

Theory Division of YerPh Review

I. History: Creation and achievements before 1991

(Written in collaboration with S. H. Matinyan)

Theoretical physics in YerPhI was always considered as one of the most important directions of investigations. In its first stage (starting from 1943) the first director of YerPhI A. I. Alikhanian tried to enlist and involve distinguished theorists from Russia such as A.B. Migdal, I.YA. Pomeranchuk etc. for research in the area of cosmic ray physics. Finally two prominent physicists of Armenian origin, G.M. Garibyan and L.M. Ter-Mikaelyan, joined the Institute as permanent staff members and embarked on serious theoretical investigations in the field of electromagnetic interactions. Their achievements in the area of the transition radiation and the interaction of the charged particles with a medium are well known and have been extensively used in various experiments at various accelerators and in other fields.

In the 'sixties' an accelerator (6 GeV) was created in YerPhI and A. I. Alikhanian understood that the existence of this accelerator necessitates the creation of a strong professional group of theorists whose task is not only to respond to the needs of the experimentalists, but also to develop research in the general area of the modern theory of elementary particles or high energy physics. After getting the subordination of the State Committee of the Atomic Energy of USSR the creation of such a group became possible. In this way the Institute formed three laboratories of theoretical physics which later united to form the Theory Division of YerPhI (under the leadership of Sergei Matinyan). The staff members of this Division were enlisted from the graduates of the Yerevan State University, as well as from Tbilisi State and Novosibirsk State Universities.

The Department had three traditional laboratories with the following directions of investigation

1. Quantum Field Theory/Phenomenology/Grand Unification/Supersymmetry(gravity)/Statistical Mechanics...(leader S. Matinyan)
2. Particle theory/Phenomenology/QCD (leader A. Amatuny)
3. Interaction of the high energy particles with medium (leader G. Garibyan)

In its best epoch (the 'eighties') the Theory Division had more than about 50 researchers, of whom more than 10 were Doctors of Science, 35 were Candidates of Science (PhD) and there were four members of the National Academy of Sciences. This was made possible by running a PhD program, by recruiting students with outstanding abilities for theoretical research, selected each year through stringent entrance examinations.

The most important scientific results obtained in the Division during the Soviet era are the following.

1)S. Matinyan and G. Savvidy, "Vacuum Polarization Induced By The Intense Gauge Field," Nucl. Phys. B 134 (1978) 539; **cited 258 times**.

G. K. Savvidy, "Infrared Instability Of The Vacuum State Of Gauge Theories And Asymptotic Freedom," Phys. Lett. B 71 (1977) 133; **cited 516 times**.

2) I.G. Aznaurian, A.S. Bagdasaryan, N.L. Ter-Isaakian.

"Relativistic Quark Model In The Infinite Momentum Frame And Static Characteristics Of Nucleons", Phys.Lett. B 112, (1982)393, "On The Asymptotics Of Baryon Form-Factors In Quark - Gluon Model

3) A.R. Kavalov, A.G. Sedrakian "Fermion Representation Of The Three-Dimensional

- Ising Model'', Nucl.Phys. B2 85: (1987) 264. A.R. Kavalov, I.K. Kostov, A.G. Sedrakian., ``Dirac And Weyl Fermion Dynamics On Two-Dimensional Surface'', Phys.Lett.B175 (1986)331
- 4) A. Y. Khodjamirian, ``Dispersion Sum Rules For The Amplitudes Of Radiative Transitions In Quarkonium'', Phys. Lett. B 90 (1980) 460.
- 5) H. Asatryan and A. Ioannisyian, ``Proton Lifetime In SO(10) Grand Unified Model. Sov. J. Nucl. Phys 41 (1985) 1097; ``Hierarchy Of Breaking Scales In SO(10) Grand Unified Theory And Particle Masses," Sov. J. Nucl. Phys 45(1987) 730
- 6)A.R.Kavalov and R.L.Mkrtchyan, ``Complete Invariant Lagrangians of $d = 10$ $n=2b$ and $d = 6$ $n=2$ Chiral Supergravities," Nucl. Phys. B 331(1990) 391. ``Lagrangian Of Six-Dimensional $N=4b$ Chiral Supergravity," Int. J. Mod. Phys. A 4(1989) 4055.
- 7) N.S. Ananikian, A. R. Avakian, and N. Sh. Izmailyan, ``Phase-Diagrams And Tricritical Effects In The Beg Model'', Physica A 172 (1991) 391
- 8) V. G. Gurzadyan, G. K. Savvidy, ``Collective relaxation of stellar systems'', Astronomy and Astrophysics, v. 160,(1986)203.

Thus the Theory Division became an important center of theoretical elementary particles physics in the USSR. An important part of this activity resulted in the organization of numerous conferences, workshops and schools, notably the

- Soviet-American workshops on the theory of gauge fields, in 1982, 1988 ;
- Workshops on the Quantum Field Theory, in 1987. 1991

II. Development from 1992 to 2003

After the disintegration of the Soviet Union, Armenia as a whole and hence also YerPhI suffered an economic collapse. As a result of bad living conditions and the severe drop in salary payments, the Department lost some of its members. Several important investigators moved to USA and Europe and found permanent positions there (S. Matinyan, G. Savvidy, A. Khodjamirian, etc.), while some others left science altogether. On the other hand a new possibility arose for members of the Department : to find temporary Postdoctoral and short term visiting positions in the West, as well as to apply for several scientific grants (Soros, INTAS, CRDF etc.), thus obtaining an income from these grants and from savings from the scientific visits and short term positions. Moreover the above mentioned extremely small salary from the government was organized in the form of grants, not for Departments but for various scientific teams with different team leaders. These very special conditions for continuing scientific research led to the splitting up of the three traditional laboratories to numerous smaller groups/teams of investigators characterized by their common scientific interests and united financial support. Despite these difficulties the Department survived and even developed experience of working outside the country with large number of collaborators in different scientific centers worldwide. These collaborations were supported by scientific foundations (Alexander-von-Humboldt-Stiftung, Volkswagen-Stiftung, ISTC, SCOPES, ANSEF etc.). Another important point of development during the last decade of last century was the increased activity (number of scientists) in the area of statistical mechanics and condensed matter physics.

During these years our theorists published a lot of seminal and good quality articles (see the top cited list below). Here we just mention some of them for getting impression about scientific interests of our scientists during 1992 -2003:

- 1) H. M. Babujian and R. Flume, "Off-shell Bethe Ansatz equation for Gaudin magnets and solutions of Knizhnik-Zamolodchikov equations," Mod. Phys. Lett. A (1994) 2029 .
- 2) D. R. Karakhanian, R. P. Manvelyan and R. L. Mkrtchian, "Trace anomalies and cocycles of Weyl and diffeomorphism groups," Mod. Phys. Lett. A (1996) 409.

- 3) I. G. Aznaurian, "On The Q^2 Dependence Of The $N \rightarrow N \text{ Gamma And Delta} \rightarrow N$ Gamma Transition Form-Factors In A Quark Model At $Q^2 < 4\text{-GeV}^2$," Phys. Lett. B (1993) 391.
- 4) G. G. Arakelian, A. A. Grigorian, N. Y. Ivanov and A. B. Kaidalov, "On the universality in the production of bosonic resonances," Z. Phys. C (1994) 137.
- 5) N.Y. Ivanov (YerPhI), A. Capella and A. B. Kaidalov, "Single spin asymmetry in heavy flavor photoproduction as a test of pQCD," Nucl. Phys. B 586 (2000) 382
- 6) V. M. Belyaev, V. M. Braun, A. Khodjamirian and R. Ruckl, "D* D pi and B* B pi couplings in QCD," Phys. Rev. D 51 (1995) 6177 **Cited 311 times.**
- 7) J. Ambjorn, D. Arnaudon, A. Sedrakyan, T. Sedrakyan and P. Sorba, "Integrable ladder t-J model with staggered shift of the spectral parameter," J. Phys. A (2001) 5887.
- 8) R. Manvelyan and A. C. Petkou, "The trace anomaly of the (2,0) tensor multiplet in background gauge fields," JHEP (2000) 003.
- 9) H. H. Asatrian, H. M. Asatrian, C. Greub and M. Walker, "Two-loop virtual corrections to $B \rightarrow X/s l+ l-$ in the standard model," Phys. Lett. B (2001).
- 10) R. Poghossian, "Structure Constants in the $N=1$ Super-Liouville Field Theory, Nucl.Phys. B496 (1997) 451.
- 11) A. Ali, H. Asatrian and C. Greub, "Inclusive decay rate for $B \rightarrow X/d + \text{gamma}$ in next-to-leading logarithmic order and CP asymmetry in the standard model," Phys. Lett. B (1998) 87.
- 12) Gurzadyan, V. G.; Kocharyan, A. A. Paradigms of the large-scale universe, Gordon and Breach, |1994 (used as textbook in several Universities, France, UK, Greece).
- 13) A. N. Ioannisian, G. Raffelt, Cherenkov radiation by massless neutrinos in a magnetic field, Phys.Rev.D55(1997)7038; P. H. Chankowski, A. Ioannisian, S. Pokorski, J.W.F Valle, Neutrino unification, Phys.Rev.Lett.86 (2001)3488.
- 14) A.E. Allahverdyan and Th.M. Nieuwenhuizen, Extraction of work from a single thermal bath in the quantum regime. Phys. Rev. Lett., 85, 1799, (2000).

And following Conference organized by the Department

- Regional conference on the theoretical physics in 1997.

III. Present state: 2004-2009, Structure and directions of investigations

Nowadays the Department of Theoretical Physics consists of 57 members including 18 Doctors of Science, 34 Candidates of Science (PhD) and 5 students. The activities of the members cover a large area of theoretical physics from mathematical high energy physics to the theory of biopolymers. The evolution of many small groups and teams, with such different topics of investigations, formed historically. The reasons are explained in the previous section of this review. Here we just mention that this variety of directions of theoretical investigations, strange for a small country, appeared as one of the optimized schemes for self organization of the scientific division in critical conditions with extremely small funding.

Nevertheless we can declare that

- The dominant and traditional direction of investigation in the Department is **Theoretical high energy physics: phenomenology and field theory** and this main direction will survive and continues to develop in the foreseeable future.
- The work of Division is based mainly on collaborations with laboratories and universities abroad, including experimental laboratories.

The corresponding proposals attached to this review in the form presented by their authors. Here we present short descriptions of attached proposals.

1. Spin in QCD and Related Hadron Phenomenology

I. G. Aznauryan, G. H. Arakelyan, A. A. Grigoryan, N. Ya. Ivanov, A. M. Kotzinian and V. M. Zhamkochyan;
60 publication, 1 PhD thesis 2004-2009.

General topic of our activity is investigation of the structure of hadronic matter and its production mechanisms in the framework of Quantum ChromoDynamics (QCD) and related phenomenological models. During last few years, our group has mainly concentrated on theoretical studies of the spin-dependent effects in the five fields of hadron physics. Our obtained theoretical results are used for phenomenological analyses of available data as well as for planning and optimization of future experiments at TJNAF, SLAC, BNL, DESY and CERN. Main directions of our studies are: spin-dependent characteristics of heavy flavor photo- and leptonproduction, amplitude analysis of the electroexcitation of nucleon resonances, string junction effects in strange baryon hadroproduction, quark-gluon plasma in heavy ion collisions and single spin asymmetries in semi-inclusive deep inelastic lepton-nucleon scattering (DIS).

Main advances in these directions can be briefly formulated as follows. It was shown in Refs. [1,2] that the charm density in the proton can, in principle, be determined from high- Q^2 data on the azimuthal $\cos(2\phi)$ asymmetry and the Callan-Gross ratio $R(x, Q^2) = F_L / F_T$ in heavy flavor leptonproduction. An improvement of the standard Dispersion Relation approach and the Unitary Isobar Model was proposed [3] that made it possible to describe the entire set of available CLAS data on electroexcitation of nucleon resonances [4]. It is demonstrated that the available data on the baryon-antibaryon asymmetry in hadroproduction can be well described in terms of the string junction propagation in rapidity space within the Quark-Gluon String Model [5] Compact analytic expressions for the cross sections of the e^+e^- , $\mu^+\mu^-$ and $\pi^+\pi^-$ pairs photoproduction (as well as of the double Compton scattering process, $\gamma + e \rightarrow e + 2\gamma$) are obtained at leading order in α_s [6]. Using the Cahn and Sivers effects for parameterization of the \mathbf{k}_\perp and spin dependences in parton distributions, we have described within the QCD parton model the single spin asymmetry $A_{UT}^{\sin(\phi_x - \phi_s)}$ measured by the HERMES collaboration at DESY [7]

2. Heavy Quark and Flavour Physics

H. M. Asatrian, R. Alanakyan, H. Gabrielyan (PhD student, 3-th year),
H. H. Asatrian, A. Yeghiazaryan (student of YSU, 6-th (last) year),
H. Sargsyan (student of YSU, 3-th year),
A. Hovhannisyan A, S. Gevorkian;
17 publications, 3 PhD theses 2004-2009.

We calculate of that part of the $O(\alpha_s^2)$ contribution to the decay width $\bar{B} \rightarrow X_s \gamma$ which arises from the self-interference term of the electromagnetic dipole operator o_7 . This NNLL contribution is an important ingredient for the complete NNLL prediction of $\Gamma(\bar{B} \rightarrow X_s \gamma)$ which will resolve the charm quark mass ambiguity appearing at NLL accuracy [8]. We compute also the $O(\alpha_s^2)$ contributions to the photon energy spectrum of the inclusive decay $\bar{B} \rightarrow X_s \gamma$ associated with the magnetic penguin operator o_7 . We study the numerical relevance of this set of NNLO contributions in the photon energy spectrum [9]. Combining our results for various $O(\alpha_s^2)$ corrections to the weak radiative B-meson decay $\bar{B} \rightarrow X_s \gamma$, we present the first estimate of the branching ratio at the next-to-next-to-

leading order in QCD. We find $\mathbf{B}(\bar{B} \rightarrow X_s \gamma) = (3.15 \pm 0.23) \cdot 10^{-4}$ for $E_\gamma > 1.6$ GeV in the \bar{B} -meson rest frame [10].

We extend existing calculations of the electromagnetic dipole operator contribution to the total decay rate and the photon energy spectrum of the decay $\bar{B} \rightarrow X_s \gamma$ at $O(\alpha_s^2)$ by working out the exact dependence on the charm quark mass [11].

We have calculated the hard function H at next-to-next-to-leading order (NNLO) in perturbation theory for $\bar{B} \rightarrow X_u l \bar{\nu}$ decay, where H enters in the factorization formula for the differential decay distribution of the form $H \cdot J \otimes S$. Combined with the known NNLO result for the jet function J, this completes the perturbative part of the NNLO calculation for this process [12].

Our future activity will be devoted to the theoretical investigation of the B and K-meson physics in the Standard Model and beyond. Important QCD corrections to the observables in B and K meson processes will be calculated. The results will be used for a comprehensive phenomenological analysis of their power with respect to testing the Standard Model and its extensions. This includes the calculations of higher order QCD corrections for $B \rightarrow X_d \gamma$, $B \rightarrow X_s \gamma$, $\bar{B} \rightarrow X_u l \bar{\nu}$ and $b \rightarrow s \gamma \gamma$ decays, the calculation of the QCD corrections to the decay widths difference of B_s and \bar{B}_s mesons and the investigations of the final state interaction for K-meson decays.

3. Physics Beyond the Standard Model and Neutrino Physics

A. Ioannisian;

6 publication, 2 MS theses 2004-2009.

The phenomenological consequences will be investigated of the physics beyond the Standard Model on low energy sector. We intend to investigate the influence of the large higgs self coupling on the running of the electroweak gauge couplings and intend to get gauge coupling unification.

We intend to get semi-analytic expressions for the 3 neutrino transition probabilities in the presence of matter along the neutrino beam trajectory. See [14]-[16].

4. Dynamical Systems in Cosmology: Cosmic Microwave Background radiation, large scale Universe, dynamics of gravitating systems

V. G. Gurzadyan

H. Khachatryan

H. Kuloghlian

G. Yegorian

T. Ghahramanyan PhD 3rd year student

S. Mirzoyan PhD applicant

E. Poghosian PhD applicant

29 publication, 3 PhD theses, 8 MS theses 2004-2009.

The studies in the Cosmology group were traditionally concentrated on the nonlinear problems, while the recent observational discoveries pose novel problems and added new content to the existing ones. The recent studies included non-Gaussianities in Cosmic Microwave Background (CMB) radiation maps and their link with the back-reaction of inhomogeneities on the propagation of photons and related observable effects in the perturbed Friedmann-Robertson-Walker universe, N-body chaos of gravitating systems at the existence of a dense core and a massive center, etc.

The degree of randomness in the CMB maps has been shown to be measurable and

indicative of the hyperbolic effect of voids on the propagation of the photon beams. In terms of an introduced porosity parameter, a criterion for a hyperbolicity due to domination of voids in the line-of-sight direction was obtained.

A novel map of the sky representing the degree of randomness in the CMB temperature was obtained. The map based on the estimation of the Kolmogorov stochasticity parameter clearly distinguishes the contribution of the Galactic disk from the CMB and reveals regions of various degree of randomness which can reflect the properties of inhomogeneities in the Universe. By its informative power Kolmogorov's map can be complementary to the CMB temperature and polarization sky maps. See [17]-[21]

5. Higher spin interacting quantum field theory, AdS/CFT and E_{11} approach to M theory

Ruben Manvelyan,
 Ruben Mkrtychyan,
 Karapet Mkrtychyan (PhD student).
 17 publications, 1 PhD thesis, 1 MS thesis 2004-2009.

The AdS/CFT conjecture requires testing. From other hand the AdS_4/CFT_3 correspondence of the critical $O(N)$ sigma model and four dimensional higher spin gauge theory in anti de Sitter space (HS(4)) extended consideration from strong to the weakly coupled boundary theory and increased the interest in the old problems of quantization and interaction of the higher spin gauge theories in AdS space. This case of the general AdS_{d+1}/CFT_d correspondence is interesting also in view of the investigation of gauge symmetry breaking and mass generation on the higher spin side which are related to well explored properties of the corresponding CFT boundary theory at next-to-leading order in $1/N$. This allows us to compare the result for the anomalous dimensions of conserved currents of the critical $O(N)$ model with the loop corrections to the bulk-to-bulk propagator of the HS(4) following from the possible special interaction between gauge and conformal scalar fields in AdS . This was done in the papers of the authors where the mass correction for the HS(4) field was evaluated. The analysis of the mass generation for the HS(4) gauge fields and its comparison with the anomalous dimensions of the conformal currents at large N limit is important not only for better understanding of the Higgs phenomenon for HS(4) theory but also for getting an answer to a more general question:

- *Does AdS/CFT works correctly on the level of loop diagrams in the general case and is it possible to use this correspondence for real reconstruction of unknown local interacting theories on the bulk from more or less well known conformal field theories on the boundary side?*

Investigation of this problem could also be important for a deeper understanding of the geometrical and topological structure of the linearized interaction of the higher spin gauge fields.

Important part of this understanding can become the notion of extended space-time, which can contain either tensorial (susy algebra's central charge) coordinates, or E_{11} extended infinite numbers of bosonic coordinates. See [22]-[27]

6. Non perturbative effects in Gauge and String Theories

R. Poghossian,
 M. Samsonyan- PhD student
 7 publications, 1 MS thesis 2004-2009.

Our understanding of nonperturbative phenomena in Supersymmetric Yang Mills theories has been increased dramatically in recent years. It was known for long time that

the (multy-) Instanton contributions to the nonperturbative effects in these theories play prominent role, but only recent developments have provided powerful practical tools to calculate these contributions. The author of the present project together with collaborators has made essential contributions in this area. Quite remarkably some new connections between topological string theories, supersymmetric Yang-Mills theories and random matrix models have been revealed recently. While the correspondences are well settled now in the leading approximation, a systematic understanding of the higher order terms of the topological expansions and their relation to gravitational couplings in Yang-Mills theories are lacking and will be one of the main objectives of our proposal. We also propose to extend these methods to make them applicable also from the string theory perspective and to investigate “stringy” instanton effects. In particular, this could shed new light on the celebrated Maldacena conjecture on the duality between SYM and superstring theories. Our methods can also be applied to the microscopical computation of the entropy of a black hole. See [28]-[31]

7. Investigations in low dimensional physics (d=1,2,3,4): Applications to non-critical strings and condensed matter physics

A. Sedrakyan, H. Babujian, D. Karakhanyan , T. Hakobyan Sh. Khachatryan, V. Mkhitaryan, T. Sedrakyan, M. Mirumyan, A. Melikyan, H. Minasyan

62 publications, 1 PhD and 3 MS theses 2004-2009.

The main goal of this research project is to investigate certain aspects of the relation between gauge theories and strings, which follows the line of the modern development of theoretical high energy physics. It is planned to further study the string/gauge correspondence, supersymmetric gauge theories and large-N matrix models which are associated with them. The present project proposes to carry out an extensive research of non-critical string theories and to gain new insight into the structure of integrable systems, their mathematical aspects and to apply it on revealing of new opportunities to construct a string theory in real (d=2,3,4) dimensions. The essential ingredient of our investigations is the string representation of the 3D Ising model considered on a regular and BCC (body center cubic) lattices. It is also planned to use 2D integrable theory to study Regge and Bjorken limits of quantum chromodynamics. We believe that the obtained results will give new insight into quantum chromodynamics and statistical physics, in particular, to extend the existing results about the string/gauge correspondence to the theories with less supersymmetries. The main tasks of the investigation include: - mathematical aspects of string and gauge theories; - matrix models and supersymmetric gauge theories; - numerical study of gauge theory on a lattice; - investigation of the string/gauge correspondence; - non-critical string and integrable models. The investigation will use the methods of Quantum Field Theory, General Relativity, Superstring Theory and Statistical Mechanics. The construction of the kernel of the universal R-operator, corresponding to the non-standard deformation of $sl(2)$ algebra in coordinates, which preserve translational invariance, in order to study the deviation from Bjorken scaling in hadron scattering in Lipatov’s approach to high- energy QCD. Investigation and calculation of the form factors in the $O(N)$ symmetric Gross- Neveu models. These models are asymptotically free and share some dynamical features with QCD. We plane also to investigate the $1/N$ expansion of our exact form factors and compare with well known $1/N$ expansion results in these models. The problem of the convergence of the form factor sum we will investigate using the method which we use in the Ising model i.e. when we calculate the integrals over rapidity in each level and got the recurrent relations, solving them we get the key object of the theory -the correlation function. See [32]-[49].

An important part of our investigations is connected with such problems in condensed matter physics as Quantum Hall Effect and Quantum Critical transitions. Our preliminary investigations show that the extension of the Chalker-Coddington model, which is a phenomenological model for plateau-plateau transitions in Hall effect, by including *randomness of the network* bring us to hidden reparametrization invariance of the model. This fact strongly relates Chalker-Coddington model to non-critical string theory. It is necessary to carry out some numerical investigations of the localization length in Chalker-coddington model on random networks in order to check the statement above. These investigations are forming our second main goal.

Another aspects of the application of low dimensional models connected with condensed matter physics, namely with physics of quasiparticles on a surface. We will investigate the problem of relaxation time of the electrons in metallic nanoparticles and clusters. See [50]-[52].

We strongly believe that this link between string theory and condensed matter physics has a great potential leading to advancements in Quantum Hall physics as well as in the field of disordered conductors.

8. Critical phenomena in lattice models

N.S. Ananikyan

N.Sh. Izmailian

R.G. Ghulghazaryan

L.N. Ananikyan

K.B. Oganesyanyan

K. G. Sargsyan

V.V. Hovhannisyana PhD 3rd year student

V.S. Abgaryan MS-student

L. A. Chakhmakhchyan MS-student

36 publications, 2 PhD theses 2004-2009

In this research project we are going to study the classical phase transitions (the Yang-Lee, Fisher zeroes on zigzag ladders; magnetization plateaus, period doubling, chaotic regime and Lyapunov exponents in Ising, Potts and quantum phase transitions (spin-1 Heisenberg model and carbon nanotubes entanglement). In parallel to this investigations, the study of the universal and finite-size properties of the Ising and dimer models on the three main two-dimensional lattices (square, triangular and honeycomb) under various boundary conditions are planned.

At first we study the partition function zeros of the ANNNI model on a zigzag ladder. Analytical equations for the distribution of the partition function zeros in the complex magnetic field (Yang-Lee zeros) and temperature (Fisher zeros) planes are derived using transfer matrix method. We plan to show that the Yang-Lee and Fisher edge singularity exponents are universal and equal to each other of the ANNNI model.

Second we research the understanding of thermal entanglement in many-body systems one-dimensional spin -1 Heisenberg model with longitudinal crystal field will bring to obtain the new information on quantum phase transitions and detect a new quantum tricritical point.

Another example of quantum phase transitions is researching of carbon nanotubes with small diameter. We would get a different concurrence and entanglement taking a honeycomb ladder with cyclic boundary condition depending on curvature. We would research von Neumann entropy $S(\rho)$ and thermal entanglement depending on curvature of cylinder in carbon nanotubes.

Third we study the behaviour of Lyapunov exponents in one- and multi-dimensional rational mapping for the Q-state Potts model ($Q < 2$) on the Bethe, three-site anti-ferromagnetic Ising model on Husimi and properties of solid He3 with multi-site exchange interactions on hexagonal lattices. The Lyapunov exponents have different behaviour in chaotic, bifurcation and period doubling cases, using recursion relation technique in these models.

And finally we plan to investigate the finite-size scaling corrections in the two-dimensional Ising and dimer models on the three main two-dimensional lattices (square, triangular and honeycomb) under various boundary conditions, that is, the cylindrical, toroidal, Möbius strip, Klein bottle and Brascamp-Kunz (BK) boundary conditions. We expect to obtain the exact asymptotical expansion for the free energy, the internal energy and the specific heat at the critical point and investigate their aspect-ratio dependence. See [53]-[58].

9. Quantum Thermodynamics and the Application of Statistical Physics to Information Processing and Helical Biopolymers.

A. Alachverdyan,

Zh.G. Gevorkian

23 publications 2004-2009

a) The present proposal has two related goals. Within the first goal we want to understand how the concepts, relations, and bounds of thermodynamics apply to finite (mesoscopic, small) systems. The basic purpose of thermodynamics is in studying energy transformation, storage and utilisation by various machines. Though in its historical development thermodynamics concentrated on macroscopic machines, it became nowadays obvious that many important types machines are of micro and nanoscale. Thus we shall study processes of work (useful energy) extraction with help of a finite (nanoscale) engine, energy storage in nanoscale batteries, energy exchange between interacting finite systems, microscopic theories of restitution coefficients, as well as the energy transfer and storage in rotating systems (encountered in ATP, the basic battery of the biological energy). Whenever possible, the approach in solving these problems will be that of quantum thermodynamics, i.e., directly deducing the relations and limitations of thermodynamics from the quantum theory.

The second goal of the proposal is to explore mutual aspects of statistical thermodynamics and information science. Some of those aspects and relations were recognized and studied since a long time ago (e.g., Maxwell's demon, maximum entropy method), while others became apparent only with the recent development of thermodynamics and information theory. We shall address the problem of energy cost of various information tasks (e.g., quantum or classical measurement, information transfer). Another related item will be to study the performance of important computational methods of information science (such as clustering, semi-supervised learning, or maximum-a posteriori decoding) via the methods and ideas of statistical mechanics.

b) Genetic recombination, packaging of DNA in cells and viruses, folding of proteins, and assembly of the organic matrix of bone are just a few of the many fundamental biological reactions that involve interactions between helical macromolecules. Recent experimental advances suggest that the key to the physics of these phenomena might be in understanding the relationships between intermolecular interactions and the structure of the molecules. The main goal of the present proposal is to address theoretically several basic problems of biopolymeric helices, e.g., the kinetics of helix formation, interaction between tertiary and secondary structures of biopolymers, statistical physics of structurally disordered proteins, structural transitions induced by water, and self-organization of collagen fibrils.

Theoretical results will be compared with experiments, in particular, with those carried out in YerPhI by S.G. Gevorkian. See [59]-[63]

10. Statistical Physics and Evolution Theory

D. Sahakian,

11 publications 2004-2009

Fundamental mathematical models of the evolutionary process are notoriously difficult to understand analytically. However, a precise mathematical analogy can be drawn between several important evolution models (e.g., the models by Chow-Kimura and Eigen) and many-body systems of statistical mechanics. This allows application of the powerful methods of both equilibrium and non-equilibrium statistical physics to analysis of evolutionary models. In several important situations the methods of statistical physics lead to exact solutions for evolutionary models. See [64]

11. Powerful coherent radiation sources and new effective methods of acceleration

Lekdar Gevorgian,

Mery Aginian,

Anahit Shamamian,

Karo Ispirian ,

Levon Hovsepyan,

17 publications, 1 PhD thesis 2004-2007

The search of compact sources for monochromatic X-ray radiation with spectral density comparable with the synchrotron radiation, in which electrons of medium energy (up to 100 MeV) are used, is among the most actual problems in modern physics. We discovered new powerful radiation sources [65]-[67].

The problem of transition radiation produced by relativistic charged particles passing through a periodically inhomogeneous medium with uniform velocity has been solved in an exact way [65]. A new phenomenon is found: that is the *coherent emission of harmonics* in the soft frequency range, when in hard frequency range we obtain *the same input from all harmonics*. Thus it is possible to obtain intense beams of soft photons using high-current electron bunches. Another powerful X-ray source for hybrid radiation of electron bunch in plasma in the presence of beat waves was found in [66]. In [67] we have shown that electrons produce powerful quasimonochromatic and narrow directed high brilliance photon beam in the submillimeter region, when electron beam moves toward two laser waves.

The second problem which will be investigated within the proposed project is related to the search of ways to increase the acceleration rate of charged particles. A new mechanism of acceleration was developed in [68].

We plan to study the influence of a dispersive medium on the characteristics of the electromagnetic radiation from helical undulators. The presence of medium provides an additional mechanism for the control of the radiation parameters.

12. Quantum Information Theory

S. Tamaryan,

L. Tamaryan -MS-course student

11 publications 2007-2009

The superior performance of quantum systems in computation and communication applications is predominantly rooted in a property of quantum mechanical states called **entanglement**. Essentially, entanglement comes along with new kinds of correlations. It is **a fundamental property of quantum systems and a basic physical resource** for Quantum Information Theory (QIT). In general, any task involving distant parties and using up entangled states as a resource benefits from a better understanding of entanglement. It is increasingly realized that quantum entanglement is at the heart of quantum physics and as such it may be of very broad importance for modern science and future technologies.

The main objectives of the team are:

- to develop a theory of multipartite entanglement,
- to engineer a quantum computer based on nuclear magnetic resonance,
- to elaborate quantum algorithms for secure communications. See [69]-[71]

References: Selected Publications 2004-2009

(The full list of publications for each group during last 5 years can be found inside of attached projects).

- [1] L. N. Ananikyan and N. Ya. Ivanov, Azimuthal asymmetries in DIS as a probe of intrinsic charm content of the proton, Nucl. Phys. B **762**, 256 (2007).
- [2] N. Ya. Ivanov, The ratio $R=F(L)/F(T)$ in DIS as a probe of the charm content of the proton, Nucl. Phys. B **814**, 142 (2009).
- [3] I. G. Aznauryan, Multipole amplitudes of pion photoproduction on nucleons up to 2 GeV using dispersion relations and the unitary isobar model, Phys. Rev. C **67**, 015209 (2003); Phys. Rev. C **68**, 065204 (2003).
- [4] I. G. Aznauryan, Electroexcitation of the Roper resonance in the relativistic quark models, Phys. Rev. C **76**, 025212 (2007).
- [5] G. H. Arakelyan, C. Merino, C. Pajares, and Yu. M. Shabelski, Midrapidity production of secondaries in pp collision at RICH an LHC energies in the quark-gluon string model, Eur. Phys. J. C **54**, 577 (2008).
- [6] E. Bartos, M. V. Galynskii, S. R. Gevorkyan, and E. A. Kuraev, The lowest order inelastic QED processes in polarized photon electron high-energy collisions, Nucl. Phys. B **676**, 390 (2004).
- [7] M. Anselmino, M. Boglione, U. D'Alesio, A. Kotzinian, F. Murgia, A. Prokudin, and C. Turk, Transversity and Collins functions from SIDIS and e^+e^- data, Phys. Rev. D **75**, 054032 (2007); M. Anselmino, M. Boglione, U. D'Alesio, A. Kotzinian, F. Murgia and A. Prokudin, The role of Cahn and Sivers effects in deep inelastic scattering, Phys. Rev. D **71**, 074006 (2005).
- [8] H.M. Asatrian, H.H. Asatryan, A. Hovhannisyan . Rare decays $\bar{B} \rightarrow X_{s(d)}\gamma$ gamma at the NLO. Phys.Lett.B585:263-275,2004.
- [9] H.M. Asatrian, A. Hovhannisyan, V. Poghosyan, T. Ewerth, C. Greub, T. Hurth., NNLL QCD contribution of the electromagnetic dipole operator to $\Gamma(\bar{B} \rightarrow X_s\gamma)$ Nucl.Phys. B749:325-337,2006.
- [10] H.M. Asatrian, T. Ewerth, A. Ferroglia, P. Gambino, C. Greub, Magnetic dipole operator contributions to the photon energy spectrum in $\bar{B} \rightarrow X_s\gamma$ at $O(\alpha_s^2)$, Nucl. Phys. B762: 212-228,2007.
- [11] H. M. Asatrian, et al., Estimate of $\mathbf{B}(\bar{B} \rightarrow X_s\gamma)$ at $O(\alpha_s^2)$. Phys. Rev. Lett.

- 98:022002,2007. Cited 197 times.
- [12] H.M. Asatrian, T. Ewerth, H. Gabrielyan, C. Greub, Charm quark mass dependence of the electromagnetic dipole operator contribution to $\bar{B} \rightarrow X_s \gamma$ at $O(\alpha_s^2)$ Phys.Lett.B647:173-178,2007.
 - [13] H.M. Asatrian, C. Greub, B.D. Pecjak, NNLO corrections to $\bar{B} \rightarrow X_u l \bar{\nu}$ in the shape-function region, Phys.Rev.D78:114028,2008.
 - [14] A.N. Ioannisian, A.Yu. Smirnov, Describing neutrino oscillations in matter with Magnus expansion. Nucl.Phys. B 2009
 - [15] A.N. Ioannisian, N.A. Kazarian, A.Yu. Smirnov, D. Wyler. A Precise analytical description of the earth matter effect on oscillations of low energy neutrinos. Phys.Rev.D71:033006,2005.
 - [16] A.N. Ioannisian, A.Yu. Smirnov, Neutrino oscillations in low density medium. Phys.Rev.Lett.93:241801, 2004.
 - [17] Gurzadyan V.G., P.A.R. Ade, P. de Bernardis, C.L. Bianco, J.J. Bock, A. Boscaleri, B.P. Crill, G. DeTroia, E. Hivon, V.V. Hristov, A.L. Kashin, A.E. Lange, S. Masi, P.D. Mauskopf, T. Montroy, P. Natoli, C.B. Netterfield, E. Pascale, F. Piacentini, G. Polenta, J. Ruhl, G. Yegorian, Is There a Common Origin for the WMAP Multipole and for the Ellipticity in BOOMERanG CMB maps? Mod.Phys.Lett. A, 20 (2005) 491.
 - [18] Djorgovski S.G., V.G. Gurzadyan, Dark Energy From Vacuum Fluctuations, Nucl. Phys. B, 173 (2007) 6
 - [19] Gurzadyan V. G., A. A. Starobinsky, T. Ghahramanyan, A. L. Kashin, H. Khachatryan, H. Kuloghlian, D. Vetrugno, G. Yegorian, Large Scale Plane-Mirroring in the Cosmic Microwave Background WMAP5 Maps, Astr. & Astrophys., 490 (2008) 929
 - [20] Gurzadyan V. G., A. A. Kocharyan, Porosity Criterion for Hyperbolic Voids and CMB, Astr. & Astrophys. (Lett.) 493 (2009) L61
 - [21] Gurzadyan V.G., A.E.Allahverdyan, T.Ghahramanyan, A.L.Kashin, H.G.Khachatryan, A.A.Kocharyan, H.Kuloghlian, S.Mirzoyan, E.Poghossian, Kolmogorov CMB Sky, Astr. & Astrophys. 2009, (in press); arxiv:0811.2732
 - [22] R. Manvelyan, K. Mkrtchyan and W. Ruhl, "Off-shell construction of some trilinear higher spin gauge field interactions," Submitted to Nucl.Phys B ;arXiv:0903.0243 [hep-th]
 - [23] R. Manvelyan, K. Mkrtchyan and W. Ruhl, "Ultraviolet behaviour of higher spin gauge field propagators and one loop mass renormalization," Nucl. Phys. B **803** (2008) 405 [arXiv:0804.1211 [hep-th]]
 - [24] R. Manvelyan and W. Ruhl, "Generalized Curvature and Ricci Tensors for a Higher Spin Potential and the Trace Anomaly in External Higher Spin Fields in AdS(4) Space," Nucl. Phys. B **796** (2008) 457 [arXiv:0710.0952 [hep-th]]
 - [25] R. Manvelyan, K. Mkrtchyan and R. Mkrtchyan, "Conformal invariant powers of the Laplacian, Fefferman-Graham ambient metric and Ricci gauging," Phys. Lett. B **657** (2007) 112 [arXiv:0707.1737 [hep-th]]
 - [26] R. Manvelyan and W. Ruhl, "The structure of the trace anomaly of higher spin conformal currents in the bulk of AdS(4)," Nucl. Phys. B **751** (2006) 285 [arXiv:hep-th/0602067]
 - [27] H. Mkrtchyan, R.Mkrtchyan, "Remarks on E11 approach", Mod. Phys. Lett. A**21** (2006) 503-514, arXiv:hep-th/0507183
 - [28] Rubik Poghossian, Marine Samsonyan, Instantons and the 5D U(1) gauge theory with extra adjoint, J.Phys. A(2009), in press, arXiv:0804.3564;
 - [29] F. Fucito, J. F. Morales, R. Poghossian, Instanton on toric singularities and black hole countings, JHEP 0612 (2006) 073, hep-th/0610154;

- [30] F. Fucito, J. F. Morales, R. Poghossian, Instantons on Quivers and Orientifolds, JHEP 0410 (2004) 037, hep-th/0408090;
- [31] F.Fucito, J.F.Morales, R.Poghossian, A.Tanzini, N=1 Superpotentials from Multi-Instanton Calculus, JHEP0601:031,2006, arXiv:hep-th/0510173 ; R. Flume, R. Poghossian, "An Algorithm for the Microscopic Evaluation of the Coefficients of the Seiberg-Witten Prepotential", Int. J. Mod. Phys. A18: 2541, 2003, hep-th/0208176;
- [32] J. Abmijurn, Sh. Khachatryan, A. Sedrakyan, *Simplified tetrahedron equations: Fermionic realization*, Nucl. Phys. B 734, (2005) 287.
- [33] M. Kohmoto, A. Sedrakyan, *Hofstadter Problem on the Honeycomb and Triangular Lattices: Bethe Ansatz Solution* Phys. Rev. B 73, 235118 (2006).
- [34] A. Sedrakyan and F. Dominguez-Adame, *Comment on "Sequencing-Independent Delocalization in a DNA-Like Double Chain with Base Pairing"*, Phys. Rev. Lett 96 (2006) 059703.
- [35] H.Babujian, A.Foerster and M.Karowski , *The nested SU(N) off-shell Bethe ansatz and exact form factors*, J.Phys.A,v.41(2008)
- [36] H.Babujian, A.Foerster and M.Karowski, *The Form Factor Program: a Review and New Results - the Nested SU(N) Off-Shell Bethe Ansatz*, SIGMA,V.2,2006
- [37] H.Babujian, A.Foerster and M.Karowski, *Exact form factors in integrable quantum field theories: the scaling Z(N)-Ising model*, Nucl.Phys.B736:169-198,2006
- [38] D. Karakhanyan, Sh. Khachatryan Solutions to the Yang-Baxter equations with $osp_q(1|2)$ symmetry: Lax operators, Nuclear Physics B 808 [FS] (2009) 525-545
- [39] S. Derkachov, D. Karakhanyan, R. Kirschner, P. Valinevich Iterative construction of $U_q(sl(n+1))$ representations and Lax matrix factorization, Lett. Math. Phys. 85(2008)221,
- [40] S. Derkachov, D. Karakhanyan, R. Kirschner Yang-Baxter R operators and parameter permutations, Nucl.Phys.B785:263-285,2007
- [41] V. Mkhitarian, A. Sedrakyan, On the next to nearest neighbor and chiral spin correlation functions in generalized XXX chain, cond-mat/0709.2481, Phys. Rev. B.77, (2007) 035111.
- [42] V.V. Mkhitarian and M.E. Raikh, Phys. Rev. B 78, 195409 (2008), "Disorder-induced tail states in a gapped bilayer graphene".
- [43] V. V. Mkhitarian, Y. Fang, J. Gerton, E. G. Mishchenko, and M. E. Raikh, Phys. Rev. Lett. 101, 256401 (2008), "Scattering of plasmons at the intersection of two metallic nanotubes: Implications for tunnelling".
- [44] T. Hakobyan, The ordering of energy levels for $SU(n)$ symmetric antiferromagnetic chains, Nucl. Phys. B , 575-594 (2004)
- [45] T. Hakobyan, Energy-level ordering and ground-state quantum numbers for a frustrated two-leg spin-1/2 ladder, Phys. Rev. B , 214421 (2007)
- [46] T. Hakobyan, Antiferromagnetic ordering of energy levels for a spin ladder with four-spin cyclic exchange: Generalization of the Lieb-Mattis theorem, Phys. Rev. B , 012407 (2008)
- [47] T. A. Sedrakyan, Nucl. Phys. B 729 [FS], 526 (2005).
- [48] T. A. Sedrakyan, E. G. Mishchenko, and M. E. Raikh, Phys. Rev. Lett. 99, 206405 (2007).
- [49] T. A. Sedrakyan, E. G. Mishchenko, and M. E. Raikh, Phys. Rev. Lett. 99, 036401 (2007).
- [50] A. Melikyan and H. Minassian, Calculation of Longitudinal Surface Plasmon Frequencies in Noble Metal Nanorods. Chem. Phys. Lett., v. 452, pp. 139-143 (2008).
- [51] A.Melikyan, H.Minassian, On Surface Plasmon Damping in Metallic Nanoparticles. Applied Physics B, Lasers and Optics, 78(3-4), pp. 455-457(2004).
- [52] T.Makaryan, A.Melikyan, H.Minassian, Surface Plasmon Frequency Spectrum in a

- System of Two Spherical Dielectric Coated Metallic Nanoparticles. *Acta Physica Polonica A*, v. 112, n5, pp.1031-1035 (2007).
- [53] N.Sh. Izmailian and Yeong-Nan Yeh, Ising model with mixed boundary conditions: Universal amplitude ratios, *Nucl. Phys. B* 814, 573 (2009).
- [54] V.V. Hovhannisyanyan, R.G. Ghulghazaryan, N.S. Ananikian, The partition function zeros of the anisotropic Ising model with multisite interactions on a zigzag ladder, *Physica A* 388, 1479(2009).
- [55] R. G. Ghulghazaryan, K. G. Sargsyan, and N. S. Ananikian, Partition function zeros of the one-dimensional Blume-Capel model in transfer matrix formalism, *Phys. Rev. E* 76, 021104 (2007).
- [56] V.R. Ohanyan, L.N. Ananikyan, N.S. Ananikian, An exact solution on the ferromagnetic face-cubic spin model on Bethe lattice, *Physica A* 377, 501 (2007).
- [57] N.Sh. Izmailian, K.B. Oganesyanyan, Ming-Chya Wu and Chin-Kun Hu, Finite-Size Corrections and Scaling for the Triangular Lattice Dimer Model with Periodic Boundary Conditions, *Phys. Rev. E* 73, 016128 (2006).
- [58] N.Sh. Izmailian, V.B. Priezhev, Philippe Ruelle and Chin-Kun Hu, Logarithmic Conformal Field Theory and Boundary Effects in the Dimer Model, *Phys. Rev. Lett.* 95, 260602 (2005).
- [59] A.E. Allahverdyan, R.S. Johal, G. Mahler, *Phys. Rev. E*, 041118 (2008). *Work extremum principle: Structure and function of quantum heat engines*
- [60] A.E. Allahverdyan, *J. Stat. Phys.*, 535 (2008). *Entropy of Hidden Markov Processes via Cycle Expansion*
- [61] A.E. Allahverdyan, Zh.S. Gevorgian, Th.M. Nieuwenhuizen, and Chin-Kun Hu, *Adhesion-Induced DNA Naturation*, *Phys. Rev. Lett.*, 098302 (2006).
- [62] A. E. Allahverdyan, Roger Balian and Th.M. Nieuwenhuizen, *Determining a quantum state by means of a single apparatus*, *Phys. Rev. Lett.* 92, 120402, (2004).
- [63] S. G. Gevorgian, A. E. Allahverdyan, D.S. Gevorgyan, and A. L. Simonian, *Thermal (In)Stability of Type I Collagen Fibrils*, *Phys. Rev. Lett.*, 048101 (2009).
- [64] D. B. Saakian and C.-K. Hu, *Exact solution of the Eigen model with general fitness functions and degradation rates*, *Proc. Natl. Acad. Sci. USA*, 4935 (2006).
- [65] L. A. Gevorgian, *Radiation of a relativistic electron in a periodically inhomogeneous medium*. *Proc. of SPIE Vol. 5974* (SPIE, Bellingham, WA, 2005). *Effect of harmonics coherence in resonant transition radiation*. *Proc. of SPIE Vol.6634*, 663413 (SPIE, Bellingham, WA, 2007).
- [66] L. Gevorgian, *Hybrid radiation of electron bunch in plasma in the presence of beat waves*. *Proc. of SPIE Vol.5974* (SPIE, Bellingham, WA, 2005).
- [67] A. Shamamian and L. Gevorgian, *Coherent sub-millimeter undulator radiation from modulated electron beam*. *Proc. of SPIE Vol.6634* (SPIE, Bellingham, WA, 2005).
- [68] L. A. Gevorgian, *High acceleration rates obtained in plasma-loaded FEL*. *Proc. of SPIE Vol.5974*, 5974OV(1-5)(SPIE, Bellingham, WA, 2005).
- [69] E. Jung, M.-R. Hwang, H. Kim, M.-S Kim, D.K. Park, J.-W. Son, and S. Tamaryan, *Reduced State Uniquely Defines Groverian Measure of Original Pure State*, *Phys.Rev. A* 77, 062317 (2008);
- [70] L. Tamaryan, D.K. Park, and S. Tamaryan, *Analytic Expressions for Geometric Measure of Three Qubit States*, *Phys. Rev. A* 77, 022325(2008); *Virtual J. of Quantum Information* (March 2008).
- [71] L. Tamaryan, D.K. Park, J.-W. Son, and S. Tamaryan, *Geometric Measure of Entanglement and Shared Quantum States*, *Phys. Rev. A* 78, 032304(2008)

V. Achievements 2004-2009

a) Publications:

The Department published more than 270 articles in international journals during 2004-2009.

b) Recent Important Results

Phenomenology

- a) The branching ratio of the $\bar{B} \rightarrow X_s \gamma$ decay at $O(\alpha_s^2)$ is calculated. The result is:
$$\mathcal{B}(\bar{B} \rightarrow X_s \gamma) = (3.15 \pm 0.23) \cdot 10^{-4}$$
 for $E_\gamma > 1.6$ GeV in the \bar{B} -meson rest frame.
Combining with the existing experimental results for the branching ratio of the $\bar{B} \rightarrow X_s \gamma$ decay, this result can be used for testing the standard model and its extensions. [11] **cited 208 times**.
- b) The hard function H at next-to-next-to-leading order (NNLO) in perturbation theory was calculated for $\bar{B} \rightarrow X_u l \bar{\nu}$ decay. Combined with the known NNLO result for the jet function J, this completes the perturbative part of the NNLO calculation for this process. This result can be used for the precise determination of CKM matrix element V_{ub} [13]. (H. Asatryan).
- Developed a new description of the neutrino oscillations in matter with varying density which is both accurate and has all advantages of a full analytic treatment. Perturbative formulas for the oscillation probabilities which are valid for arbitrary density profile is derived and applied for propagation of the solar, supernova and accelerator neutrinos in matter of the Earth. (A. Ioannisian [16]).
- Recently, a global analysis of the experimental data on azimuthal asymmetries in semi-inclusive deep inelastic scattering (SIDIS), from the HERMES and COMPASS Collaborations, and in $e^+ e^-$ annihilation processes from the Belle Collaboration was performed [7]. The extraction of the Collins fragmentation function and (*for the first time*) of the transversity distribution function for u and d quarks were done. (A. Kotzinian [7])
- An improvement of the standard Dispersion Relation approach and the Unitary Isobar Model was proposed, that made it possible to describe the entire set of available CLAS data on electroexcitation of nucleon resonances (I. Aznaurian [3, 4]).
- It was shown that the charm density in the proton can, in principle, be determined from high- Q^2 data on the azimuthal $\cos(2\phi)$ asymmetry and the Callan-Gross ratio $R(x, Q^2) = F_L / F_T$ in heavy flavor leptonproduction (N. Ivanov [1,2]).

Approved Proposals and LOI:

Members of the Department (I. G. Aznaurian, N. Ya. Ivanov and A. M. Kotzinian) made key contributions to preparation of the following research projects approved by TJNAF PACs:

- "Measurement of the Beam Spin Asymmetry in the Deuteron Disintegration by Linearly Polarized Photons at $E_\gamma = 1.2 - 2.2$ GeV", LOI-06-101.

- "Meson spectroscopy in the coherent production on ^4He with CLAS", E-07-009.
- "Determination of the Azimuthal Asymmetry in Deuteron Disintegration by Linearly Polarized Photons at $E_\gamma = 1.1 - 2.3$ GeV", approved by CLAS Collaboration, June 2008.
- "Nucleon Resonance Studies with CLAS12 in the Transition from Soft to Partonic Physics", PR-09-003.
- "Semi-inclusive Pion Production with Longitudinally Polarized Target at 12 GeV", LOI12-06-109.
- "Probing the Proton's Quark Dynamics in Semi-Inclusive Pion Production at 12 GeV", PR12-06-112.
- "Studies of Spin-orbit Correlations with Longitudinally Polarized Target", PR12-07-107.
- "Lambda Polarization in the Target Fragmentation Region", LOI12-07-101.

Observational Cosmology

- In collaboration with the Boomerang team (University of Rome) our Cosmology Group studied non-Gaussianities in the CMB maps: analyzed the properties of excursion sets in Boomerang (150 GHz), then of Wilkinson Microwave Anisotropy (WMAP) satellite's 3 and 5-year 94 GHz temperature maps. (V. G. Gurzadyan [17])

Field Theory

- The quantum one loop trace anomaly of the higher spin conformal conserved currents in the bulk of AdS_4 is obtained. The structure of this trace anomaly in the external higher spin fields is investigated. (R. Manvelyan [24, 26]).
- A new procedure, allowing to calculate the higher instanton contributions (2, 3 and 4-) to the Seiberg-Witten prepotential is obtained. Some applications to non perturbative effects in Gauge and String Theories are considered. (R. Poghosian [31]).
- A general form factor formula for the scaling $Z(N)$ -Ising model is constructed. Exact expressions for matrix elements are obtained for several local operators. In addition, the commutation rules for order, disorder parameters and para-Fermi fields are derived. Because of the unusual statistics of the fields, the quantum field theory seems to be not related to any classical Lagrangian or field equation. (H. Babujian [37]).
- A new 4×4 solution to the $osp_q(1|2)$ -invariant Yang-Baxter equation with simple dependence on the spectral parameter is found and 2×2 matrix expressions for the corresponding Lax operator is proposed. The general inhomogeneous universal spectral-parameter dependent \mathbf{R} -matrix is derived. It is proven, that there are two independent solutions to the homogeneous $osp_q(1|2)$ -invariant YBE, defined on the fundamental three dimensional representations (D. Karakhanyan, Sh. Khachatryan [38]).

Statistical Physics

- New method for quantum state determination via purely commutative measurement is proposed (A. E. Allahverdyan [62]).
- The general algorithm to compute exact asymptotic expansions for the partition functions and their derivatives for critical lattice models, including the Ising model, dimer model, and Gaussian model is developed (N. Izmailian [53]).

Quantum Information

- The entanglement of generic tripartite states is computed analytically which classifies tripartite states by types of entanglement. The classification applicable for the quantum teleportation and superdense coding (S. Tamaryan [70]).

c) PhDs:

12 PhD theses were defended during 2004-2009.

d) Grants:

More than 40 grants were obtained from the following Sources:

INTAS, Alexander von Humboldt Foundation, Volkswagen Foundation, ISTC, SCOPES, ANSEF, CRDF, NFSAT, Science Foundation Ireland etc.

e) Collaborations with other divisions worldwide

The members of the Department had successful collaborations with the following institutions:

USA

1. Department of Physics, Northeastern University, Boston, 2. Caltech, 3. University of Massachusetts, Amherst., 4. TJNAF, Newport News, 5. JLab, 6. Chicago University, 7. Stony Brook University

Russia

1. ITEP, Moscow, 2. JINR, Dubna, 3. SPbNPI, S.Petersburg

Germany

1. University of Bonn, 2. Technical University of Kaiserslautern, 3. University of Stuttgart, 4. Free University of Berlin, 5. Hamburg Universit, 6. DESY.

Italy

1. University of Rome "Tor Vergata", 2. International School for Advanced Studies of Trieste (SISSA), 3. Scuola Normale Superiore of Pisa, 4. ICTP, 5. Turin University , 6. Cagliari University

Ireland

1. Dublin Institute of Advance Study 2. National University of Ireland, Maynooth

Switzerland

1. CERN, 2. University of Zurich, 3. University of Bern

The Netherlands

1. Institute for Theoretical Physics Amsterdam

France

1. SPhT, 2. CEA Saclay, 3. LPT, 4. Universite de Paris XI

Belgium

1. Department of Physics, University Catholique Louvain,

Spain

University Santiago de Compostela

Denmark

Niels Bohr Institute- University of Copenhagen

Taiwan

1. Institute of Physics, Academia Sinica, 2. Institute of Mathematics, Academia Sinica

Japan

Osaka University, Osaka

Korea

1. Kyungnam University, 2. Semyung University

Data analyses were performed in cooperation with corresponding experimental collaborations:

- ALICE, SMC and COMPASS (CERN, Switzerland)
- H1 and HERMES (DESY, Germany)
- E160/161 (SLAC, USA)
- CLAS (JLab, USA)

- Boomerang
- Wilkinson Microwave Anisotropy (WMAP)

- **Scientific council memberships:**

8 members of the Department are involved in scientific councils of YerPhI and Yerevan State University.

- **Editorial Boards:**

V. G. Gurzadyan: co-editor of Int. Journ. Mod. Phys. D; of book series "Advances in Astronomy and Astrophysics", Cambridge Sci. Publ. (UK).

VI. Expected development

What we expect and suggest for the near future of the Theory Division of YerPhI (5-10 year)?

- The ages of most active members is in the 40-55 range, and one can expect that most of them will continue to work in a next 5-10 years. Younger members will do the same, probably, and one can expect that some new younger members will appear from among the post-graduate student body. Whether some may return or relocate from abroad is questionable, but possible, especially for some postdoctoral fellows.
- Scientific scope of our researches is defined by personal interests of *staff members* and is expected to be a natural continuation of present ones, according to international development of corresponding fields.
- Important influence on Division has a policy of our government. Up to now main feature of that policy is small increase of funding weakly connected with results of the Division's work.
- For development we need a continuous funding (provided by the government) for 1-2 Ph.D. students per year.
- The most natural way of finding new opportunities for the Theory Division is connected with teaching. Taking into account that in general the members of the Theory Division are able to provide a high level teaching of corresponding subjects for MS-courses a reasonable suggestion would be:
To organize permanent MS programs/courses (5'th and 6'th years of university education) for theoretical and mathematical physics on the basis of the Theory Division of YerPhI.
- Another way could be the creation of an international theoretical physics laboratory in Yerevan, with national and international positions, filled on a competitive basis, with reasonable salaries. Funding of such a laboratory can be provided by e.g. long-term international grants and financial support of the Armenian government. The establishment of such joint programs requires decisions and agreements on a level of e.g. the Commission of European Communities, one country's government or even one large western university, depending on a source of funding on one hand, and the Armenian government on the other.