1.1 Fields and Particles

Theoretical research in *Fields and Particles* division of BLTP covers a wide field of activity in "pure theory" and phenomenology of particle physics. The "pure theory" research reflects modern tendency in theoretical and mathematical physics motivated by the string theory, while phenomenology of fundamental interactions is linked to modern experimental development in accelerator and non-accelerator physics.

In "pure theory" one should mention the following main topics:

- Integrable models
- Quantum Lie algebras
- Noncommutative geometry
- Supersymmetry and brane dynamics
- Quantum gravity
- Lattice gauge theories
- Constrained dynamics

High energy physics phenomenology includes the Standard Model of fundamental interactions and its extension, and low-energy hadron physics. The main topics are:

- QCD structure functions
- Spin and polarization phenomena
- Nonperturbative QCD
- Heavy flavours and B-physics
- Chiral models and meson spectroscopy
- Supersymmetry phenomenology

In recent two years considerable progress was achieved in several directions. Below one can find a collection of mini reports on various topics which contain a detailed description of the results obtained at BLTP in both pure theory and phenomenology.

In "pure theory" one should mention first of all the development of the systematic approach to quantum integrable systems based on quantum group theory and BRST symmetry where BRST operator for quantum Lie algebras was found (A. Isaev). Further progress was in harmonic superspace formulation of nonlinear Born-Infeld and Dirac-Born-Infeld actions which provide a systematic method of constructing manifestly off-shell supersymmetric actions in D=4, (E. Ivanov, B. Zupnik), the concept of partial spontaneous breaking of global supersymmetry was used to describe superbranes providing potential approach to implications in string theory (E. Ivanov, S. Krivinos). Superfield formulation of softly broken supersymmetric theories with the Fayet-Iliopoulos term were completed (D. Kazakov, V. Velizhanin). New results were obtained in the investigation of the supersymmetrc Toda lattice hierarchy (V. Kadyshevsky, A. Sorin). The explicitly analytically integreble models in 1+1 dimensional dilaton gravity were proposed (A. Filippov). Interesting phenomenon that happens in extreme conditions and strong fields was studied within the nonlinear spectral problem and spectral geometry (D. Fursaev), a pure geometrical approach was proposed to describe the free energy of proteins proceeding from the general invariance requirements and functionals linear in curvature (V. Nesterenko). New special functions of mathematical physics which provide elliptic generalizations of q-hypergeometric series were derived in the theory discrete nonlinear integrable equations (V. Spiridonov). Phenomena in intensive electromagnetic fields were considered in the framework of the modified QFT containing a new universal parameter – fundamental mass (V. Kadyshevsky, V. Rodionov).

Among phenomenological applications it should be mentioned the next-to-leading QCD analysis of the polarized structure functions and x-dependence of higher twist contributions (A. Sidorov), comparative analysis of the BFKL and DGLAP equations in supersymmetric gauge theories (A. Kotikov), study of azimutal asymmetries in semi-inclusive deep-inelastic scattering of polarised protons which allows one to extract the distribution of transversely polarized quarks in nucleon (A. Efremov), investigation of the crossing properties of nonperturbative QCD matrix elements - the generalized parton distributions - in deeply virtual Compton scattering (O. Teryaev), analysis of CLEO and E791 data aimed to extract the pion distribution amplitude within the nonlocal condensate QCD sum rule method (A. Bakulev, S. Mikhailov), application of nonperturbative expansions to the threshold behaviour for inclusive τ-decay and extraction of the Adler function (I.Solovtsov), new approach to studing meson properties based on nonlocal effective chiral quark model induced by instanton exchanges and nonlocal quark condensate (A. Dorokhov, M. Volkov, V. Yudichev), detailed analysis of exclusive B-decays which allows one to extract the Cabibbo-Kobayashi-Maskawa matrix elements (M. Ivanov), the phenomenology of very high multiplicity processes based on the thermodynamic description (J. Manjavidze, A. Sissakian), search for a possible manifestation of supersymmety in cosmic ray experiments in space (D. Kazakov), etc.

One can find rather a wide diversity of topics demonstrating broad research interests in *Fields and Particles* division of BLTP, though not all of them are included in this report. Still even this long list does not cover the whole field of particle physics. One can notice, however, that the main topics reflect an up-to-date research in the directions of activity in the world leading centers.

D. Kazakov

BRST SYMMETRY AND BRST OPERATORS FOR QUANTUM LIE ALGEBRAS

A.P. Isaev

The understanding of the BRST symmetry on cohomological grounds made possible a unified approach to a solution of many problems in gauge theories. The BRST symmetry is generated by the BRST operator Q which is a boundary operator ($Q^2 = 0$) for a standard complex of Lie algebras in the case of gauge Lie groups. From the point of view of the differential geometry, the Lie algebras are vector fields over the space of Lie groups.

The quantum group theory is a theory of symmetries of quantum integrable models. The noncommutative differential geometry on quantum groups leads to the notion of quantum Lie algebras which are noncommutative analogs of the vector fields over quantum group spaces. The problem we are working on is an investigation of the *Quantum standard complex and BRST operator for quantum Lie algebras.* We hope that our BRST theory for quantum Lie algebras will be helpful for a deeper undestanding of the deformation quantization of (irregular) Poisson brackets associated with the classical Yang-Baxter equation [3].

A quantum Lie algebra is a special example of quadratic algebras. The quantum Lie algebra has generators χ_i, ($i = 1, 2, \ldots, N$) subject to defining relations:

$$\chi_i\,\chi_j - \sum_{k,n} \sigma_{ij}^{kn}\,\chi_k\,\chi_n = \sum_k C_{ij}^k\,\chi_k,$$

where σ_{ij}^{kl} and C_{ij}^k are structure constants constrained by certain consistency relations (for details see [1]). The consideration of this algebra is also motivated by the Woronowicz theory of differential calculi on Hopf algebras $\mathcal{A}$, where the elements $\{\chi_i\}$ are interpreted as noncommutative vector fields over $\mathcal{A}$. Moreover, the quantum Lie algebra is a direct generalization of Lie superalgebras: it can immediately be recovered from the defining relations for the special choice of the matrix σ_{ij}^{kn} as the super-permutation matrix. For these quantum Lie algebras the BRST operator (which generates the differential in the Woronowicz theory) was proposed in [1]. In this paper we deduce the inductive equations which define the BRST operator uniquely. The explicit solution of these inductive equations were found recently in [2].

Then, the following conjecture was formulated: the quantum Lie algebra complex (for which the boundary operator is given by the action of the BRST operator) can be included as a subcomplex into the Hochschild complex for the quantum Lie universal enveloping algebra. To prove this conjecture, we need to check a number of complicated identities on the structure constants σ_{ij}^{kl} and C_{ij}^k. Similar identities appeared in the inductive definition [1] of the BRST operator for quantum Lie algebras. An elegant proof of these identities was found. First, we combine the constants σ_{ij}^{kl} and C_{ij}^k into a bigger matrix which realizes an R-matrix representation of the braid group $\mathcal{B}_\bullet$ (see [2]). Then we use the properties of the Jucys - Murphy elements in $\mathcal{B}_\bullet$, the notion of the quantum shuffle product and the so-called Zagier identities for the braid group algebra.

Now we investigate, by means of Koszul's type arguments, the acyclicity of the standard complex for meaningful examples of the quantum Lie algebras. A review of the theory of quantum Lie algebra $U_q(gl(n))$ with an emphasis on the explicit constructions of the relevant BRST, anti-BRST and quantum Laplace operators was presented in [4].

Note that the (anti)commutator with this BRST operator defines the differential on the de Rham complex over the quantum group $GL_q(N)$. For this complex we also formulated (see [4]) the Hodge decomposition theorem which is needed to prove the acyclicity.

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GOLDSTONE SUPERFIELD ACTIONS IN ADS BACKGROUNDS

E. Ivanov and S. Krivonos

The description of superbranes in terms of worldvolume Goldstone superfields based on the concept of partial spontaneous breaking of global supersymmetry (PBGS) is advantageous in many respects. Its main attractive feature is that the corresponding invariant actions reveal manifest off-shell linearly realized worldvolume supersymmetry. The second half of the full supersymmetry is nonlinearly realized.

The PBGS approach has many potential capacities and implications in string theory, e.g. for constructing non-Abelian Born-Infeld actions, as well as their supersymmetric extensions, for describing different possibilities of a nonstandard partial supersymmetry breaking (such as $1/4, 3/4, \ldots$) and studying the Hamiltonian and quantum structure of the relevant models, etc. It has actively been developed in Sector 3 of BLTP for the last few years.

Most PBGS theories constructed so far (including those constructed by the authors, see [1] and references therein) correspond to superbranes on flat super Minkowski backgrounds. On the other hand, at present, keeping in mind the renowned AdS/CFT correspondence hypothesis[2], of primary interest are the AdS$\times S^n$ and pp-wave type superbackgrounds. While Green-Schwarz type actions for branes on such backgrounds are known, not too many explicit examples of the worldvolume superfield PBGS actions were presented. Until now such actions were given only for $N = 1$ supermembrane in AdS$_4$ [3], $N = 1$ superstring in AdS$_3$ [4] , $N = 2$ superparticle in AdS$_2$ [5], $N = 1$ L3 brane on AdS$_5$ and its dual version – scalar super 3-brane on AdS$_5 \times S^1$ [6, 7]. The corresponding groups of superisometries coincide with superconformal groups in dimensions lower by 1, so the construction of these PBGS systems amounts to setting up appropriate nonlinear realizations of superconformal symmetries.

The key difference between PBGS theories on flat Minkowski- and curved AdS-type backgrounds lies in the structure of the superconformal groups realized as superisometries of the AdS backgrounds. These groups contain higher dimensional Lorentz groups in the anticommutators of Poincaré and conformal supersymmetry. Being nonlinearly realized, conformal supersymmetry forces spontaneous breaking of Lorentz symmetry. One may demonstrate that the requirement of covariance under the nonlinearly realized Lorentz symmetry provides an alternative way of deducing the nonlinear constraints which define the corresponding minimal PBGS actions for Goldstone superfields. In the curved cases these constraints should be imposed from the very beginning in order to obtain the appropriate realization in terms of the Goldstone supermultiplet.

The most interesting AdS superbrane case among those worked out so far corresponds to L3 brane in AdS_5 superbackground, with the $N = 1, d = 4$ superconformal group $SU(2,2|1)$ as the group of superisometries. In [6, 7], we have shown that the implementation of the automorphism $SO(1,4)$ symmetry in the framework of a "linear" realization of spontaneously broken $N = 2$ supersymmetry puts additional strong constraints on the Goldstone $N = 2$ tensor multiplet. In terms of $N = 1$ superfields this version involves, as the basic Goldstone multiplet, the so-called improved $N = 1$ tensor multiplet L obeying the constraints

$$\frac{1}{m}D^2 e^{-2mL} = \frac{1}{m}\bar{D}^2 e^{-2mL} = 0 \tag{1}$$

and a pair of mutually conjugated $N = 1$ chiral and antichiral superfields $F, \bar{F}$ which are subjected to the following nonlinear constraints:

$$F = -\frac{e^{-2mL} D^\alpha L D_\alpha L}{2 - e^{4mL} D^2 \mathbb{F}} \ , \ \bar{F} = -\frac{e^{-2mL} \bar{D}_{\dot\alpha} L \bar{D}^{\dot\alpha} L}{2 - e^{4mL} \bar{D}^2 F} \tag{2}$$

(here m is the inverse AdS_5 radius). Therefore, the "linear realization" of conformal supersymmetry $SU(2,2|1)$ in the framework of the PBGS approach is intrinsically and unavoidably nonlinear. Thus, we see that, in the AdS_5 case, there are no direct analogs of either the linear PBGS realization of the flat cases, or the Goldstone tensor $N = 2$ superfield. An analog of the latter can be consistently defined only on the surface of the nonlinear constraints (2). Nevertheless, similarly to their flat counterparts, the constraint (2) can be easily solved and the static gauge Nambu-Goto action for L3 brane on AdS_5 can be constructed:

$$S = \frac{1}{4}\int d^4x d^4\theta \left[\frac{1}{m} L e^{-2mL} + \frac{\psi^2 \bar\psi^2}{1 + \frac{1}{2}A + \sqrt{1 + A + \frac{1}{4}B^2}} \right], \tag{3}$$

where

$$\psi_\alpha \equiv D_\alpha L \ , \ \bar\psi_{\dot\alpha} \equiv \bar{D}_{\dot\alpha} L \ , \ A = \frac{1}{2} e^{2mL} \left(D^2 \bar\psi^2 + \bar{D}^2 \psi^2 \right) \ , \ B = \frac{1}{2} e^{2mL} \left(D^2 \bar\psi^2 - \bar{D}^2 \psi^2 \right). \tag{4}$$

The study in [3-7] can be regarded as first steps in a program of constructing off-shell Goldstone superfield actions for various patterns of partial breaking of $AdS \times S$ supersymmetries and their nontrivial contractions corresponding to pp-wave type backgrounds. One of the obvious related tasks is the quest for an action corresponding to the half-breaking of the $N = 2$ AdS_5 supergroup $SU(2,2|2)$, in a supercoset with the $AdS_5 \times S^1$ bosonic part. In this case, the basic Goldstone superfield that we expect to deal with should be the appropriate generalization of the $N = 2$ Maxwell superfield strength. The relevant minimal action should be a superconformally invariant version of the Dirac-Born-Infeld action describing $N = 4 \to N = 2$ partial breaking in flat superspace.

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N=3 HARMONIC SUPERSPACE AND NONLINEAR ELECTRODYNAMICS

E.A. Ivanov, B.M. Zupnik

Supersymmetric extensions of the Born-Infeld (BI) and Dirac-Born-Infeld actions, being essential parts of the worldvolume actions of Dp-branes, are of pivotal importance in modern string theory. The nonlinear realization approach provides a systematic method of constructing manifestly off-shell supersymmetric $D = 4$ BI actions as the Goldstone-Maxwell actions for some partially broken higher-order supersymmetries. In this way, $N = 1$ and $N = 2$ supersymmetric superfield BI actions were found. They describe partial spontaneous breaking of the appropriate $N = 2$ and $N = 4$ supersymmetries (see [3] for a review). Until recently, no off-shell superextension of the $D = 4$ BI action with higher manifest supersymmetry is known. The first example of this kind, the off-shell $N = 3$ supersymmetric $D = 4$ Born-Infeld action, was constructed in [2] in the framework of $N = 3$ harmonic superspace.

The N=3 harmonic superspace was originally introduced in [3]-[5] as a tool for constructing an off-shell unconstrained superfield formulation of $N = 3$ gauge theory (amounting to $N = 4$ gauge theory on shell). The off-shell action of $N = 3$ gauge theory has an unusual form of superfield Chern-Simons-type term and exists entirely due to a few unique (almost miraculous) peculiarities of $N = 3$ harmonic superspace. The opportunity to construct the $N = 3$ BI action also amounts to one of such peculiarities, namely, to the presence of bispinor auxiliary fields in the off-shell $N = 3$ gauge multiplet.

It was shown in [6, 7] that the on-shell $N = 3$ Abelian superfield strength 'lives' in the Grassmann-analytic $N = 3$ superspace with six odd coordinates. The free $N = 3$

equations of motion can be formulated as harmonic-analyticity conditions for this superfield strength, which guarantees the ultrashortness of its on-shell component structure. In [2], we constructed an off-shell generalization of this analytic superfield strength, with an infinite number of auxiliary fields. On shell some auxiliary fields are expressed through derivatives of physical fields, and another (major) part of auxiliary fields vanishes. In particular, the component electromagnetic action turns out to be a bilinear form of the standard Maxwell field strength $F_{\alpha\beta}$ and an auxiliary bispinor field $V_{\alpha\beta}$. The standard Maxwell action is restored after eliminating this auxiliary field.

A crucial new feature of the $N = 3$ super BI action compared to the $N = 1$ and $N = 2$ ones is that its interaction part contains only terms of the order of $4k$ in the $N = 3$ superfield strengths. It was shown that the yet simplest 4-th order superfield term, after elimination of bispinor auxiliary fields, generates an infinite series of component electromagnetic terms F^{2k} which, starting with $k = 4$, is not identical to a 'naive' expansion of the Born-Infeld action. Nonminimal superfield terms with additional spinor derivatives contribute to the component electromagnetic terms with $k \geq 4$. These superfield terms reproduce the auxiliary-field terms in the component electromagnetic action as well as the corresponding nonlinear interactions of scalar and fermionic fields of the $N = 3$ vector multiplet. The correct component BI action arises as the result of elimination of bispinor auxiliary fields in the entire $N = 3$ superfield action.

This unusual mechanism of reproducing the component BI action inspired by the $N = 3$ supersymmetric formulation offers a new approach to the analysis of the important class of nonlinear extensions of the Maxwell theory, namely those revealing the property of self-duality. The BI action is merely a particular case of such actions. We have analyzed a new (F, V)-representation of this nonlinear electrodynamics, using an arbitrary self-interaction E depending on the auxiliary field $V_{\alpha\beta}$. It has been shown that the nonlinear condition of the $U(1)$ duality amounts to the *linear* condition of the $U(1)$ invariance of the self-interaction E in this new representation. The generic choice of the interaction function gives us a wide set of duality-symmetric nonlinear extensions of the Maxwell action. All these nonlinear electrodynamics models admit off-shell $N = 3$ supersymmetrization.

In ref.[8] we also discussed the $U(n)$ duality-symmetric interactions of n Abelian fields, using linearly transforming auxiliary bispinor fields. The whole class of the $U(n)$ duality-symmetric Lagrangians is described by $U(n)$-invariant self-interactions of the auxiliary fields.

This new approach to the $U(1)$ and $U(n)$ dualities allowed us to find new examples of the duality-symmetric systems. Its extension to the most interesting non-Abelian case is now under way.

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SUPERSYMMETRIC DISCRETE AND CONTINUUM TODA LATTICE HIERARCHIES

V.G. Kadyshevsky and A.S. Sorin

In several recent decades, quantum field theory, having incorporated efficient mathematical methods, has become a theory satisfying the most rigorous mathematical requirements. After the formulation of supersymmetric quantum field theories, the main attention of investigators was attracted by numerous problems whose solution is interesting in both mathematical physics and important physical applications.

In [1], we considered the integrable $N{=}(1|1)$ supersymmetric generalization of the two-dimensional bosonic Toda lattice hierarchy (2DTL hierarchy). It is given by an infinite system of evolution equations (flows) for an infinite set of bosonic and fermionic lattice fields evolving in two bosonic and two fermionic infinite "towers" of times; as a subsystem, it involves $N{=}(1|1)$ supersymmetric integrable generalization of the 2DTL equation

$$D_1^+ D_1^- \ln v_{0,j} = v_{0,j+1} - v_{0,j-1}. \tag{1}$$

We constructed two new infinite series of fermionic flows of the $N{=}(1|1)$ 2DTL hierarchy. This hierarchy was shown to actually have a higher symmetry, namely, the $N = (2|2)$ supersymmetry. Together with the previously known bosonic flows of the $N{=}(1|1)$ 2DTL hierarchy, these flows are symmetries of the $N{=}(1|1)$ 2DTL equation.

In [1], we also proposed the two-dimensional $N = (0|2)$ supersymmetric Toda lattice hierarchy as well as its $N = (0|2)$ superfield formulation. Bosonic and fermionic solutions to the symmetry equation corresponding to the two-dimensional $N = (0|2)$ supersymmetric Toda lattice equation

$$\partial_- \ln\Big((\overline{D}_+ F_{j+1})(D_+ \overline{F})\Big) = -F_j \overline{F}_j + F_{j+1} \overline{F}_{j+1} \tag{2}$$

and their algebra were constructed. An infinite class of new two-dimensional supersymmetric Toda-type hierarchies were proposed.

Although the $N{=}(1|1)$ 2DTL hierarchy and the dispersionless $N{=}(1|1)$ 2DTL equation have been known for a relatively long time, the problem of constructing the continuum (semiclassical) limit with respect to the lattice constant (which plays the role of the Planck constant here) for all the $N{=}(1|1)$ 2DTL hierarchy flows was solved only quite recently in [2, 3]. Apart from the purely academic significance of this problem, its solution is also interesting in relation to a number of important physical and mathematical applications.

Thus, in [2, 3] generalizing the graded commutator in superalgebras, we first proposed a new bracket operation

$$\Big[\mathbb{O}_1, \mathbb{O}_2\Big\} := \mathbb{O}_1\mathbb{O}_2 - (-1)^{d_{\mathbb{O}_1} d_{\mathbb{O}_2}}\ {\mathbb{O}_2}^{*(d_{\mathbb{O}_1})}\ {\mathbb{O}_1}^{*(d_{\mathbb{O}_2})} \tag{3}$$

on the space of graded operators $\mathbb{O}_k$ with the grading $d_{\mathbb{O}_k}$ ($d_{\mathbb{O}_k} \in \mathbb{Z}$) and an involution $*$ which is defined in sufficiently general terms to allow a broad spectrum of applications. Furthermore, we studied properties of this operation and showed that the Lax representation of the two-dimensional N=(1|1) supersymmetric Toda lattice hierarchy can be realized via the generalized bracket operation

$$D_n^{\pm} L^{\alpha} = \mp\alpha(-1)^n \Big[(((L^{\pm})_*^n)_{-\alpha})^*, L^{\alpha}\Big\}, \quad \alpha = +, -, \quad n \in \mathbb{N},$$
$$(L^{\alpha})_*^{2n} := \Big(\frac{1}{2} \Big[(L^{\alpha})^*, (L^{\alpha})\Big\} \Big)^n, \quad (L^{\alpha})_*^{2m+1} := L^{\alpha} \, (L^{\alpha})_*^{2n}. \tag{4}$$

where $D_{2n}^{\pm}$ ($D_{2n+1}^{\pm}$) are bosonic (fermionic) evolution derivatives. This is important in constructing the semiclassical (continuum) limit of this hierarchy. Then, we constructed the continuum limit

$$\hbar \to 0, \quad s = \lim_{\hbar\to 0,\ j>>1}(\hbar j), \quad D_{2n+1}^{\pm} \to \sqrt{\hbar} D_{2n+1}^{\pm}, \quad D_{2n}^{\pm} \to \hbar D_{2n}^{\pm}, \quad L^{\pm} \to \frac{1}{\sqrt{\hbar}} \mathcal{L}^{\pm} \tag{5}$$

of the N=(1|1) Toda lattice hierarchy, the dispersionless N=(1|1) Toda hierarchy. In this limit, we obtained the Lax representation

$$D_n^{\pm} \mathcal{L}^{\alpha} = \mp\alpha(-1)^n \Big\{(((\mathcal{L}^{\pm})_*^n)_{-\alpha})^*, \mathcal{L}^{\alpha}\Big\}, \quad n \in \mathbb{N}, \quad \alpha = +, -,$$
$$(\mathcal{L}^{\alpha})_*^{2m} := \Big(\frac{1}{2} \Big\{(\mathcal{L}^{\alpha})^*, \mathcal{L}^{\alpha}\Big\} \Big)^m, \quad (\mathcal{L}^{\alpha})_*^{2m+1} := \mathcal{L}^{\alpha} \, (\mathcal{L}^{\alpha})_*^{2m}, \tag{6}$$

with the generalized graded bracket becoming the corresponding Poisson bracket

$$\Big\{\mathbb{F}_1, \mathbb{F}_2\Big\} = 2p \left(\frac{\partial \mathbb{F}_1}{\partial p} \frac{\partial \mathbb{F}_2}{\partial s} - \frac{\partial \mathbb{F}_1}{\partial s} \frac{\partial \mathbb{F}_2}{\partial p} + \frac{\partial \mathbb{F}_1}{\partial \pi} \frac{\partial \mathbb{F}_2}{\partial \pi} \right) + \pi \left(\frac{\partial \mathbb{F}_1}{\partial \pi} \frac{\partial \mathbb{F}_2}{\partial s} - \frac{\partial \mathbb{F}_1}{\partial s} \frac{\partial \mathbb{F}_2}{\partial \pi} \right) \tag{7}$$

on the graded phase superspace $\mathbb{F}_{1,2} \equiv \mathbb{F}_{1,2}(\pi, p, s)$. We also found bosonic symmetries of the dispersionless N=(1|1) supersymmetric Toda equation

$$D_1^+ D_1^- \ln v_0 = 2\partial_s v_0. \tag{8}$$

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INTEGRABLE MODELS OF HORIZONS AND COSMOLOGIES

A.T. Filippov

In the last decade 1+1 and 0+1 dimensional dilaton gravity coupled to scalar matter fields proved to be a reliable model for higher dimensional black holes and string inspired cosmologies. The connection between high and low dimensions was demonstrated in different contexts of gravity and string theory - symmetry reduction, compactification, holographic principle, AdS/CFT correspondence, and duality. For spherically symmetric black holes, branes, and cosmologies the description of static configurations is even simplified to 0+1 dimensional dilaton gravity - matter models, which in many interesting cases are explicitly analytically integrable (see e.g. [1], [2], [3], [4] and references therein).

However, generally, they are not integrable. For example, spherical black holes coupled to Abelian gauge fields are usually described by integrable 0+1 dimensional models, while adding the cosmological constant term destroys integrability. In 1+1 dimension, pure dilaton gravity is integrable, but coupling to scalar matter fields usually destroys integrability. The one very well studied exception is the CGHS model. In [2], a more general integrable model of dilaton gravity coupled to matter was proposed which incorporates as limiting cases the CGHS and other known integrable models. It reduces to two Liouville equations, the solutions of which should satisfy two constraints. Since the general analytic solution of the constraints was not found at that time, the model of Ref.[2] received little attention and was not studied in detail.

Recently, the author proposed a class of more general integrable dilaton gravity models in dimension 1+1, which are reducible to N-Liouville equations (a brief summary is published in Ref.[5]). For these models the general analytic solution of the constraints was found. We demonstrated that the N-Liouville models are closely related to physically interesting solutions of higher dimensional supergravity theories describing the low-energy limit of superstring theories. The 1+1 dimensional N-Liouville theories describe the solutions of higher dimensional theories in some approximation. On the other hand, their reduction to dimensions 1+0 (cosmological) and 0+1 (static, black holes) give an exact solution of higher dimensional theories.

Static black holes and cosmological models are described by one-dimensional solutions of the 1+1 dimensional theories. In the standard approach the deep connection between these two types of solutions is not transparent and is usually ignored (even the precise relation between the dimensional reductions used by 'cosmologists' and by 'black holes investigators' is not quite obvious). We thus start from the 1+1 dimensional formulation to get a unified description of these two objects. A characteristic feature of static solutions of the models derived from string theory is the existence of horizons with nontrivial scalar field distributions. What must be characteristic features of string cosmologies is as yet a much discussed problem.

The explicitly analytically integrable models proposed in [5] may be of interest for different applications. The most obvious is to use them to construct first approximations to generally non integrable theories describing black holes and cosmologies. Realistic theories of these objects are usually not integrable (even in dimension 0+1). Having explicit general solutions of the zeroth approximation in terms of elementary functions it is not difficult to construct different sorts of (classical) perturbation theory.

It may be useful to combine this approach with the recently proposed analytic perturbation theory allowing to find approximate analytic solutions near horizons for most general nonintegrable 0+1 dilaton gravity theories [6]. The detailed description of the N-Liouville (and of the Toda type) integrable theories as well as applications to black holes and cosmology will be the subject of further investigations [7].

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FINITE-TEMPERATURE THEORIES IN EXTERNAL BACKGROUND FIELDS AND NON-LINEAR SPECTRAL PROBLEMS

D. Fursaev

Search for new efficient methods applicable to description of matter in extreme conditions (under high temperature, density and in the presence of strong gravitational, gauge and other background fields) is dictated by current and anticipated in future experimental data. The central place here belongs to experiments with heavy ion collisions at RHIC and LHC aimed at studying properties of quark-gluon plasma. Also, the astrophysical data from Hubble, Chandra and other telescopes on effects produced by neutron stars and black holes are highly important. If the hypothesis of strange stars finds further support from the observation, there will be a possibility of studying effects of quark-gluon plasma in "natural laboratories" created under strong gravity.

The development of thermal field theories went mostly in two directions. The first is the loop computations at a finite temperature. The second direction is studying instanton effects in the framework of the Euclidean approach. Although both these developments are highly important, they cannot be directly used to describe effects in the presence of strong background fields. The problem is that methods used in loop computations require zero or trivial background fields. Instantons are formally nontrivial backgrounds but they belong to the Euclidean theory. For this reason their role is to interpolate between different vacua rather than present actual physical background fields.

To fill this gap, part of my activity in 2001-2002 [1]–[3] was related to work on a method which would allow one to make successful computations in stationary background fields of quite a general form. To calculate the free energy of noninteracting fields on such backgrounds, one has to find the spectrum of energies ω of single-particle excitations. It is studying the spectrum of ω where the main problem comes out. The difficulty is that the corresponding eigenvalue equation has the form

$$\left[\omega^2 - L(\omega)\right] \phi_\omega(x) = 0, \tag{1}$$

$$L(\omega) = L_2 + \omega L_1 + \omega^2 L_0 \quad , \tag{2}$$

where L_k are some kth order differential operators. The problem (1) is not conventional in general because the operators L_k do not commute to each other. In the mathematical literature such problems belong to the class of polynomial operator pencils. In particular, (1) is called the quadratic operator polynomial. Fundamentals of the theory of the operator polynomials were formulated in the works by the Soviet mathematician M.V. Keldysh. Equations like (1) also appear in many other physical problems (for instance, in studying oscillations of a viscous fluid or in the Schrödinger equation with energy-dependent potential, etc).

The main result of [1] is in showing that the notion of spectral geometry and the developed machinery is applicable to the quadratic operator polynomials (1). This has been done by demonstrating that the nonlinear spectral problem (1) for physically interesting systems can be related to the eigenvalue problem for the operator $L(\omega)$ where ω is treated as a free parameter.

Concerning physical applications, our results [1]–[3] enable one to study the free energy (for example, its high temperature behaviour) for a variety of complicated systems without knowing an explicit form of the spectrum ω. The suggested method is highly efficient. For instance, it yields the Debye screening mass in hot plasma in an arbitrary external electric field (while other methods usually assume the weak field approximation and use a perturbation theory). For systems in the gravitational field, no matter how complicated the background metric can be, it yields a generic form of the free-energy which takes into account the effects of rotation.

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CONFORMAL COSMOLOGY APPROACH TO THE Ω_Λ PROBLEM

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The analysis of the magnitude – redshift relation from observation of distant-type Ia Supernovae in terms of standard cosmology (SC), which explains the redshift of spectral lines by the Doppler effect of receding galaxies, a perfect fit of the data is obtained for a nonvanishing positive cosmological constant $\Omega_\Lambda = 0.7$, i.e. for accelerated expansion of the universe. The origin of this dark energy component in the cosmic equation of state is a challenging puzzle of modern cosmology. As a possible solution, we suggested a conformal cosmology (CC) approach in which the universe is not expanding and the observed redshift is caused by the time-dependence of all particle masses [1]. Such a scenario provides a solution to the problems of fine-tuning (coincidence) and vacuum condensates which arise from the SC expansion. These alternative scenarios give different predictions for high-redshift supernovæ so that falsification is possible, see Fig. 1. Other constraints for the CC scenario are discussed in [2]. They mainly concern the element abundances [1] and the origin of the cosmic microwave background radiation [3, 4].

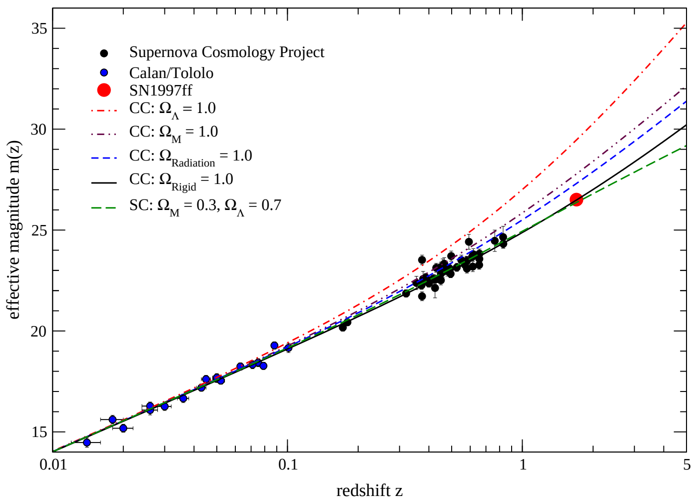

Fig. 1: Luminosity-redshift-relation for a flat universe model in SC an CC. An optimal fit to these data within the SC requires a cosmological constant $\Omega_\Lambda = 0.7$, whereas in the CC these data require the dominance of the rigid state [1].

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NEW SPECIAL FUNCTIONS OF MATHEMATICAL PHYSICS

V.P. Spiridonov

Series of hypergeometric type are among the most widely used classes of special functions in mathematical physics. Their theory has been developing over centuries in two instances: the plain generalized hypergeometric functions ${}_sF_r$, ${}_sH_r$ and their basic analogues ${}_s\Phi_r$, ${}_s\Psi_r$, known as q-series. About six years ago, it was recognized by Frenkel and Turaev that elliptic solutions of the Yang-Baxter equation (i.e. the Boltzmann weights of the Baxter's XYZ spin chain model, their generalizations due to Andrews, Baxter and Forrester together with further extensions found by Date, Jimbo, Kuniba, Miwa and Okado) provide elliptic generalizations of q-hypergeometric series of a special type. In an independent setting, such functions were derived in the theory of discrete nonlinear integrable equations [7]. Starting with the latter result, the author worked on general foundations of the theory of these and more general special functions.

A principally new type of biorthogonal functions was discovered in [3, 7]. It generalizes the Rahman-Wilson biorthogonal rational functions (BRF) which are known to contain Askey-Wilson polynomials, the most general set of classical orthogonal polynomials, as particular subcases. As a first step, an elliptic extension of the Wilson functions with a discrete biorthogonality measure was constructed in [7]. These functions are expressed in terms of a terminating ${}_{12}E_{11}$ elliptic hypergeometric series. An appropriate understanding of their internal structure (leading to a crucial change of the system of notation) and a formulation of the general theory of *theta hypergeometric series*, or series of hypergeometric type associated with Jacobi theta functions, were reached in [4]. For the first time, the Bailey chains technique was generalized to the elliptic level in [5]. Bailey chains provide regular tools for building infinite sequences of identities (summation of transformation formulae) for series of hypergeometric type. The corresponding results gave a completely new viewpoint on the origins of very old notions of balancing, well-poisedness, and very-well-poisedness for hypergeometric series connecting them to some properties of elliptic functions.

As a next step, elliptic generalizations of the Rahman's continuous BRF were built in [3]. The normalization condition of the corresponding absolutely continuous part of the measure is determined by the elliptic beta integral discovered in [2]. This integral represents a new class of exact integration formulae of mathematical analysis, in particular, the most general known beta-type integral generalizing the Askey-Wilson and Nassrallah-Rahman integrals. It employs the elliptic gamma function and contains the Frenkel-Turaev ${}_{10}E_9$ series sum as a particular fininte-dimensional subcase.

As a further generalization of hypergeometric BRF, an unusual class of *non-self-dual* BRF expressed through the plain ${}_9F_8$, basic ${}_{10}\Phi_9$, and elliptic ${}_{12}E_{11}$ hypergeometric series is derived in [7]. In it, even at the ${}_9F_8$-level, one has to solve an algebraic equation of the fifth degree for representation of BRF in the hypergeometric series form.

The most general class of presently known explicit terminating continued fractions was determined in [7] with the help of the three-term recurrence relation for ${}_{12}E_{11}$ discrete elliptic BRF. It represents an elliptic extension of the Gupta-Masson ${}_{10}\Phi_9$ continued fractions which include the famous Ramanujan and Watson examples. Uniqueness of the elliptic BRF follows from the fact that the most general rational functions admitting divided-difference symmetry operators must live upon the elliptic grids [7].

Finally, a system of meromorphic functions generalizing self-dual elliptic BRF was introduced in [3]. It contains one more discrete parameter and satisfies an unusual condition of biorthogonality over two discrete indices. It is expected that these functions determine the most general elliptic $6j$-symbols and define the top level "classical" special functions in the theory of biorthogonal functions.

In [1], a multivariable extension of the elliptic beta integral of [2] was proposed (this integral is an elliptic extension of the celebrated Selberg integral). It generalizes the most general Gustafson's q-beta integral for the C_n root system which is known to be reducible to various Macdonald-Morris constant term identities for different limiting values of parameters. The latter play an important role in the theory of multivariable orthogonal polynomials and symmetric functions. A different C_n multiple elliptic beta integral and a rigorous analysis of interrelations between the two are given in the subsequent puiblications [1]. The corresponding residue calculus was considered and shown to lead to some multiple analogues of the Frenkel-Turaev sum, including the sum proposed by Warnaar. Some new summation formulae for multiple elliptic hypergeometric series related to root systems A_n and D_n are suggested in [6] (they were introduced independently and proved by Rosengren as well). It is expected that the integrals proposed in [1] provide the measure for multivariable elliptic biorthogonal functions generalizing the one-variable functions of [3, 7] and the celebrated Macdonald polynomials. The obtained results should find various applications in mathematical physics, namely, in solvable lattice models of statistical mechanics, quantum multiparticle systems, random matrices and models of inhomogeneous Coulomb gases.

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INTENSIVE ELECTROMAGNETIC FIELDS IN THE THEORY WITH FUNDAMENTAL MASS

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Phenomena in intensive electromagnetic fields are considered in the framework of the modified QFT containing a new universal parameter – *fundamental mass* [1, 2]. Considerable reduction of distances, characterizing formation of processes in these fields, leads to effects determined by the relation between two parameters - the fundamental mass and the electromagnetic length. The analysis of the threshold phenomena in the external magnetic field is based on exact solutions of the modified Dirac equation in *QED with the fundamental mass*. This approach shows that the fundamental mass results in a new field parameter that can naturally be called the *fundamental field*. Dispersion relations are proved for some threshold reactions in rather general external electromagnetic fields without any restriction on the electromagnetic field strength. Influence of intensive electromagnetic fields on quasistationary states for different quantum systems is considered by the method of analytic continuation to the complex plane of energy values [3]–[5]. This approach to the problem of deriving and understanding dispersion relations was used to establish the characteristic parameters of the length determining process formation in superstrong fields and to find their connections with the scale of the *fundamental length*. The subsequent use of the analytic continuation method allowed obtaining a number of nonlinear equations. These equations determine complex energy in an external field when a nonzero angular momentum of a system is taken into account. The asymptotic behavior of real and imaginary values of energy are investigated in the limits of weak and strong electromagnetic fields. The exact Lagrange function of intensive constant magnetic field is calculated within the framework of the theory with the fundamental mass in the one-loop approximation [6]. This function substitutes for the Heisenberg-Euler Lagrangian of the traditional QED. In the limit of a weak field the Lagrangian of the modified theory coincides with the known Heisenberg-Euler formula. In the case of extremely strong fields the dependence of the new Lagrangian on a field completely disappears and is defined by the relation of fundamental and lepton masses. It is established that the generalization of the Lagrange function at any values of a magnetic field is real.

Further development of the *method of exact solutions* refers to a formalism of complex quasi-energy [7]–[10]. The possibility of decay stabilization of bound states of any spinor and scalar particles by means of the intensive magnetic field is clarified. It is established that the results demand revision of the conventional idea of the stabilizing role of a strong magnetic field in the processes of atom ionization.

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FUNCTIONALS LINEAR IN CURVATURE AND PROTEIN FOLDING

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A fascinating and open question challenging physics, biochemistry and even geometry is the presence of highly regular motifs such as $\alpha-helices$ and $\beta-sheets$ in the folded state of biopolymers and proteins. A wide range of approaches was proposed to rationalize the existence of such secondary structures [1, 2, 3]. In principle, in order to find the stable native state of a protein, one should compute, for every possible conformation of the chain, the sum of free energies of atomic interactions within the protein as well as with the solvent and then find the conformation with the lowest free energy. However, it is not feasible, because the number of conformations of a protein chain grows exponentially with the chain length.

We propose a pure geometrical approach to describe the free energy of proteins, proceeding with the most general invariance requirements and basic experimental facts concerning the protein conformation. Taking into account the one-dimensional nature of the protein chains, the relevant macroscopic free energy F should be considered as a functional defined on smooth curves $\mathbf{x}(s)$ (or paths) in the three dimensional Euclidean space

$$F = \int \mathcal{F}[\mathbf{x}(s)]ds,$$

where s is the length of a protein molecule. The reparametrization invariance of the functional F demands the free energy density $\mathcal{F}$ to be a scalar function depending on the geometrical invariants of the position vector $\mathbf{x}(s)$ which describes the spatial shape of the protein chain. In three- dimensional ambient space a smooth curve has two local invariants: curvature $k(s)$ and torsion $\kappa(s)$ [4]. Curvature of a curve characterizes the local bending of a curve. Hence, the dependence of free energy density $\mathcal{F}$ on $k(s)$ specifies the resistance of a protein chain to be bent. Torsion $\kappa(s)$ is determined by the relative rotation, around the tangent $d\mathbf{x}(s)/ds$ at the point s, of two neighbor infinitely short elements of the protein chain. It is well known [1] that, in the case of protein molecules, such a rotation is quite easy, as it requires little effort. In other words, this rotation results in small energy differences, allowing many overall conformations of a protein chain to arise. Thus, the dependence of the free energy density $\mathcal{F}$ on torsion $\kappa(s)$ can be neglected at least as a first approximation. Finally, one can consider the free energy density $\mathcal{F}$ to be a function only of the curvature $k(s)$, i.e., $\mathcal{F} = \mathcal{F}(k(s))$.

We confine ourselves to helical proteins and try to answer the question: Is it possible to specify the function $\mathcal{F}(k(s))$ in such a way that the extremals of the functional $F = \int \mathcal{F} ds$ would be only helices? The answer to this question turns out to be positive and unique, namely, the density of the free energy $\mathcal{F}(k(s))$ should be a linear function of the curvature $k(s)$:

$$\mathcal{F}(k) = \alpha - |\beta|\, k(s),$$

where the constants α and β are the parameters specifying the phenomenological model proposed, $\alpha > 0$, $\beta < 0$. A rigorous proof of this assertion is given in [5] by making use of the results of our previous papers [6, 7], where the integrability in quadratures of the Euler-Lagrange equations is shown for arbitrary function $\mathcal{F}(k(s))$ in Minkowski space-time.

Certainly, our simple model does not pretend to describe all the aspects of the protein folding. However, one can hope that it could be employed, for example, in Monte Carlo simulation to search for a stable native state of the protein. In this case the model can be used for the description of the free energy of individual parts (blocks) of a protein chain which have the helical form. Without any doubt, it should result in simplification and acceleration of the exhausting searching for the native stable state of the protein chain by a computer [1].

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DGLAP AND BFKL EQUATIONS IN THE N=4 SUPERSYMMETRIC GAUGE THEORY

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The Balitsky-Fadin-Kuraev-Lipatov (BFKL) equation and the Dokshitzer-Gribov-Lipatov-Altarelli-Parisi (DGLAP) equation are used now for a theoretical description of structure functions of the deep-inelastic *ep* scattering. The next-to-leading order (NLO) QCD corrections to the splitting kernels of the DGLAP equation are well known. On the other hand, the calculation of the corresponding corrections to the BFKL kernel was completed comparatively recently [1, 2, 3].

In supersymmetric gauge theories the structure of the BFKL and DGLAP equations is significantly simplified. In the case of an extended $N = 4$ SUSY the NLO corrections to the BFKL equation were calculated in ref. [3] for an arbitrary value of the conformal spin $|n|$. The cancellation of nonanalytic contributions proportional to δ_n^0 and δ_n^2 in $N = 4$ SUSY was observed (such terms are remarkable and they contribute in the case of QCD and in N=1,2 supersymmetric models, as it was demonstrated in [3]). The analyticity of the eigenvalue of the BFKL kernel as a function of the conformal spin $|n|$ gives a possibility to relate the DGLAP and BFKL equations in this model.

Indeed, the analytic continuation of the BFKL kernel to negative $|n|$ values in the leading logarithmic approximation (LLA) allows one to obtain (see [5]) the residues of anomalous dimensions of the twist-2 operators in the nonphysical points of the Lorenz spin j: $j = 0, -1, ...$ from the BFKL equation in agreement with their direct calculation in the framework of the DGLAP approach in the same approximation. Moreover, in the multi-color limit of the $N = 4$ theory the BFKL and DGLAP dynamics in LLA for an arbitrary number of particles turns out to be integrable because the eigenvalues of the LLA pair kernels in the DGLAP equation for the matrix elements of the quasipartonic operators are proportional to $\Psi(j-1) - \Psi(1)$ [5]. This means that the corresponding Hamiltonian coincides with the local Hamiltonian for an integrable Heisenberg spin model [6].

As it was shown in [3], the analogous correspondence between the residues of the eigenvalues of the BFKL and DGLAP equations also takes place at the points $j = 0, -1, ...$ also in the NLO approximation which leads in particular to prediction of the NLO corrections to the anomalous dimensions of the twist-two operators of the Wilson expansion without a direct calculation.

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SEARCH FOR SUSY MANIFESTATION IN SPACE

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1. Search for various manifestations of supersymmetry in Nature was one of the main aims of numerous experiments at colliders and non-accelerator facilities in the previous decade. Theoretical investigation of the Minimal Supersymmetric Standard Model (MSSM) [1] showed that it was possible to meet different requirements such as a) unification of the strong and electroweak forces, thus providing a prototype theory for a Grand Unified Theory (GUT), b) spontaneous electroweak symmetry breaking (EWSB) by radiative corrections through the heavy top quark, c) unification of the Yukawa couplings resulting in the correct values of the masses of the third generation quarks and leptons, d) small corrections to the rare meson decays allowing one to fill the gap between the SM and experiment, e) right amount of the Dark matter in the Universe due to the presence of a light stable particle - neutralino, etc.

The constrained MSSM which simultaneously fulfills all the requirements happens to be a very predictive theory. Within the allowed regions in the parameter space it gives the spectrum of superpartners and the Higgs bosons, thus providing the pattern for experimental search. Two main scenarios selected by the above mentioned requirements are usually referred to as low and high $\tan\beta$ ones, $\tan\beta$ being the ratio of the v.e.v.s of the two Higgs bosons. The first scenario typically predicts relatively light superpartners and the lightest Higgs boson below 100 GeV, and is practically excluded by modern collider data. Search for the light charginos and neutralinos and the Higgs boson at LEP II collider gave no results and increased the bound for $\tan\beta$ up to 4.3. On the contrary high $\tan\beta$ scenario predicts relatively heavier particles and is under test now [2].

With the shut-down of LEP the only high energy machine operating at the moment is the proton collider Tevatron. Its energy may be sufficient to create strongly interacting superpartners and the Higgs bosons. However, the existing luminosity does not provide us with such new data so far. In this situation, our main attention is given to the low energy experiments and experiments in space.

2. Among the recent non-accelerator experiments which attracted much attention due to the almost 3σ discrepancy with the SM was the measurement of the anomalous magnetic moment of muon [3]. The observed deviation from the SM, although small, may be described by additional SUSY contributions, thus proving new constrains on the parameter space. In spite of the uncertainty of the value of the deviation from the SM, the sign of the deviation is fixed. This, in its turn, fixes the sign of the Higgs mixing parameter, μ, killing half of the parameter space. Modern regions of the allowed parameter space are shown at the top of Fig.1. They correspond to the high $\tan\beta$ scenario and are obtained as a result of a global statistical analysis of all the constraints [3].

3. Supersymmetry provides us with an excellent candidate for the cold Dark matter in the Universe. The neutralinos, which are the Lightest Supersymmetric Particles (LSP), are stable if R-parity is conserved. This new multiplicative quantum number for the supersymmetric partners of the Standard Model (SM) particles is needed to prevent proton decay and simultaneously a) prevents the LSP to decay into lighter SM particles and b) allows it to interact with normal matter only by producing additional supersymmetric particles. The cross sections for the latter are typically of the order of the weak ones, so the LSP is "neutrino-like", i.e. it would form halos around the galaxies and consequently, it is an excellent candidate for dark matter.

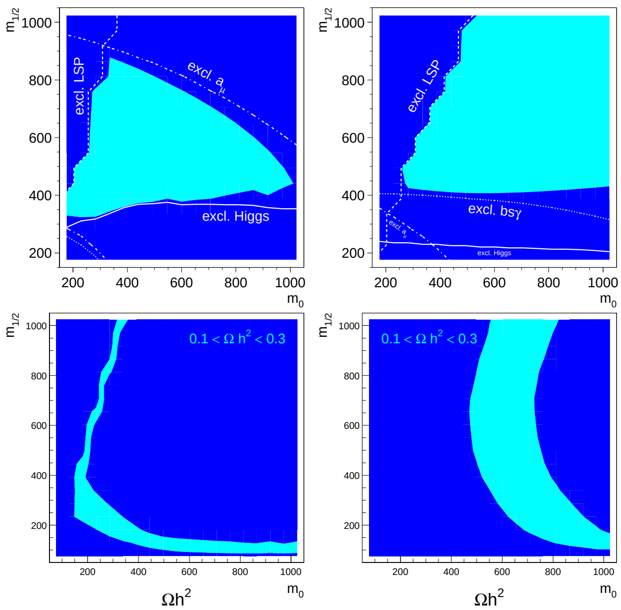

Fig. 1: Allowed regions in the parameter space ($\tan\beta = 35$ left and $\tan\beta = 50$ right)

Having in mind recent data for the amount of the dark matter ($23\pm4\%$) one gets severe constraints on the parameter space shown at the bottom of Fig.1 [3]. A range between 0.1 and 0.3 is preferred by the determination of the cosmological parameters from the red shift of distant supernovae and the acoustic peak in the microwave background[4].

4. The new possible manifestations of supersymmetry are related to experiments in space. The cosmic ray positron fraction at momenta above 7 GeV, as reported by the HEAT collaboration, is difficult to describe by the background hypothesis only [5]. The data at lower momenta agree with the previous data from the AMS experiment [6]. A contribution from the annihilation of neutralinos can improve the fits considerably [7, 8].

Neutralino annihilation can occur through Z- and Higgs exchanges in the s-channel and sfermion exchange in the t-channel. This annihilation in the halo of the galaxies will produce antimatter at high momenta; thus, anomalies in the spectra of positrons and antiprotons provide an excellent signal for dark matter annihilation.

The boost factors needed for the best fit to describe the HEAT data at large momenta are correspondingly lower and were used in the fit as arbitrary normalization, since the dark matter is not expected to be homogeneous, but shows some clumpiness due to gravitational interactions. Fig.2 shows the fit to the data for different regions of parameter space with different main annihilation channels [9]. The region with a large cross section and correspondingly lower boost is also the region with a relic density parameter between 0.1 and 0.5 of the critical density.

The fits were repeated for all values of m_0 and $m_{1/2}$. One observes a fast decrease in χ^2 for values of $m_{1/2}$ above 230 GeV, i.e., for LSP masses above $\approx$ 100 GeV. Unfortunately, the data are not precise enough to prefer a certain value of the LSP mass. However, the HEAT balloon experiments correspond to only a few days of data taking. With future experiments, like PAMELA [10] on a Russian satellite or AMS-02 [11] on the ISS (International Space Station), one will take data for several years, thus being able to decide if the excess in the HEAT data above the present best background estimate is due to a

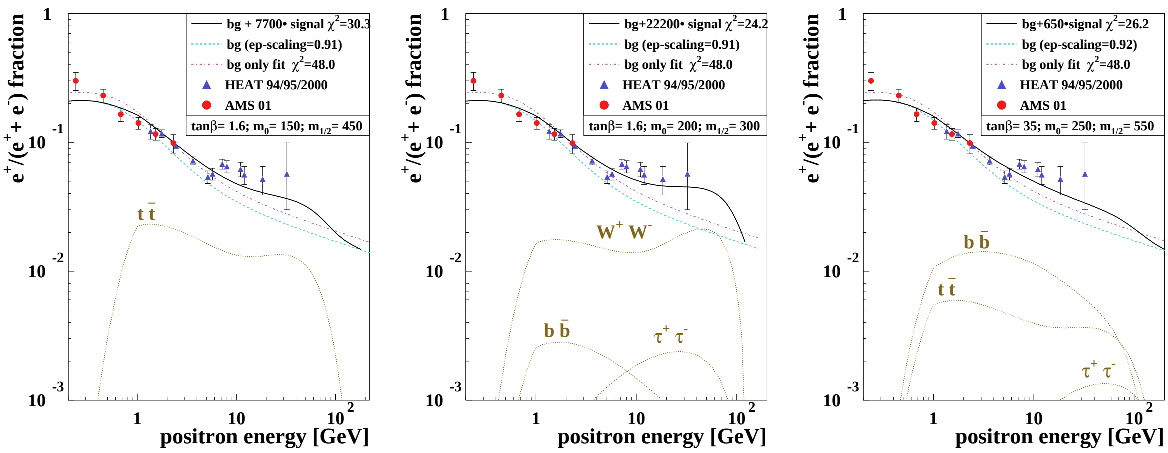

Fig. 2: Fits to the data for $\tan\beta = 1.6$ and LSP masses of 180 and 130 GeV have $t\bar{t}$ and W^+W^- as dominant annihilation channels, but the fit for large $\tan\beta$ with $b\bar{b}$ as a dominant channel yields a similar χ^2.

bad knowledge of the background or if it is really a signal for new physics. Clearly, if the background estimates are confirmed by accurate measurements of the electron spectrum, as will be done by the future experiments, then the positron spectra can give a clear indication of neutralino annihilation with a rather precise determination of the neutralino mass.

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NONPERTURBATIVE EXPANSIONS AND THRESHOLD RESUMMATION FOR THE INCLUSIVE τ-decay AND e^+e^- ANNIHILATION INTO HADRONS PROCESSES

I.L. Solovtsov

A description of quark-antiquark systems near the threshold requires us to take into account the resummation factor which summarizes the threshold singularities of the perturbative series. In a nonrelativistic approximation, this is the known Sommerfeld-Sakharov factor. For a systematic relativistic analysis of quark-antiquark systems, it is essential from the very beginning to have a relativistic generalization of this factor. Moreover, it is important to take into account the difference between the Coulomb potential in the case of QED and the quark-antiquark potential in the case of QCD. This factor, which could have a significant impact on interpreting strong-interaction physics, has been proposed in [1]. In many physically interesting cases, $R(s)$ occurs as a factor in an integrand, as, for example, for the case of inclusive τ-decay, for smearing quantities corresponding to the process of e^+e^- annihilation into hadrons, and for the Adler D-function. The threshold region turns out to be important and the perturbative expression for $R(s)$ cannot be applied [2, 3, 4]. An analytic approach in QCD (see brief review [5] and some new results in [6]) which modifies the perturbative expansion can be used to this aim [7, 8].

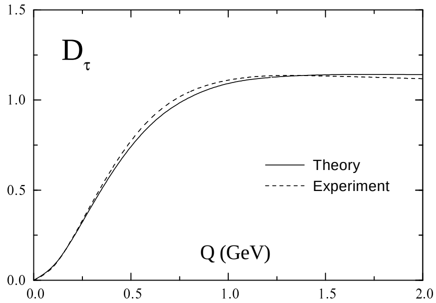

Fig. 1: *The "light" D-function. The experimental curve corresponding to ALEPH τ-decay data.*

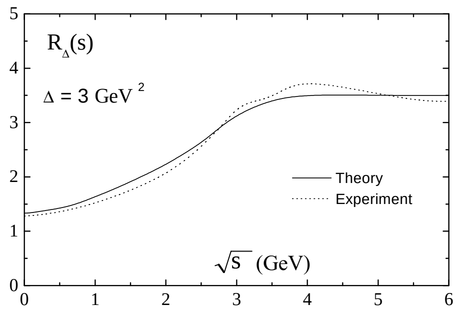

Fig. 2: *The smeared quantity $R_\Delta(s)$.*

Results obtained for the D-function and the smeared quantities within the a-expansion technique [2, 3] and within the analytic approach [4] are close to each other and agree well with experimental data. The "light" D-function corresponding to the to the non-strange vector channel τ-decay experimental data is shown in Fig. 1. The smeared quantity $R_\Delta(s)$ with $\Delta = 3$ GeV^2 is plotted in Fig 2.

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COLLINS ANALYZING POWER AND AZIMUTHAL ASYMMETRIES

A.V. Efremov

Introduction. Recently azimuthal asymmetries were observed in pion electro-production in semi-inclusive deep-inelastic scattering off longitudinally (with respect to the beam) and transversely polarized protons. These asymmetries containing information on the T-odd "Collins" fragmentation function $H_1^{\perp a}(z)$ and the transversity distribution $h_1^a(x)$ $H_1^{\perp a}(z)$ describe the left-right asymmetry in fragmentation of transversely polarized quarks into a hadron (the "Collins asymmetry"), and $h_1^a(x)$ describes the distribution of transversely polarized quarks in nucleon. Both $H_1^{\perp a}(z)$ and $h_1^a(x)$ are twist-2, chirally odd, and unknown experimentally. Only some years ago experimental indications of $H_1^{\perp}$ in e^+e^--annihilation appeared, while the HERMES and SMC data provide first experimental indications of $h_1^a(x)$.

Here we explain the observed azimuthal asymmetries and predict pion and kaon asymmetries from a deuteron target for HERMES by using information on $H_1^{\perp}$ from DELPHI and the predictions for the transversity distribution $h_1^a(x)$ from the chiral quark-soliton model (χQSM). Our analysis is free of any adjustable parameters. Moreover, we use the model prediction for $h_1^a(x)$ to extract $H_1^{\perp}(z)$ from the z-dependence of HERMES data. Finally, using the new information on $H_1^{\perp}(z)$, we extract the twist-3 distribution $e^a(x)$ from very recent CLAS data.

Transversity and Collins PFF The χQSM is a quantum field-theoretical relativistic model with explicit quark and antiquark degrees of freedom. This allows unambiguous identification of quark *and* antiquark distributions in the nucleon which satisfy all general QCD requirements due to the field-theoretical nature of the model. The results of the parameter-free calculations for unpolarized and helicity distributions agree within (10 − 20)% with parameterizations, suggesting a similar reliability of the model prediction for $h_1^a(x)$.

$H_1^{\perp}$ is responsible in e^+e^- annihilation for a specific azimuthal asymmetry of a hadron in a jet around the axis in the direction of the second hadron in the opposite jet. This asymmetry was probed using the DELPHI data collection. For the leading particles in each jet of two-jet events, averaged over quark flavors, the most reliable value of the analyzing power is

$$\left|\frac{\langle H_1^{\perp}\rangle}{\langle D_1\rangle}\right| = (12.5 \pm 1.4)\% \tag{1}$$

with unestimated but presumably large systematic errors.

The azimuthal asymmetry. The cross section for $l\vec{p} \to l'\pi X$ was measured by HERMES depending on the azimuthal angle ϕ, i.e. the angle between the lepton scattering plane and the plane defined by momentum of virtual photon $\mathbf{q}$ and momentum $\mathbf{P}_h$ of produced pion. The twist-2 and twist-3 azimuthal asymmetries read

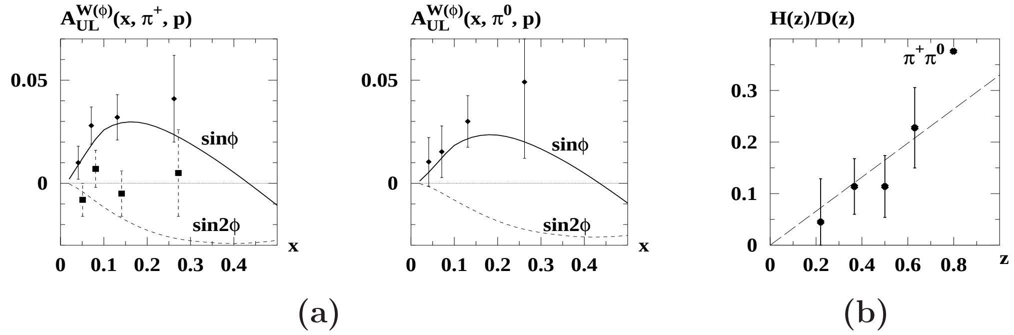

Fig. 1: **(a).** Azimuthal asymmetries $A_{UL}^{W(\phi)}$ weighted by $W(\phi) = \sin\phi, \sin 2\phi$ for pions as a function of x. Rhombuses (squares) denote data for $A_{UL}^{\sin\phi}$ ($A_{UL}^{\sin 2\phi}$). **(a).** $H_1^\perp/D_1$ vs. z, as extracted from HERMES data for π^+ and π^0 production.

$$A_{UL}^{\sin 2\phi}(x) \propto \sum_a e_a^2 h_{1L}^{\perp(1)a}(x)\langle H_1^{\perp a/\pi}\rangle \Big/ \sum_a e_a^2 f_1^a(x)\langle D_1^{a/\pi}\rangle \;, \tag{2}$$

$$A_{UL(1)}^{\sin\phi}(x) \propto \frac{M}{Q}\sum_a e_a^2 x h_L^a(x)\langle H_1^{\perp a/\pi}\rangle \Big/ \sum_a e_a^2 f_1^a(x)\langle D_1^{a/\pi}\rangle \;, \tag{3}$$

$$A_{UL(2)}^{\sin\phi}(x) \propto -\sin\theta_\gamma \cdot \sum_a e_a^2 h_1^a(x)\langle H_1^{\perp a/\pi}\rangle \Big/ \sum_a e_a^2 f_1^a(x)\langle D_1^{a/\pi}\rangle \;, \tag{4}$$

with $\sin\theta_\gamma \approx 2x\sqrt{1-y}(M/Q)$ and $A_{UL}^{\sin\phi} = A_{UL(1)}^{\sin\phi} + A_{UL(2)}^{\sin\phi}$. In Eqs.(2-4) the pure twist-3 $\widetilde{h}_L$ terms are neglected. This justifies to use WW-type approximation in which $xh_L = -2h_{1L}^{\perp(1)} = 2x^2\int_x^1 \mathrm{d}\xi\, h_1(\xi)/\xi^2$.

We assume isospin symmetry and favoured fragmentation for D_1^a and $H_1^{\perp a}$, i.e. $D_1^\pi \equiv D_1^{u/\pi^+} = D_1^{d/\pi^-} = 2D_1^{\bar{u}/\pi^0}$ etc. and $D_1^{\bar{u}/\pi^+} = D_1^{u/\pi^-} \simeq 0$ etc.

HERMES asymmetries. When using Eq.(1) to explain HERMES data, we assume a weak scale dependence of the analyzing power. We take $h_1^a(x)$ from χQSM and $f_1^a(x)$ from GRV parametrization, both LO-evolved to the average scale $Q_{\rm av}^2 = 4\,\mathrm{GeV}^2$.

In Fig.1a HERMES data for $A_{UL}^{\sin\phi}(x)$, $A_{UL}^{\sin 2\phi}(x)$ are compared with the results of our analysis. We conclude that the azimuthal asymmetries obtained with $h_1^a(x)$ from χQSM combined with the DELPHI result Eq.(1) for the analyzing power are consistent with data.

We exploit the z-dependence of HERMES data for π^0, π^+ azimuthal asymmetries to extract $H_1^\perp(z)/D_1(z)$. For that we use the χQSM prediction for $h_1^a(x)$ which introduces a model dependence of an order of $(10-20)\%$. The result is shown in Fig.1b. The data can be described by a linear fit $H_1^\perp(z) = (0.33 \pm 0.06) z D_1(z)$. The average $\langle H_1^\perp\rangle/\langle D_1\rangle = (13.8 \pm 2.8)\%$ is in good agreement with the DELPHI result Eq.(1).

The approach can be applied to predict azimuthal asymmetries in pion and kaon production off *a longitudinally polarized deuterium* target which were under current study at HERMES. The additional assumption used is that $\langle H_1^{\perp K}\rangle/\langle D_1^K\rangle \simeq \langle H_1^{\perp\pi}\rangle/\langle D_1^\pi\rangle$. Our predictions are shown in Fig.2a. The "data points" are recently published HERMES data. Asymmetries for $\bar{K}^0$ and K^- are close to zero in our approach.

Interestingly, all $\sin\phi$ asymmetries change sign at $x \sim 0.5$ (unfortunately, the HERMES cut is $x < 0.4$). This is due to the negative sign in Eq.(4) and the harder behaviour

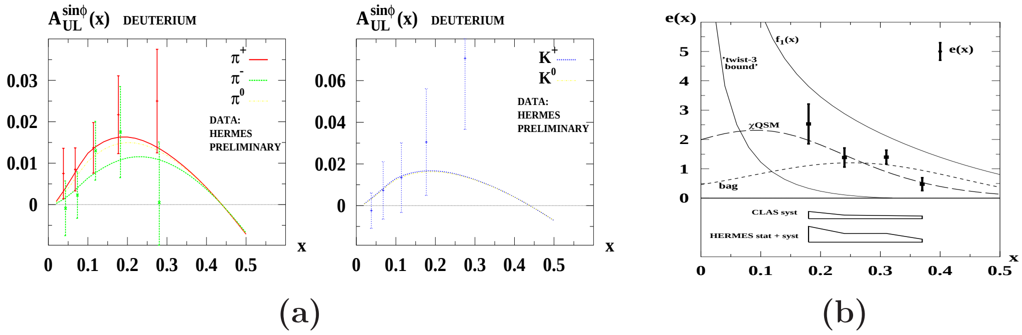

Fig. 2: **(a).** Predictions for $A_{UL}^{\sin\phi}$, $A_{UL}^{\sin 2\phi}$ from a deuteron target for HERMES. **(b).** The flavour combination $e(x) = (e^u + \frac{1}{4}e^{\bar{d}})(x)$, with error bars due to statistical error of CLAS data, vs. x at $\langle Q^2\rangle = 1.5\,\mathrm{GeV}^2$. For comparison $f_1^u(x)$ and the twist-3 Soffer bound are shown.

of $h_1(x)$ with respect to $h_L(x)$.

We learn that transversity could be measured also with a *longitudinally* polarized target, e.g. at COMPASS, simultaneously with ΔG.

Extraction of e(x) from CLAS data. Very recently the $\sin\phi$ asymmetry of π^+ produced by scattering of polarized electrons off unpolarised protons was reported by CLAS collaboration. This asymmetry is interesting since it allows to access the unknown twist-3 structure functions $e^a(x)$ which are connected with nucleon σ-term:

$$\int_0^1 \mathrm{d}x \sum_a e^a(x) = \frac{2\sigma}{m_u + m_d} \approx 10\ . \qquad (5)$$

The asymmetry is given by

$$A_{LU}^{\sin\phi}(x) \propto \frac{M}{Q}\,\frac{\sum_a e_a^2 e^a(x)\langle H_1^{\perp a/\pi}\rangle}{\sum_a e_a^2 f_1^a(x)\langle D_1^{a/\pi}\rangle}\ . \qquad (6)$$

Disregarding unfavored fragmentation and using the Collins analysing power extracted from HERMES in Sect., which yields for z-cuts of CLAS $\langle H_1^{\perp\pi}\rangle/\langle D_1^{\pi}\rangle = 0.20 \pm 0.04$, we can extract $e^u(x) + \frac{1}{4}e^{\bar{d}}(x)$. The result is presented in Fig.2b. For comparison the Soffer lower bound, $e^a(x) \geq 2|g_T^a(x)| - h_L^a(x)$, and the unpolarized distribution function $f_1^u(x)$ are plotted. The obtained points for $e(x)$ are close to calculations as in bag model as in χQSM. One can guess that the large number in the sum rule Eq.(5) might be due to, either a strong rise of $e(x)$ in the small x region, or a δ-function at $x = 0$.

For more details and complete references see:
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CROSSING PROPERTIES OF NONPERTURBATIVE QCD MATRIX ELEMENTS

O.V. Teryaev

Deeply Virtual Compton Scattering (DVCS) cleanest hard process which is sensitive to the non-perturbative QCD matrix elements - the so-called Generalized Parton Distributions (GPD), and has been the subject of extensive theoretical investigations for a few years. First experimental data became recently available and much more data are expected from JLAB, DESY, and CERN in the near future. The twist-three contribution to this process may be estimated by making use of the Wandzura-Wilczek approximation [1], which consists in neglecting physical components of the gluon field in comparison with quark transverse momentum.

The crossing version of DVCS is provided by the process $\gamma^*\gamma \to \pi\bar{\pi}$ with a highly virtual photon but small hadronic invariant mass W. It allows one to study the pion pair produced in the isoscalar channel where the huge ρ-meson peak is absent. This process is analogous to the single pi on production, described by the pion transition form-factor, being the long time object of QCD studies. In particular, the generalized distribution amplitude (GDA), describing the nonperturbative stage of this process, is a natural counterpart of the pion light cone distribution amplitude. For the last two years the GDA analysis was generalized to the twist-three case [2] and to the case of the production of two $\rho - mesons$ [3]. Pion GDA were also used as a probe [4, 5] to observe the BFKL Pomeron / BKP Odderon interference in small-x QCD.

The most natural way of analyzing the crossing properties of GPD and GDA is provided by the Radon transform technique [6] when they correspond to the integration of the *same* function (so-called double distributions f extensively studied in the GPD case by Radyushkin) over the *different* lines:

$$H(z,\xi) = \int_{-1}^{1} dx \int_{|x|-1}^{1-|x|} dy f(x,y)\delta(z - x - \xi y). \tag{1}$$

As a result, double distributions may be recovered from the combined data on GDA Φ and GPD H, related by the crossing transformation

$$H(z,\xi) = sign(\xi)\Phi(\frac{z}{\xi}, \frac{1}{\xi}). \tag{2}$$

The use of the slightly modified formula for the inverse Radon transform results in

$$f(x,y) = -\frac{1}{2\pi^2}\int_{-\infty}^{\infty}\frac{dz}{z^2}\int_{-\infty}^{\infty} d\xi (H(z + x + y\xi, \xi) - H(x + y\xi, \xi)). \tag{3}$$

where unphysical values of the skewedness ξ for GPD correspond to GDA.

The important object appearing in the physical cross-sections is the convolution

$$\mathcal{H}(\xi) = \int_{-1}^{1} dx \frac{H(x,\xi)}{x - \xi + i\epsilon}, \tag{4}$$

The consideration of its analytical properties, which happen to be deeply connected to the properties of Radon transform [7], allows one to reduce it, up to the subtraction constant, to the form:

$$\mathcal{H}(\xi) = \int_{-1}^{1} dx \frac{H(x,x)}{x - \xi + i\epsilon} \tag{5}$$

It expresses the "holographic" [7] property of GPD, when the most essential information about it (at fixed Q^2 and at leading order) is encoded in its values for coinciding arguments, defining the imaginary part of the DVCS amplitude. This suggests the modification of experimental strategy of its studies, when special emphasis should be put on the imaginary part (appearing in spin asymmetries) while the real one should be recovered by dispersion relations.

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CLEO AND E791 DATA: DO THEY FIX THE PION DISTRIBUTION AMPLITUDE?

A.P. Bakulev, S.V. Mikhailov

CLEO data analysis. The recent high-precision CLEO results for the $\pi\gamma$ transition form factor gave rise to dedicated theoretical investigations. These experimental data are of particular importance because they can provide crucial quantitative information on nonperturbative parameters of the pion distribution amplitude (DA) and on the QCD vacuum nonlocality parameter λ_q^2, which specifies the average virtuality of the vacuum quarks. In the absence of a direct solution of the nonperturbative sector of QCD, we are actually forced to extract related information from the data, relying upon a theoretical analysis as complete and as accurate as currently possible.

It was shown by Khodjamirian that the most appropriate tool to analyze the CLEO data is provided by the light-cone QCD sum-rule (LCSR) method. Schmedding and Yakovlev (SY) applied these LCSRs to the NLO of QCD perturbation theory and determined the admissible region for the first two Gegenbauer coefficients a_2 and a_4 that fix the pion DA.

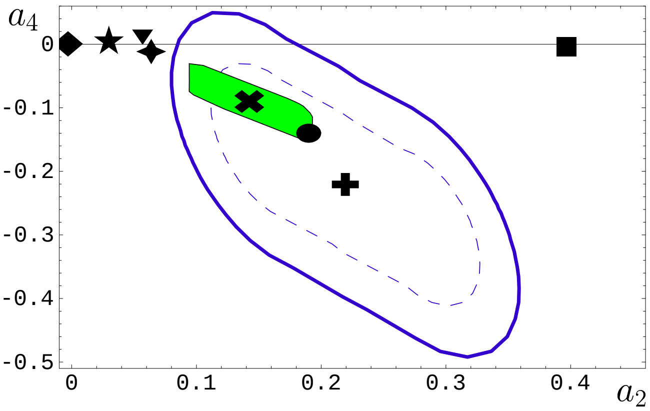

Fig. 1: Analysis of the CLEO data on $F_{\pi\gamma^*\gamma}(Q^2)$ in terms of error ellipses in the (a_2,a_4) plane contrasted with various theoretical models explained in the text. The solid line denotes the 2σ-contour; the broken line stands for the 1σ-contour. The slanted shaded rectangle represents the constraints on $(a_2,\ a_4)$ posed by the NLC QCD SRs for the value $\lambda_q^2 = 0.4$ GeV^2. All constraints are evaluated at $\mu_{SY}^2 = 5.76$ GeV^2 after NLO ERBL evolution.

More recently, we have taken up this sort of data processing in an attempt to (i) account for a correct ERBL evolution of the pion DA to each measured momentum scale, (ii) estimate more precisely the contribution of the (next) twist-4 term, and (iii) improve the error estimates in determining the 1- and 2-σ error contours.

We present in Fig. 1 the results of the data analysis for the twist-4 scale parameter $k \cdot \delta^2$ varied in the interval $[0.15 \leq k \cdot \delta^2 \leq 0.23]$ GeV^2 with the best-fit point (✚). Here we represent also the asymptotic DA (◆), the BMS model (✖), the Chernyak–Zhitnitsky (CZ) DA (■), the SY best-fit point (●), a recent transverse lattice result (▼), and two instanton-based models, viz., Petrov et al. (★) and Praszalowicz–Rostworowski (✦).

We have established that a two-parameter model $\varphi_\pi(x; a_2, a_4)$ factually enables us to fit all the moment constraints that result from Non-Local Condensate (NLC) QCD SRs. The only parameter entering the NLC SRs is the correlation scale λ_q^2 in the QCD vacuum, known from nonperturbative calculations and lattice simulations. A whole bunch of admissible pion DAs resulting from the NLC QCD SR analysis associated with $\lambda_q^2 = 0.4$ GeV^2 at $\mu_0^2 \approx 1$ GeV^2 was determined, with the optimal one, see ✖ in Fig.1, given analytically by

$$\varphi_\pi^{BMS}(x) = \varphi_\pi^{as}(x)\Big[1 + a_2^{opt} \cdot C_2^{3/2}(2x-1) + a_4^{opt} \cdot C_4^{3/2}(2x-1)\Big] , \qquad (1)$$

where $\varphi_\pi^{as}(x) = 6x(1-x)$ and $a_2^{opt} = 0.188$, $a_4^{opt} = -0.13$. From Fig.1 we observe that the NLC QCD SR constraints encoded in the slanted shaded rectangle are in rather good overall agreement with the CLEO data at the 1σ-level. This agreement could eventually be further improved adopting smaller values of λ_q^2, say, 0.3 GeV^2, which however are not supported by the QCD SR method and lattice calculations. On the other hand, the agreement between QCD SRs and CLEO data fails for larger values of λ_q^2, e. g., 0.5 GeV^2.

Let us summarize our findings, which have been obtained by: (i) correcting the mass thresholds in the running strong coupling, (ii) incorporating the variation of the twist-4 contribution more properly and (iii) extracting a direct constraint on the inverse moment $\langle x^{-1}\rangle_\pi(\mu_0^2)$ of the pion DA out of the CLEO data – the crucial element of pQCD form-factor calculations. The main outcome of these theoretical analyses appears to be as follows: (i) the asymptotic pion DA (◆) and the CZ (■) one are both outside the 2-σ error regions; (ii) our model (✖) belongs to the 1σ deviation region, providing compelling argument in favor of NLC SR approach; (iii) the CLEO data allow us to estimate the correlation scale in the QCD vacuum, λ_q^2, to be $\lesssim 0.4$ GeV^2.

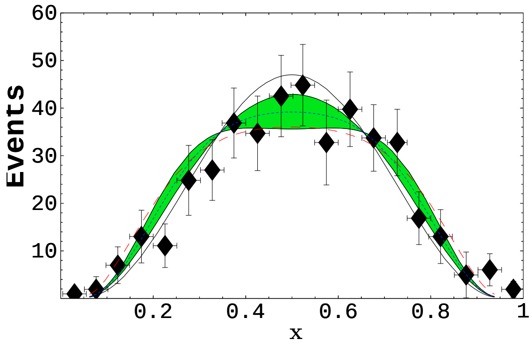

Fig. 2: Comparison of φ^{as} (solid line), φ^{CZ} (dashed line), and the BMS bunch of pion DAs (strip) with the E791 data.

E791 data analysis. To compare our model DA for the pion with the E791 di-jet events, we adopt the convolution approach developed by Braun–Ivanov–Schafer–Szymanowski. The results are displayed in Fig.2 making evident that they are in good agreement with our prediction. By the way, the data from E791 do not allow us to exclude other shapes for the pion DA, also displayed for comparison. Nevertheless, our bunch appears to be more preferable than CZ and asymptotic alternatives.

Conclusions. As a conclusion, both analyzed experimental data sets (CLEO and Fermilab E791) converge to the conclusion that the pion DA is not everywhere a convex function, like the asymptotic one, but has instead two maxima with the end points ($x = 0, 1$) strongly suppressed – in contrast to the CZ DA. These two key features are controlled by the QCD vacuum correlation length λ_q^2, whose value suggested by the CLEO data analysis here and is approximately 0.4 GeV^2 in good compliance with the QCD SR estimates and lattice simulations.

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THE QCD ANALYSIS OF THE DATA FOR g_1 AND xF_3 STRUCTURE FUNCTIONS AND THE x-DEPENDENCE OF A HIGHER TWIST CONTRIBUTION.

A.V. Sidorov

We ontinued a next-to-leading order (NLO) analysis of the world data on polarized DIS [1]-[4] and NNLO analysis of CCFR data on the xF_3 structure function [5]-[7] in order to extract the x-dependence of a higher hwist contribution.

Using the results for the NNLO QCD corrections to anomalous dimensions of odd xF_3 Mellin moments and N^{3}LO corrections to their coefficient functions we improve our previous analysis of the CCFR'97 data for xF_3. The possibility of extracting from the fits of $1/Q^2$-corrections is analysed using three independent models, including infrared renormalon one. Theoretical question of applicability of the renormalon-type inspired large-β_0 approximation for estimating corrections to the coefficient functions of odd xF_3 and even nonsinglet F_2 moments are considered. The comparison with [1/1] Padé estimates is given. The obtained NLO and NNLO values of $\alpha_s(M_Z)$ are in agreement with the world average value $\alpha_s(M_Z) \approx 0.118$. We also present first N^{3}LO extraction of $\alpha_s(M_Z)$. The interplay between higher-order perturbative QCD corrections and $1/Q^2$-terms is demonstrated.

The higher twist corrections $h(x)/Q^2$ to the spin dependent proton and neutron structure functions $g_1^N(x,Q^2)$ are extracted in a model independent way from experimental data on g_1^N and found to be non-negligible. It is shown that the NLO polarized parton densities determined from the data on g_1, including higher twist effects, are in good agreement with those found earlier from our analysis of the data on g_1/F_1 and A_1 where higher twist effects are negligible. On the contrary, the LO polarized parton densities obtained from the data on g1, including higher twist, differ significantly from our previous results. A set of polarized parton densities is extracted from the data (The FORTRAN code is available at http://durpdg.dur.ac.uk/HEPDATA/DPF).

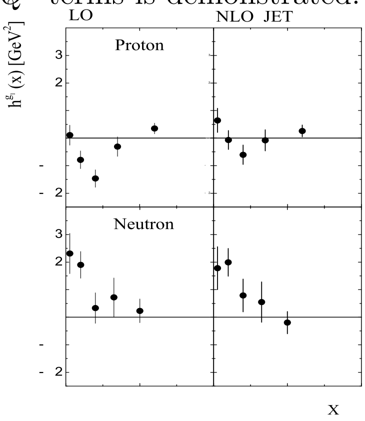

Fig. 1: The x-dependence of twist-3 contribution to $g_1(x,Q^2) = g_1^{LT}(x,Q^2) + h(x)/Q^2$.

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THERMALIZATION PHENOMENA IN HADRON PHYSICS

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The first attempts to understand general features of extremely inelastic high energy hadron collisions, on condition that the multiplicity of produced hadrons considerably exceeds its mean value, was undertaken in [1]. For this purpose, the phenomenology of this very high multiplicity (VHM) processes was offered. It allows one to classify the possible VHM asymptotics and, at the same time, to ascertain the problems with existing hadron production models. The superior of them is the special kinematics of the VHM processes when all produced particles are "soft". For this purpose the usage of LLA of pQCD becomes problematic despite the fact that apparently the initial stage of VHM processes is hard.

Another issue was the determination of the main characteristics of the future theory of VHM processes. Considering the many particle final state, it seems natural to introduce the thermodynamic description. The real-time finite-temperature S-matrix theory is offered for this purpose. It allows one to find necessary and sufficient conditions when the thermodynamical description becomes applicable. Just the value of multiplicity and energy, when these conditions are held, are called the VHM region. It must be noted that these conditions resemble the principle of "correlations vanishing" offered by N.N. Bogolyubov.

The "hardness" of VHM processes means the possibility of suppressing the nonperturbative effects. This point of view was discussed in [2, 3]. So, there is a question: why is the ordinary hadron multiple production process stopped at such an early stage that the mean multiplicity is only the logarithm of incident energy. The latter was considered as the indication of absence of complete thermalization in mostly probable inelastic hadron processes.

The status of the thermodynamical approach to the multiple production processes was discussed [4]. This approach is quite popular in the heavy ion collision physics. It is argued that the "principle of vanishing of correlations" must be used for the quantitative estimation of the rate of thermalization. The existing theoretical models and the corresponding generators of events are unable to predict the thermalization phenomenon. A brief review of attendant papers was given.

The transition to the thermodynamic equilibrium was discussed in [5] from the quantitative point of view. The prediction of various models was discussed and was shown that the symmetry constrains are able to prevent the thermalization. It was underlined that the multiperipheral-type models cannot predict even the tendency of the equilibrium.

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EFFECTIVE CHIRAL QUARK MODELS, TRANSITION FORM FACTORS, AND DISTRIBUTION AMPLITUDES OF LIGHT MESONS

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A great number of papers are devoted to studies of meson properties in various approaches: constituent quark models, effective low-energy models, perturbative QCD (pQCD), QCD sum rules, lattice QCD etc. However, in the most part, one or another method is applicable to either low or high energies. In our papers [1, 2, 3, 4], we suggested a new approach that allows one to extend the domain of applicability of the models from a small energy region to the large energy one where the processes are described by pQCD.

The new approach is based on the usage of a nonlocal effective chiral quark model where the quark interaction is induced by instanton exchanges and embodies fundamental properties of the QCD vacuum, — Instanton induced Quark Model (IQM). The main feature of the new model is the relation [5] between the dynamic quark mass in the contour gauge and the gauge-invariant nonlocal quark condensate [6]. This relation is important because it imposes a constraint on the dynamic mass shape in the infrared region. We have also shown how the instanton and constraint instanton solutions of the Yang–Mills equations [7] give different possible shapes to the dynamical quark mass. It turned out that the nonlocal condensate can be taken in the form that ensures absence of poles in the quark propagator on the real axis, which is a necessary condition for the quark confinement. The explicit gauge-invariant form of the interaction with external electro-weak fields is an essential property of IQM. In our works there was emphasized that the gauge invariance of the nolocal interaction is important at large energies. In earlier investigations of the pion distribution amplitude (DA) within the instanton model, the gauge invariance was not preserved (see e. g. [8, 9]).

In the framework of IQM and a chiral quark model of the Nambu–Jona-Lasinio (NJL) type, the form factors of transition processes $Mes \to \gamma^*\gamma^*$, where $Mes = (\pi, \eta, \eta', \sigma)$, were calculated in an arbitrary kinematics [3, 10, 11]. For large photon virtualities, using the expansion of the form factor in powers of momentum transfer, we found leading (LO) and next-to-leading (NLO) terms with the factors given as convolutions of the coefficient functions and the twist-2 and twist-4 DA [10]. The twist 2 and 4 DA are expressed through the dynamical quark mass $M(k^2)$ and the nonlocal quark-pion vertex $F(k^2, k'^2)$ as follows:

$$\varphi_\pi^{(2)}(x) = \frac{N_c}{4\pi^2 f_\pi^2} \int_{-\infty}^{\infty} \frac{d\lambda}{2\pi} \int_0^\infty du \frac{F(u_+, u_-)}{D(u_-)\, D(u_+)} \left[xM(u_+) + (x \leftrightarrow \overline{x}) \right], \tag{1}$$

$$\varphi_\pi^{(4)}(x) = \frac{1}{\Delta^2} \frac{N_c}{4\pi^2 f_\pi^2} \int_{-\infty}^{\infty} \frac{d\lambda}{2\pi} \int_0^\infty du \frac{uF(u_+, u_-)}{D(u_-)\, D(u_+)} \left[\overline{x}M(u_+) + (x \leftrightarrow \overline{x}) \right], \tag{2}$$

where $u_+ = u + i\lambda\overline{x}$; $u_- = u - i\lambda x$; $D(u) = u + M^2(u)$, and x — is the fraction of the meson momentum carried by the quark, $\bar{x} = 1 - x$. The shape of the twist-2 DA calculated within our model at the low-energy normalization point is close to that obtained in QCD sum rules [12]. The coefficients in the asymptotics of the form factor at large and equal photon virtualities are expressed through the pion weak decay constant (in LO) and through the mean-square momentum of quarks in the pion (in NLO), Δ^2.

The last magnitude characterizes the power corrections in the hard exclusive processes with pion. When one of the photons is real while the other is virtual, the asymptotic coefficients are expressed through inverse moments of DA and thus are very sensitive to the shape of DA and, as a consequence, to the nonlocality of the primary quark interaction [10]. Our results for the transition form factors are in agreement with recent experimental [3] and theoretical studies conducted now in leading physical centers [11, 13].

Finally, we demonstrated that IQM and NJL models can be used to calculate soft parts of the amplitudes of high-energy processes, where the factorization of soft and hard subprocesses is allowed.

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EXCLUSIVE B-DECAYS

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Over the last years B-physics received a lot of attention from both theorists and experimentalists. The B-physics studies the properties of b-flavored hadrons (B and B_c mesons, Λ_b and Ξ_{bc} baryons). The present and future experiments (BaBar (SLAC), BELLE (KEK), HERA-B (DESY), CLEO (Cornell), CDF and D0 (Fermilab), ATLAS, CMS and LHC-B (LHC, CERN)) are planning to study their inclusive and exclusive decays, CP-violation, rare decays and other topics (for review see Refs. [1]-[3]).

The semileptonic decays of heavy mesons and baryons are clean modes to extract the Cabibbo-Kobayashi-Maskawa matrix elements. The heaviest flavored bottom-charm B_c-meson was observed by the CDF Collaboration [4] in the analysis of the decay mode $B_c \to J/\psi \bar{l} \nu$. The discovery of the B_c-meson raises hopes that double heavy flavored baryons will also be discovered in the near future. The theoretical treatment of the systems with two heavy quarks is complicated because the expansion in terms of the inverse heavy quark masses is not reliable.

We have studied [5] semileptonic transitions of doubly heavy B_c-meson: $B_c \to \eta_c$, J/ψ, D, D^*, B, B^*, B_s, B_s^*. We computed semileptonic B_c form factors and gave predictions for various semileptonic B_c decay modes including their τ-modes when they are kinematically accessible. We reproduced the relations between form factors at zero recoil in the heavy quark limit and gave explicit expressions for them. Finally, we compared our predictions for the branching ratios with the results of other approaches. The planned RUN-II at Tevatron will certainly give us more experimental information about various decay channels of the B_c-meson. We extend our approach to explore the baryons as relativistic states of three quarks [6]. We studied semileptonic decays of the lowest lying double heavy baryons Ξ_{bc} without employing heavy quark mass expansion but kept the masses of the heavy quarks and baryons finite. We calculated all relevant form factors and decay rates.

The flavor-changing neutral current transitions $B \to K(K^*) + (\gamma, l^+l^-, \bar{\nu}\nu)$ and $B_c \to D(D^*) + (\gamma, l^+l^-, \bar{\nu}\nu)$ are of special interest because they proceed at the loop level in the Standard Model (SM) involving also the top quark. They may therefore be used for determination of the Cabibbo-Kobayashi-Maskawa (CKM) matrix elements V_{tq} (q=d,s,b). The decay $B \to K\, l^+l^-$ $(l = e, \mu)$ was observed by the BELLE Collaboration [7] with the branching ratio of $\mathrm{Br}\,(B \to K\, l^+l^-) = (0.75^{+0.25}_{-0.21} \pm 0.09) \times 10^{-6}$.

The theoretical study of the exclusive rare decays proceeds in two steps. First, the effective Hamiltonian for such transitions is derived by calculating the leading and next-to-leading loop diagrams in the SM and by using the operator product expansion and renormalization group techniques. The modern status of this part of the calculation is described in the review [8] (and references therein). Second, one needs to evaluate the matrix elements of the effective Hamiltonian between hadronic states. This part of the calculation is model dependent since it involves nonperturbative QCD.

We have studied the exclusive rare decays $B \to K\bar{l}l$ and $B_c \to D(D^*)\bar{l}l$ [9, 10] with special emphasis on the cascade decay $B_c \to D^*(\to D\pi)\bar{l}l$. We derived a four-fold angular decay distribution for this process in terms of helicity amplitudes including lepton mass effects. The four-fold angular decay distribution allows to define a number of physical observables which are amenable to measurement. We calculated the relevant form factors within a relativistic constituent quark model, for the first time without employing the impulse approximation. The calculated form factors were used to evaluate differential decay rates and polarization observables. We presented results on the q^2-dependence of a set of observables with and without long-distance contributions. In particular, we found that $\mathrm{Br}\,(B \to K\, l^+l^-) = 0.5 \times 10^{-6}$ which is consistent with the experimental value.

As was pointed out in [3], the decays $B_c^+ \to D_s^+ D^0(\overline{D^0})$ are well suited for extraction of the CKM angle γ through amplitude relations. These decays are better suited for extraction of γ than similar decays of the B_u and B_d mesons because the triangles in latter decays are very squashed. We performed [11] the straightforward calculation of their nonleptonic decay rates within a relativistic quark model. We confirmed that the decays $B_c \to D_s\overline{D^0}$ and $B_c \to D_s D^0$ are well suited to extract the Cabibbo-Kobayashi-Maskawa angle γ through the amplitude relations because their decay widths are the same order of magnitude. In the $b - c$ sector the decays $B \to DK$ and $B_c \to DD$ lead to squashed triangles which are therefore not so useful to determine the angle γ experimentally. We also determined the rates for other nonleptonic B_c-decays and compared our results with the results of other studies.

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GROUND-STATE ENERGY OF PIONIC HYDROGEN TO ONE LOOP

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The theory of strong interactions entered a high precision phase in recent years, both experimentally and theoretically. On the experimental side, one can mention i) the muon anomalous magnetic moment measurement at Brookhaven [1]. A calculation of $(g-2)_\mu$ that matches the foreseen experimental accuracy requires that the cross section $e^+e^- \to \pi^+\pi^-$ in the low–energy region is known to better than one percent; ii) experiments that aim to determine hadronic scattering lengths with high precision are presently running at CERN [2] and at PSI [3, 4]. On the theory side, the $\pi\pi$ scattering lengths have recently been calculated at the few-percent level in Ref. [5]. In [6] we are concerned with the ongoing experiment on the measurement of the energy levels and decays of the $\pi^- p$ atom (pionic hydrogen) at PSI [3, 4]. It is planned to measure the strong interaction width and shift of the ground state at the percent level. These measurements can then be used to directly extract from data the πN scattering amplitude at the threshold. The aim of the experiment goes, however, further: it intends to extract

from these measurements the S-wave πN scattering lengths $a_{0+}^+ + a_{0+}^-$ in pure QCD with high precision. In order to achieve this goal, the relation between the scattering lengths and the threshold amplitude must be known at accuracy that matches the accuracy of the experiment. In other words, one has to remove isospin–breaking effects from the threshold amplitude with high precision, in the framework of QCD+QED.

The relation between the strong energy-level shift ϵ_{1s} of the ground state and the threshold $\pi^- p$ scattering amplitude was worked out in the effective theory in Ref. [7],

$$\epsilon_{1s} = -\frac{\alpha^3 \mu_c^3 \mathcal{T}_{\pi N}}{2\pi M_\pi} \left\{ 1 - \frac{\alpha(\ln\alpha - 1)\mu_c^2 \mathcal{T}_{\pi N}}{2\pi M_\pi} \right\} + \cdots . \tag{1}$$

Here, $\mu_c = m_p M_\pi (m_p + M_\pi)^{-1}$ denotes the reduced mass and $\mathcal{T}_{\pi N}$ is the threshold amplitude for the process $\pi^- p \to \pi^- p$ evaluated at the next–to–leading order in isospin breaking. In the isospin symmetry limit, the threshold amplitude is proportional to a particular combination of the S-wave pion-nucleon scattering lengths $a^{\pm}_{0+}$

$$\begin{aligned} \mathcal{T}_{\pi N} &= \mathcal{T}^0_{\pi N} + \alpha \mathcal{T}^\gamma + (m_d - m_u)\mathcal{T}^m , \\ \mathcal{T}^0_{\pi N} &= 4\pi \Big(1 + \frac{M_\pi}{m_p}\Big)\,(a^+_{0+} + a^-_{0+}) \end{aligned} \tag{2}$$

1. We have evaluated the ground–state energy of pionic hydrogen in the framework of QCD+QED. We have performed the calculation at next–to–leading order in the low–energy expansion, relying on the method of effective field theories.

2. We have invoked relativistic baryon ChPT in manifestly Lorentz invariant form [8], and generalized the procedure to allow for virtual photons.

3. We have then calculated the $\pi^- p$ elastic scattering amplitude at threshold - in the presence of isospin breaking - at $O(p^3)$ in the low–energy expansion. The result contains unitarity corrections and counterterm contributions generated by low-energy constants (LECs).

4. At leading order, the contribution to the energy shift is generated [7] by three counterterms f_1, f_2 and c_1. Whereas the latter two can be determined from other sources, the size of f_1 needs yet to be determined in a model-independent manner.

5. The loop contributions, which contain mass splitting effects from diagrams with strong loops, turn out to be sizeable. Graphs with a particular topology (triangle graphs) turn out to be particularly important - their contribution to the energy shift indeed is large and negative, a sizeable fraction of the leading order term. Graphs with the same topology play an important role e.g. in photo production of neutral pions.

6. The LECs at next–to–leading order are suppressed by one power of M_π and thus expected to have a small effect on the energy shift. This expectation turns out to be correct for one of the couplings that has recently been determined [9] in a comprehensive analysis of πN scattering. Estimating the size of the remaining terms with dimensional arguments, it indeed turns out that their contribution is about an order of magnitude smaller than the leading order result. Writing the energy shift in the form

   $$\epsilon_{1s} = -2\alpha^3 \mu_c^2\,(a^+_{0+} + a^-_{0+})(1 + \delta_\epsilon)\,, \tag{3}$$

   one can finally get

   $$\delta_\epsilon^{\rm LO} = (-4.8 \pm 2.0) \cdot 10^{-2} \tag{4}$$
   $$\delta_\epsilon^{\rm NLO} = (-7.2 \pm 2.9) \cdot 10^{-2} \tag{5}$$

whereas the calculation by Ref. [10] in a potential model framework leads to $\delta_\epsilon = (-2.1 \pm 0.5) \cdot 10^{-2}$. As has been pointed out in Ref. [7], the leading order terms in the effective theory are due to effects that are not all consistently taken into account in the potential model calculation. We conclude that the uncertainty in Ref. [10] is underestimated - it does not reflect the systematic errors inherent in the method.

7. A precise determination of the scattering lengths $a^+_{0+} + a^-_{0+}$ from a precise measurement of the ground-state energy-level shift of pionic hydrogen has to await a more precise determination of f_1 in our opinion. This fact is hidden in the potential model calculation [10], that quotes a very small uncertainty. As we outlined above, this result does not reflect all systematic uncertainties hidden in this approach: potentials in general do not incorporate the constraints from QCD+QED, unless one imposes these constraints on them [11]. A method different from effective field theories to perform this matching is not in sight. We conclude that one is bound to know the LECs, quite independently of the framework used.

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