theory models. An original derivation of the theoretical predictions concerning a discrete (photon polarization) version of the Einstein-Podolsky-Rosen experiment and the violation of Bell's inequalities in a quantum entangled state has been presented. The exposition covers both the "philosophical discussion" between H. Bohr, A. Einstein and E. Schrodinger and the experimental setting that have confirmed that a classical interpretation in terms of "hidden variables" is inadequate.

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, K.P. Hristov, S.G. Mikhov, O. Stoychev,*)

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

LA continued the investigation of strongly coupled gauge theories with the nonperturbative methods of the gauge/gravity duality. In particular, I found new classes of solutions of type IIB supergravity, that are relevant for studying certain strongly coupled gauge theories in de Sitter space. This is important since the Universe has a positive cosmological constant. A specific modification of those solutions opens the possibility for building gravity duals of models of Cosmological Inflation, in which the inflaton is a glueball in a strongly coupled gauge sector. Exploring that further, I constructed a gravity dual of a Glueball Inflation model of the so called 'ultra-slow roll' kind. The latter could play a role in understanding the observed low-l anomaly in the CMB power spectrum.

In 2015 the research of KH addressed and solved a long standing problem in the string theory community, the counting of the microstates of supersymmetric asymptotically AdS black holes in terms of a holographically dual field theory. One of the great successes of string theory is the microscopic explanation of the entropy of a class of asymptotically flat black holes. An immense literature followed the seminal paper of Strominger-Vafa. No similar result existed for asymptotically AdS black holes. This is curious since holography suggests that the microstates of the black hole should correspond to states in a dual conformal field theory. The AdS/CFT correspondence should be the natural setting where to explain the black hole entropy in terms of a microscopical theory. Together with his collaborators F. Benini and A. Zaffaroni, KH focused on a class of asymptotically AdS4 static black holes preserving two real supercharges which are dual to a topologically twisted deformation of the ABJM theory. They evaluated in the large N

limit ofthe topologically twisted index of the ABJM theory and showed that it correctly reproduces the entropy of the AdS4 black holes.

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

Four-point correlators in Toda conformal field theory are constructed and a surprising relation to 4-point correlators in Liouville theory with different central charge is demonstrated. The relevance of the classical limits of the constructed 3-point functions and braiding matrices to problems in 4d conformal theories along the AdS/CFT correspondence is discussed.

Another main topic of research during 2015 was the problem of computation of the beta-function and the anomalous dimensions in perturbed two-dimensional conformal field theories. The corresponding integrable models describe a RG flow from an UV to IR fixed point. The problem is the computation of the corresponding correlation functions in the second order of the perturbation theory. We found the mixing coefficients for certain fields in the specific theories, the general coset models. The latter can be computed alternatively using the domain wall construction which gives a non-perturbative result for the mixing matrix. It turned out that both results coincide in the leading order. The results will be published soon

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

We continued the programme of construction of invariant differential operators for various noncompact semisimple Lie groups. In particular, was made the multiplet classification of the reducible elementary representations and the corresponding invariant differential operators for the conformal group SU(2,2) induced from the maximal cuspidal parabolic subgroup. This induction is almost not considered in the literature - standardly induction is from the maximal non-cuspidal parabolic subgroup. We have also done the multiplet classification for the group SO*(12) which was not consudered in the literature until now.

We continued our work on the representation of the superalgebra osp(1/2n,R). We have made a hypothesis for the list of all irreducible unitary representations with positive energy formulated as Dobrev-Zhang-Salom Theorem. We proved the Theorem for the case n=3 (the simple cases n=1,2 being done earlier) and we gave a detailed sketch for the proof in the general case.

A realization of 1D conformal algebra (isomorphic to the usual one) has been proposed to be a dynamical symmetry algebra of collisionless Boltzmann Transport Equation(BTE). The corresponding representations of the conformal algebra (one space and one time dimensions) are found to be finite-dimensional and in terms of an additional variable denoting the velocity of the particles. This remains valid, if also a force term is included to BTE. Actually, the commutators of conformal algebra determine a system of differential equations for the "force" term and for the functions determining the representation. Although, the complete analysis of this system is left for a future work, we discuss some particular solutions.

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 main results in 2015 belong to the following closely related and actively developing modern research areas in gravity and cosmology ((i)-(v)):

(i) Unified description of the evolution of early and late (modern epoch) Universe; "emergent universe" – a non-singular initial phase of universe's evolution preceding the inflationary phase (creation without "Big-Bang").

(ii) A new self-consistent unified description of "dark energy" as a dynamically generated cosmological constant, and "dark matter" as a dust fluid flowing along spacetime geodesics – i.e., "dark energy" and "dark matter" as two different manifestations of one single matter source. Quantum Wheeler-De Witt equation for the universe's wave function as Schrödinger-like equation for inverted harmonic oscillator – absence of "Bing-Bang" singularity.

(iii) Qualitatively new realization of the supersymmetric Brout-Englert-Higgs mechanism for dynamical spontaneous supersymmetry breaking in supergravity, in particular, simultaneously leading to a very large physical gravitino mass and very small observable cosmological constant.

(iv) Electrovacuum gravitational "bags".

(v) Thin-shell lightlike wormholes – we extended our previous mathematically correct treatment of the Einstein-Rosen "bridge" as a wormhole generated via a lightlike brane "exotic matter" source occupying the wormhole "throat" by providing the systematic Kruskal-Penrose descriptiob of the full analytically extended wormhole spacetime manifold.

(3b) ***Gauge/gravity duality and integrability in string theory relevant for the Anti-de-Sitter/conformal-field-theory correspondence*** (P. Bozhilov). We compute some normalized structure constants in the η-deformed AdS5×S5 in the framework of the semiclassical approach. This is done for the cases when the "heavy" string states are finite-size giant magnons carrying one angular momentum and for three different choices of the "light" state: primary scalar operators, dilaton operator with nonzero momentum, singlet scalar operators on higher string levels. Since the dual field theory is still unknown, the results obtained must be considered as predictions from the string theory side.

(3c) ***Relativistic gravity and astrophysics – exact solutions of Einstein's equations*** (B. Ivanov). An investigation of collapsing spheres of anisotropic fluids with heat flow, representing models of collapsing and radiating stars in astrophysics, has been initiated. In the study of geodesic collapse, when the four-acceleration of the fluid particles vanishes, a special object, called the horizon function, is introduced. It is closely related to the stellar characteristics and satisfies a simple Riccati equation. This equation is partially integrated and many of its solutions are found in terms of one generating function. Some previous solutions are regained and further investigated.

(3d) ***Models and dynamics of rapidly rotating neutron stars*** (D. Doneva). We study neutron stars in Einstein's theory of gravity and one of its most natural and widely used generalizations – the f(R) gravity. Static as well as rapidly rotating solutions are obtained and their astrophysical implications, such as quasiperiodic oscillation and gravitational wave emission, are investigated. Special attention is paid to the so-called universal relations that connect the neutron star properties in an equation of state independent way. This is very important, since the uncertainties in the neutron star structure due to the poorly constrained high density nuclear matter equation of state are quite large. The results in generalized theories of gravity are compared to the pure general relativistic case and predictions for possible observational manifestations of deviations from Einstein's theory are made.

(3e) ***Electromagnetic spectra of the Kerr black hole*** (D. Staicova). We continue our thorough study of the quasinormal modes -- complex frequencies describing the perturbation of the Kerr metric in late times, which is an important subject due to its relevance to the physics of the gravitational waves.

(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. We apply methods based on algebra of generalized Colombeau functions 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, P. Danev)

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

(i)The fragmentation functions (FFs), which describe the fragmentation of quarks and anti-quarks into hadrons, play a key role for the determination of the polarized quark and anti-quark parton densities in the nucleon, Δq and $\Delta \bar{q}$. An NLO QCD analysis of the semi-inclusive deep inelastic HERMES data on pion multiplicities is performed (D. Stamenov in a collaboration with E. Leader, Imperial College, London and A.V. Sidorov, JINR, Dubna), and a new set of pion FFs is extracted from the best fit to the data. It is shown that the obtained FFs differ from those extracted in the analyses of other groups before the HERMES data were available. The importance of semi-inclusive unpolarized processes for the correct determination of the fragmentation functions is discussed.

(ii) At present, enormous efforts are made in JLab, COMPASS (CERN) and HERMESS (DESY) towards measuring the spin-asymmetries that determine the 3-dimentional structure of the nucleon – the transverse momentum dependent parton densities. We consider the same asymmetries, but using the difference cross sections of hadrons with opposite charges. We show that this considerably simplifies the theoretical expressions for the asymmetries and determine the valence-quark densities without any assumptions. In addition, we show that simple relations between the different asymmetries exist, that present simple tests of the used assumptions and of the used approach. The results are obtained by E. Christova in collaboration with Elliot Leader and are presented at the SPIN conference in Dubna.- 2015.

(4b) ***Physics beyond the Standard Model*** (E. Christova). Search for the Higgs boson is a priority for LHC and crutial for the Standard Model. The most promising search is the decay H into 2 gamma. However, at present there is some discrepancy in the calculations of the process, using different regularizations. We have calculated H -> 2 gamma using the dispersion method without subtraction. The advantage of this approach is that it deals only with convergent quantities. The result of our calculations agrees with some of the previous papers, and reduces the decay rate more than twice and thus leaves room for physics beyond the Standard Model. The work is done by E. Christova in collaboration with Ivan Todorov.