Contents

SUPERSYMMETRIC INTERPRETATION OF THE EGRET EXCESS OF DIFFUSE GALACTIC GAMMA RAYS FLUX AND RELATED PARTICLE PHENOMENOLOGY

A.V. Gladyshev, and D.I. Kazakov

Cold Dark Matter (CDM) makes up 23% of the energy of the Universe, as deduced from the temperature anisotropies in the cosmic microwave background in combination with data on the Hubble expansion and the density fluctuations in the Universe. One of the most popular CDM candidates is the neutralino, a stable neutral particle predicted by supersymmetry. The neutralinos can annihilate into pairs of Standard Model particles. A large fraction of the annihilations is expected to go into quark-antiquark pairs. Since the DM particles are strongly nonrelativistic, the initial energy is simply given by two times the neutralino mass which is converted into energy of the quarks that are mono-energetic. The spectral shape of the gamma rays from Dark Matter Annihilation (DMA) is well known from the fragmentation of mono-energetic quarks studied at electron-positron colliders like LEP at CERN which has been operating up to centre-of-mass energies of about 200 GeV, i.e., it corresponds to gamma spectra from neutralino masses up to 100 GeV. Experimentally, the spectral shape of the diffuse galactic gamma rays was measured with the EGRET satellite in the range of 0.1-10 GeV. The EGRET data are publicly available as high resolution (0.5°) sky maps from the NASA archive, which allows an independent analysis in many different sky directions.

Fitting two components, namely background and DMA, yields a perfect fit in all sky directions for a CDM particle mass around 60 GeV. From the normalization factors for the background and DMA components in 180 independent sky directions the distribution of DM was obtained. Combining this with the known distribution of the visible matter yields a complete mass distribution which in turn can be used to reconstruct the rotation curve of our Galaxy. The DM halo is consistent with an almost spherical isothermal profile with a substructure in the Galactic plane in the form of toroidal rings at 4 and 14 kpc from the center. These rings lead to a peculiar shape of the rotation curve, in agreement with the data, which proves that the EGRET excess traces the Dark Matter [1,2].

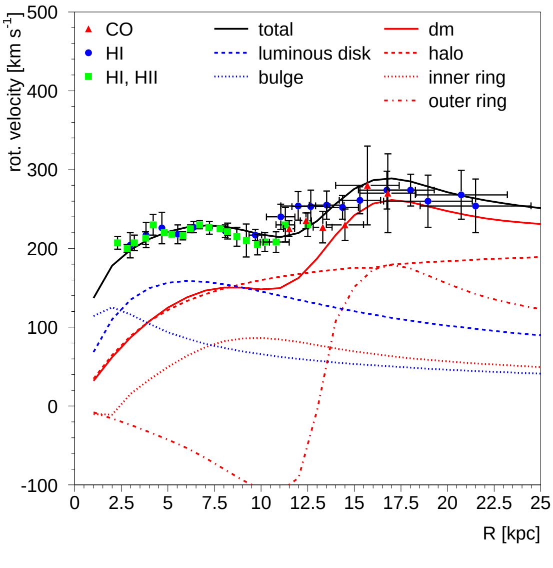
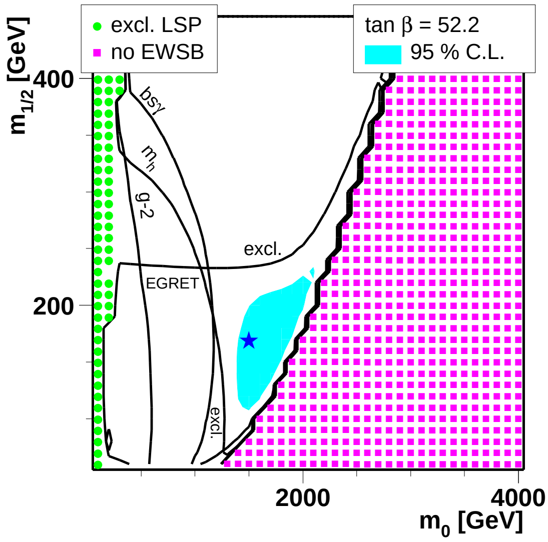


Рис. 1: The rotation curve of the Galaxy. The contributions from the individual mass components are indicated. Note the negative contribution of the massive ring of DM at 14 kpc which exerts an outward and hence negative force on a tracer inside that ring.

Since the mass of the neutralinos is constrained to be between 50 and 100 GeV from the EGRET data, the masses of all other SUSY particles are strongly constrained if mass unification at the GUT scale is assumed. Combining the EGRET data with other constraints, like the electroweak precision data, Higgs mass limits, chargino limits, radiative electroweak symmetry breaking and relic density leads to a very constrained SUSY mass spectrum with light gauginos and heavy squarks and sleptons [3].

The splitting of light gauginos from heavy squarks and sleptons leads to very interesting phenomenological consequences. The cross-sections for chargino and neutralino production in this case are relatively large not being suppressed by masses and being unexpectedly large and comparable with squark and gluino production. The latter being enhanced by strong interactions remains suppressed by heaviness of squarks. This means that in the EGRET region leptonic channels are not suppressed and so might give a clear leptonic signature for supersymmetry in the upcoming LHC experiments.



Particle	Mass [GeV]
$\tilde{\chi}^0_{1,2,3,4}$	64, 113, 194, 229
$\tilde{\chi}^{\pm}_{1,2}, \tilde{g}$	110, 230, 516
$\tilde{u}_{1,2} = \tilde{c}_{1,2}$	1519, 1523
$\tilde{d}_{1,2} = \tilde{s}_{1,2}$	1522, 1524
$\tilde{t}_{1,2}$	906, 1046
$\tilde{b}_{1,2}$	1039, 1152
$\tilde{e}_{1,2} = \tilde{\mu}_{1,2}$	1497, 1499
$\tilde{\tau}_{1,2}$	1035, 1288
$\tilde{\nu}_e, \tilde{\nu}_\mu, \tilde{\nu}_\tau$	1495, 1495, 1286
$h, H, A, H^{\pm}$	115, 372, 372, 383

Рис. 2: The light shaded area indicates the 95% C.L. parameter range in the $m_0 - m_{1/2}$ plane allowed by the EGRET data if the constraints from electroweak data, neutrality of the lightest supersymmetric particle, and electroweak symmetry breaking are imposed as well. The individual constraints are indicated by the lines and dots. The best fit values of mSUGRA parameters are $m_0 = 1400$ GeV, $m_{1/2} = 180$ GeV.

Sparticle decay modes lead to a number of jets (mostly b) and/or leptons in the final states with additional missing energy carried away by neutralinos. These events have an exceptional signature that allows one to distinguish them from the Standard Model background providing enough integrated luminosity and may be promising for SUSY searches within the advocated scenario [4].

In the discussed region of the mSUGRA parameter space prospects for ATLAS observation of a SUSY-like signal from two gluinos are investigated [5]. The cross section of the pair gluino production via gluon-gluon fusion is estimated at a rather high level of 13 pb (corresponding to the particluar choice of the parton distribution function). The parameters corresponding to the EGRET point ($m_0 = 1400$ GeV, $m_{1/2} = 180$ GeV, $\text{sign}\,\mu = +1$, $A_0 = 0$, $\tan\beta = 50$) were used as an input for the ISAJET code for calculation of the superparticle spectrum. Later the PYTHIA generator used the spectrum for event generation. It is worth mentioning that the whole generation process was performed within the ATLAS software ATHENA. The condition for choosing a certain SUSY channel was not only the large cross-section but also a peculiar signature which would tell it from different Standard Model background events.

At the EGRET point the process of pair gluino production and their subsequent decay appeared to be the most interesting:

$$
\begin{array}{l}
gg \to \tilde{g}\tilde{g} \\
\qquad\quad \downarrow \\
\qquad\quad \bar{b} + b + \tilde{\chi}^0_2 \\
\qquad\qquad\qquad\quad \downarrow \\
\qquad\qquad\qquad\quad \mu^- + \mu^+ + \tilde{\chi}^0_1
\end{array}
\qquad (1)
$$

Here we assume that both gluinos decay in the same way. So in the final state the gluino pair gives 4 b-quarks (b-jets), 4 muons, and a pair of the lightest stable neutralinos $\tilde{\chi}^0_1$ giving the high missing transverse momentum. There are B-hadrons in these jets and, in general, the event could have up to 4 secondary vertices depending on the efficiency of b-tagging.

The expected number of events for the ATLAS detector after a year of running with the total LHC luminosity 10^{34} cm^{-2}s^{-1} is 150. The preliminary estimation of the SM background gives its negligible contribution to the total signal.

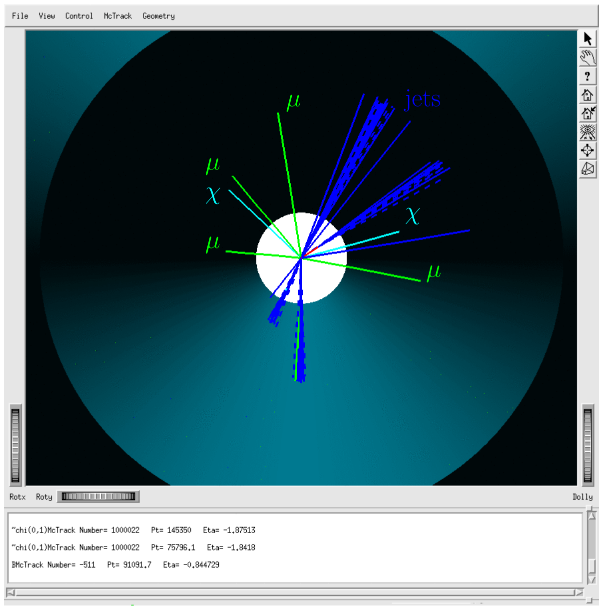


Рис. 3: Visualisation of the process inside the ATLAS detector. One can see 4 muon tracks (green lines), 2 tracks from neutralino (light blue lines), 4 jets (dark blue lines), and one long-lived B-meson (red line).

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CALCULATING FOUR LOOP TADPOLES

B.A. Kniehl[1], and A.V. Kotikov
[1]II. Institut für Theoretische Physik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

Calculations of higher-order corrections are very important for precision tests of the Standard Model in present and future high-energy physics experiments. The complexity of such calculations and the form of final results strongly increase with the number of quantum loops considered, and one rapidly reaches the limits of the present realm of possibility when one attempts to exactly account for all mass scales of a given problem, already at the two-loop level. To simplify the calculations and also the final expressions, various types of expansions were proposed during the last couple of years (see, for example, the book [1] and references cited therein). These approaches usually provide a possibility to reduce the problem of evaluating complicated Feynman integrals to the calculation of tadpoles and loops with massless propagators which have simple representations.

In our paper [2], we introduced a technique that allows to analytically evaluate a large class of four-loop tadpole diagrams with one nonzero mass. Specifically, the considered diagrams are transformed into integral representations whose integrands contain only one-loop tadpoles with new propagators having masses that depend on the variables of integration.

These results offer an opportunity to obtain analytical results for terms of the expansion in ϵ of the master integrals denoted as T_{54}, T_{62}, and T_{91} in recent papers [3,4] for which only numerical values have been available so far. They represent essential ingredients for high-precision predictions of a number of observables of current phenomenological interest.

As such an application, we considered [5] the vacuum polarisation induced by a heavy quark in the four-loop approximation of QCD and expressed the first two coefficients of its Taylor expansion in the ratio of virtuality to heavy-quark mass in a fully analytical form. Another application (see [6]) includes the four-loop matching condition of $\alpha_s(\mu)$ at the heavy-quark thresholds. Before, the considered values were presented only in a semi-analytic form (see Refs. [3,7] and [8], respectively).

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POLARIZED PARTON DENSITIES PARAMETERIZATION: LSS‘06

A.V. Sidorov

The world data on inclusive polarized DIS, in both NLO and LO QCD, including the new HERMES and COMPASS data on g_1 structure function have been analyzed. The updated NLO polarized densities are given in both the $\overline{\mathrm{MS}}$ and JET schemes and presented at HEPDATA web site http://durpdg.dur.ac.uk/hepdata. The x-dependence of higher twist corrections to the spin proton and neutron g_1^p and g_1^n structure functions and to the nonsinglet combination $g_1^p - g_1^n$ have been found for the first time in [1] (see Fig. 1).

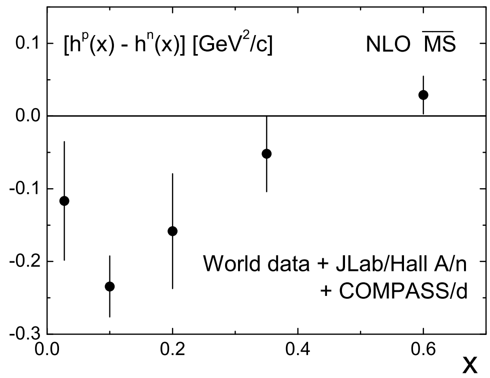

Рис. 1: Difference of higher twist contributions $h^p(x) - h^n(x)$ to the nonsinglet combination of structure functions $g_1^p - g_1^n$.

The first moment of this combination is found [2]. It agrees quantitatively and in sign with earlier theoretical predictions of the QCD sum rules and the instanton model. The above results have been used in the approved proposal of experiment at the upgraded JLAB facility (USA) "The Longitudinal Spin Structure of the Nucleon"(A 12 GeV Research Proposal to Jefferson Lab) (unpublished)

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ADLER FUNCTION WITHIN THE ANALYTIC APPROACH TO QCD

A.V. Nesterenko and J. Papavassiliou[1]
[1] University of Valencia, E–46100, Valencia, Spain

An important source of the nonperturbative information about the hadron dynamics at low energies is provided by the relevant dispersion relations. The latter, being based on the general principles of the local Quantum Field Theory, supply one with the definite analytic properties in a kinematic variable of a physical quantity at hand. The idea of employing this information together with the perturbative treatment of the renormalization group method forms the underlying concept of the Analytic approach to Quantum Chromodynamics (QCD) [1]. Some of the main advantages of this method are the absence of unphysical singularities and a fairly good higher–loop and scheme stability of outcoming results. The analytic approach has been successfully applied in studies of the strong running coupling [1, 2], perturbative series for QCD observables (for a recent overview of the so–called "Analytic perturbation theory" and its applications see Ref. [3]), and some other intrinsically nonperturbative aspects of the strong interaction [2, 4].

The Adler function $D(Q^2)$, being defined as the logarithmic derivative of the hadronic vacuum polarization function, is a quantity of central importance in various fields of elementary particle physics. In particular, it is essential for the analysis of strong interaction processes such as electron–positron annihilation into hadrons and τ lepton decay. Furthermore, the Adler function plays a key role when confronting precise experimental measurements of some electroweak observables (e.g., muon anomalous magnetic moment and shift of the electromagnetic fine structure constant) with their theoretical predictions, giving rise to decisive tests of the Standard Model and furnishing stringent constraints on possible new physics beyond it.

New integral representations for the Adler function and the R–ratio of the electron-positron annihilation into hadrons have recently been derived in the general framework of the analytic approach to QCD [5]. These representations capture both the effects due to the interrelation between spacelike and timelike domains and the effects due to the nonvanishing pion mass. The latter plays a crucial role in this analysis, forcing the Adler function to vanish in the infrared limit. Within the developed approach the Adler function is calculated by employing its perturbative approximation as the only additional input. The obtained result is found to be in reasonable agreement with the experimental prediction for the Adler function in the entire energy range, Fig. 1.

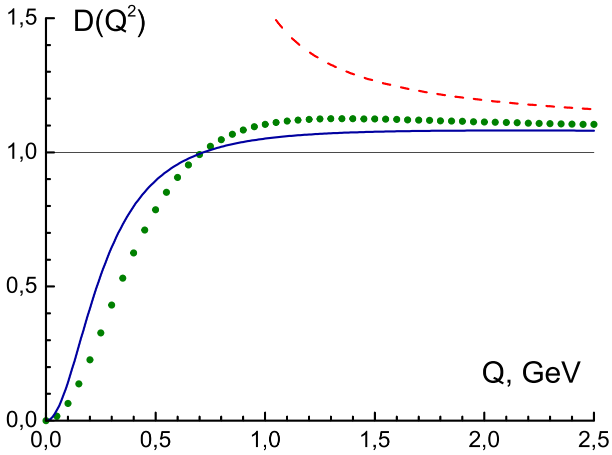

Рис. 1: The Adler function obtained in Ref. [5] (solid curve), its experimental prediction (•), and the one-loop perturbative approximation (dashed curve).

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TRANSVERSITY AND ITS ACCOMPANYING T-ODD DISTRIBUTION FROM DRELL-YAN PROCESSES WITH PION-PROTON COLLISIONS

A. Sissakian, O. Shevchenko, A. Nagaytsev, O. Denisov, and O. Ivanov

The advantage of DY process for extraction of PDFs is that there is no need in any fragmentation functions. It is well known that the double transversely polarized DY process $H_1^\uparrow H_2^\uparrow \to l^+ l^- X$ allows one to directly extract the transversity distributions (see Ref. [1] for review). In particular, the double polarized DY process with an antiproton beam is planned to be studied at PAX [2]. However, this is a rather difficult task to produce antiproton beam with the sufficiently high degree of polarization. So, it is certainly desirable to have an alternative (complementary) possibility allowing to extract the transversity PDF from unpolarized and single-polarized DY processes. This could be a matter of especial interest for the COMPASS experiment [3] where the possibility to study DY processes with unpolarized pion beam and with both unpolarized and transversely polarized proton targets $\pi^- p \to \mu^+ \mu^- X$, $\pi^- p^\uparrow \to \mu^+ \mu^- X$ is under discussion now.

The original expressions for unpolarized and single-polarized DY cross-sections [4] are very inconvenient for applications, since all parton distribution functions (PDFs) dependening on the quark transverse momentum k_T enter into these expressions in the complex convolution. So, at first sight it seems that there is no possibility to avoid application of some strong and badly argued model assumptions on the k_T dependence of PDFs. To avoid this problem, a special method was proposed and elaborated in our paper [5]. Within the method the new asymmetries were introduced for both unpolarized and single-polarized Drell-Yan processes which contain simple products of k_T independent PDFs. As a result, the method proposed in Ref. [5] allows us to extract the transversity h_1 and the first moment

$$h_{1q}^{\perp(1)}(x) \equiv \int d^2\mathbf{k}_T \left(\frac{\mathbf{k}_T^2}{2M_\pi^2}\right) h_{1q}^{\perp}(x_\pi, \mathbf{k}_T^2) \quad (1)$$

of the Boer-Mulders PDF $h_1^\perp$ directly, without any model assumptions about the k_T-dependence of $h_1^\perp(x, k_T^2)$.

In the preceding paper [5], the method was applied to the $\bar{p}p$ Drell-Yan processes, while in the described paper the method was extended and adopted to the Drell-Yan processes with the pion-proton collisions. The possibility was shown of direct extraction of the transversity and its accompanying T-odd Boer-Mulders PDF from accessible for COMPASS experiment, Drell-Yan processes with unpolarized pion beam and with both unpolarized and transversely polarized proton targets. To estimate a possibility of transversity measurement, a special simulation of Drell-Yan events with the COMPASS kinematics was performed [6]. The preliminary estimations demonstrate that it is quite real to extract both transversity and its accompanying T-odd PDF in the COMPASS conditions.

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NLO QCD METHOD OF THE POLARIZED SIDIS DATA ANALYSIS.

A. Sissakian, O. Shevchenko, and O. Ivanov

One of very important topics in modern high energy physics is the investigation of the partonic spin structure of nucleon. In this connection, nowadays, there is a huge growth of interest in the SIDIS experiments with a longitudinally polarized beam and target such as SMC [5], HERMES [6], COMPASS [7]. It is of importance that the SIDIS experiments, where one identifies the hadron in the final state, provide us with additional information on the partonic spin structure in comparison with the usual DIS experiments. Namely, contrary to the DIS data, the SIDIS data allow us to extract the sea and valence quark helicity distributions separately.

At the same time, it is argued (see, for example, Ref. [8]) that to obtain reliable distributions at relatively low average Q^2 available in modern SIDIS experiments, the leading order (LO) analysis is not sufficient and the NLO analysis is necessary. In Ref. [9], the procedure allowing a direct extraction from the SIDIS data of the first moments (truncated to the accessible for measurement Bjorken x region) of the quark helicity distributions in NLO QCD was proposed. However, in spite of the special importance of the first moments, it is certainly very desirable to have a procedure of reconstruction in NLO QCD of the polarized densities themselves. At the same time, it is extremely difficult to extract the local in Bjorken x (x_B) distributions directly, because of the double convolution product entering into the NLO QCD expressions for the semi-inclusive asymmetries. Contrary to LO, where a direct extraction of PDFs is possible, it seems at first sight that dealing with SIDIS asymmetries in NLO one cannot avoid some fitting procedure. However, the modern SIDIS data provide us with a rather small number of points for the measured asymmetries (and, besides, they suffer from large statistical errors). Thus, purely semi-inclusive data very weakly constrain a large number of fit parameters entering into the NLO analysis (for example, twenty free parameters are used in Ref. [11]). At the same time, the addition of DIS data in analysis cannot help us to solve the main task of SIDIS – to extract the valence, sea, and strange PDFs separately. Fortunately, operating just as in Ref. [9], one can directly extract not only the first moments, but the Mellin moments of any required order. Using the truncated moments of parton distribution functions (PDFs) and applying the modified Jacobi polynomial expansion method (MJEM) proposed in Ref. [10] one can reconstruct PDFs in the entire x_B region accessible for measurement. In [10] MJEM was tested using only simple numerical (idealized) examples, where the exact values of the input moments entering into MJEM are known. However, in the conditions of the experiment we have at our disposal a rather small number of measured asymmetry values (one point for each bin with rather wide bin widths at middle and large x_B). Thus, extracting the moments from the measured asymmetries one calculates the integrals over x_B using rather small number of points. So because of this problem, even for the data obtained with very high precision (small errors) the extracted moments always suffer from deviation from their true values. In this extended paper we investigated this problem in detail: MJEM was tested with simulations corresponding to the kinematics of the HERMES experiment, where the accessible x_B region is the most narrow in comparison with the SMC and COMPASS regions.

After testing we applied the proposed method to the NLO QCD analysis of the HERMES data on semi-inclusive asymmetries. Using these asymmetries [12], we performed the reconstruction in NLO QCD of the valence PDFs from the HERMES data. The LO results of the valence distribution reconstruction are in good accordance with the respective leading order of SMC and HERMES results, while the NLO results are in agreement with the existing NLO parametrizations on these quantities.

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STUDY OF USUAL AND EXOTIC HADRONS IN HARD REACTIONS VIA GPDS AND GDAS

I.V. Anikin , O.V. Teryaev, B. Pire[1], L. Szymanowski[2] , and S. Wallon[3]
[1] CPHT, Ecole Polytechnique, France
[2] Soltan Nuclear Institute, Warsaw, Poland
[3] LPT, Orsay, France

We present a theoretical study of exotic hybrid meson ($J^{PC} = 1^{-+}$) production in photon-photon collisions where one of the photons is deeply virtual, including twist 2 and twist 3 contributions. We calculate the cross section of this process which turns out to be large enough to imply sizeable counting rates in the present high luminosity electron-positron colliders. We emphasize the importance of the $\pi\eta$ decay channel for detection of the hybrid meson candidate $\pi_1(1400)$, and calculate the cross section and the angular distribution for pi eta pair production in the unpolarized case. This angular distribution is a useful tool for disentangling the hybrid meson signal from the background. Finally, we calculate the single spin asymmetry associated with one initial longitudinally polarized lepton [1].

We study the factorization for the processes involving two fragmentation functions in the case of fairly small transverse momenta. Considering e^+e^- annihilation where two outgoing hadrons have been detected, we demonstrate a new simple and illustrative method of factorization for such processes including leading order α_S corrections [2].

The QCD analysis of the recent experimental data (L3@LEP) of the hard exclusive $\rho\rho$ production in two photon collisions shows that these data can be understood as a signal for the existence of an exotic isotensor resonance with a mass around 1.5GeV. We also argue that hard exclusive reactions are a powerful tool for an experimental study of exotic hybrid mesons with $J^{PC} = 1^{-+}$ [3].

The sizeable cross section for deep exclusive electroproduction of an exotic $J^{PC} = 1^{-+}$ hybrid meson in the Bjorken regime has been estimated [4]. It is shown that the production amplitude scales like the one for usual meson electroproduction, *i.e.* as $1/Q^2$ due to the nonvanishing leading twist distribution amplitude for the hybrid meson, which may be normalized thanks to its relation to the energy momentum tensor and to the QCD sum rule technique. The hard amplitude is considered up to next–to–leading order in α_S and we explore the consequences of fixing the renormalization scale ambiguity through the BLM procedure. We study a particular case where the hybrid meson decays through a $\pi\eta$ meson pair [5]. We discuss the $\pi\eta$ generalized distribution amplitude and then calculate the production amplitude for this process. We propose forward-backward asymmetry in the production of π and η mesons as a signal for the hybrid meson production. We briefly comment on hybrid electroproduction at very high energy, in the diffractive limit where a QCD Odderon exchange mechanism should dominate. The conclusion of our study is that hard electroproduction is a promissing way to study exotic hybrid mesons, in particular at JLAB, HERA (HERMES) or CERN (Compass).

The BLM scale fixing procedure in exclusive electroproduction processes in the Bjorken regime has been discussed [6]. We showed that in the case of vector meson production the usual way to apply the BLM method fails due to singularities present in equations fixing the BLM scale. We argued that the BLM scale should be extracted from the squared amplitudes which are directly related to observables.

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PROTON TRANSVERSITY AND AZIMUTHAL ASYMMETRIES IN SIDIS AND IN DRELL-YAN

A.V. Efremov

It is well known that three most important (twist-2) Parton Distributions Functions (PDF) in a nucleon are the nonpolarized distribution function $f_1(x)$, helicity distribution $g_1(x)$ and the transverse spin (transversity) distribution $h_1(x)$. The first two have been more or less successfully measured experimentally in classical Deep Inelastic Scattering (DIS) experiments but the measurement of the last one is especially difficult since it corresponds to interference of helicity amplitudes, belongs to the class of the so-called chiral-odd structure functions and cannot be seen in DIS. That is why it was completely unknown experimentally till recent time. The only information comes from the Soffer inequality $|h_1(x)| \leq \frac{1}{2}[f_1(x) + g_1(x)]$ which follows from density matrix positivity and theoretical models.

To access the transversity, one needs either to scatter two polarized hadrons and to measure the transversal spin correlation A_{TT} in Drell-Yan process, or to know the transverse polarization of the quark scattered from the transversely polarized target. The latter could be done using a new spin dependent T-odd parton fragmentation function (PFF) responsible for the left-right asymmetry in one particle fragmentation of transversely polarized quark with respect to quark spin–momentum plane. (The so-called "Collins effect".)

This Collins PFF can be independently measured in e^+e^- annihilation into two back-to-back jets resulting from $q\bar{q}$ fragmentation since in spite of the fact that both q and $\bar{q}$ being not polarized transversally, its transversal spins are 100% correlated and the Collins effect reveals a specific azimuthal correlation of two hadrons from the opposite jets.This effect was probed earlier [1] using the DELPHI data and was accurately measured very recently by the BELLE collaboration.

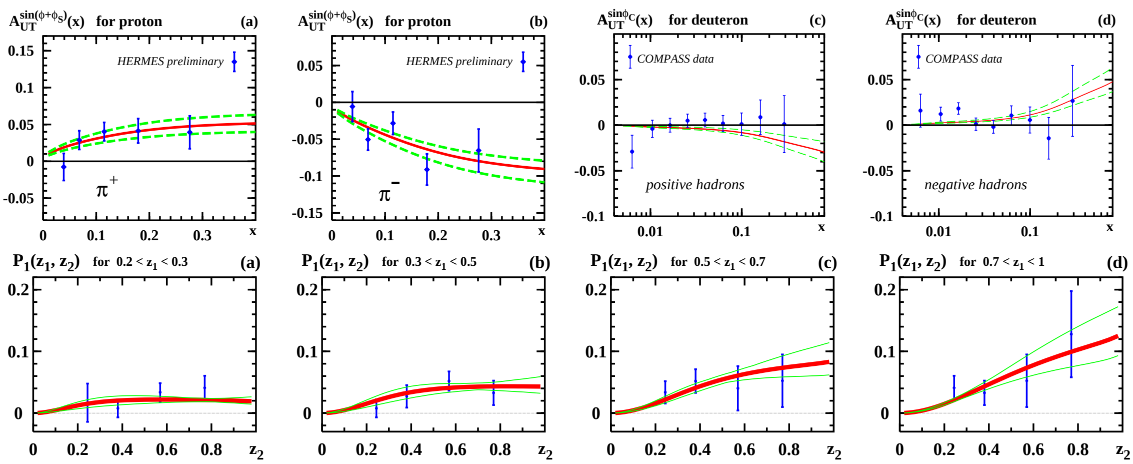
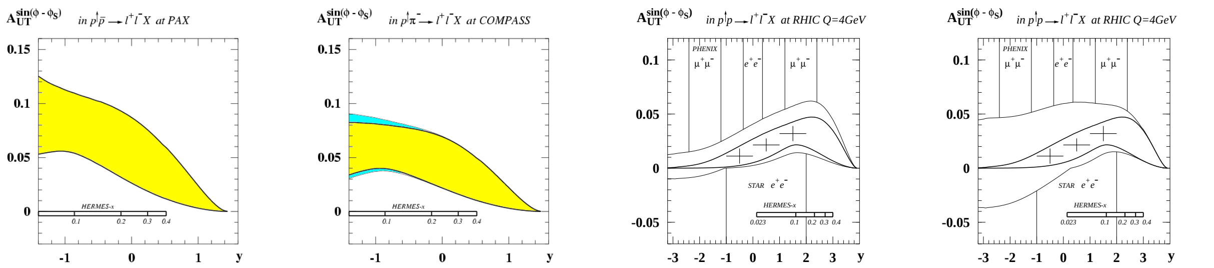


Рис. 1: *Top: The HERMES (a,b) and COMPASS (c,d) data on the Collins asymmetry. Bottom: The BELLE data on the Collins effect.*

Using transversity distribution calculated in the chiral quark-soliton model, the Collins fragmentation function was extracted from HERMES data on azimuthal single spin asymmetries (SSA) in semi-inclusive deeply inelastic scattering (SIDIS) and BELLE data on azimuthal correlation in e^+e^- annihilations [2]. It was found that the HERMES and BELLE data yield a consistent picture of the Collins PFF which is compatible with COMPASS data (Fig. 1) and with the information obtained from earlier DELPHI data. Estimates for future experiments are also made.

Another source of SSA in SIDIS is the so-called Sivers effect responsible for the left-right asymmetry of parton distributions in transversally polarized nucleon. QCD predicts that the Sivers PDFs possess a specific "universality property namely, they have opposite signs in SIDIS and in the Drell-Yan process. On the basis of existing HERMES data it is discussed [3, 4] how this remarkable QCD prediction could be checked experimentally in future experiments of the PAX and COMPASS collaborations by measurement of SSA due to the Sivers effect in the Drell-Yan pair production (see Fig. 2a,b) .



a **b** **c** **d**

Рис. 2: *Azimuthal asymmetries $A_{UT}^{\sin(\phi_h-\phi_S)}$ in production of the Drell-Yan lepton pair, $p^\uparrow h \to \mu^+\mu^- X$, depending on rapidity y: (**a**) for kinematics of PAX, where hadron $h = \bar{p}$, (**b**) for kinematics of COMPASS, where $h = \pi^-$. The shaded area corresponds to 1σ uncertainty of the fit. (**c**,**d**)The azimuthal SSA $A_{UT}^{\sin(\phi-\phi_S)}$ in Drell-Yan lepton pair production, $p^\uparrow p \to l^+l^- X$, as a function of y for kinematics of the RHIC experiment with $\sqrt{s} = 200\,\mathrm{GeV}$. The left and right plots correspond to different anzatz for Sivers antiquark PDFs. For $Q = 4\,\mathrm{GeV}$ the estimated statistical error for STAR is shown.*

In *pp*-collisions antiquark PDFs are inevitably involved and the counting rates are smaller. It was demonstrated [5], however, that the Sivers effect SSA in DY can nevertheless be measured at RHIC with accuracy sufficient to unambiguously test the sign prediction. In particular, by focusing on certain kinematic regions the effect of the unknown Sivers antiquark PDF can be minimized. And, by focusing on the opposite kinematic regions one can gain first information on the Sivers antiquark PDF itself (see Fig.2c,d).

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Electroweak Radiative corrections to Drell–Yan like processes at LHC

A.B. Arbuzov[1]

The Drell–Yan like processes [1] at high energy hadron colliders provide an advanced tool for precision studies of several problems in the elementary particle phenomenology. Studies of single Z and W boson production with the subsequent decays into leptonic pairs play a very important role in the physical programs of Tevatron and LHC. These processes have large cross sections and clean signatures in the detectors. That allows to reach at LHC the 1% experimental accuracy for the total cross sections of these processes as well as high precision in the measurements of differential distributions. In particular, Drell–Yan like processes are planned be used at LHC for luminosity monitoring, W-boson mass and width measurement, detector calibration, extraction of parton density functions, new physics searches, and other purposes.

Adequately precise theoretical predictions for single Z and W production at LHC are required. For this reason we have to scrutinize several effects involved in the derivation of the theoretical accuracy: QCD and electroweak (EW) radiative corrections (RC), uncertainties in the partonic density functions, technical precision of Monte Carlo event generators *etc.* Due to the smallness of the fine structure constant α in comparison with the strong coupling constant α_s, we can limit ourselves to the evaluation of only the first order EW corrections together with certain higher order leading logarithmic contributions [2]. At the same moment QCD corrections have to be treated at least at NNLO [3].

Results for the one-loop EW RC were obtained by the SANC team with help of the automatized system [4]. The details of our calculations for the charged current case (single W-boson production) were presented in [5]. Comparisons of our results with analogous calculations of other groups [6, 7, 8] were performed within the Les Houches [9] and TEV4LHC [10] workshops, where we derived a common conclusion on the present level of theoretical uncertainty in the description of Drell-Yan like processes. The EW corrections for the realistic LHC observables were found to be of the order of several perent for inclusive quantities and can reach up to 30% in corners of differential distributions.

In paper [11] we considered the particular contribution of the first order electroweak radiative corrections coming from the photon induced process $h_1 + h_2 \to X + \gamma + q \to X + q' + l_1 + \bar{l}_2$, where $h_{1,2}$ stand for the initial colliding hadrons; l_1 and $\bar{l}_2$ is a pair of leptons (*e.g.* μ^- and μ^+, or ν_e and e^+); $X + q'$ denotes the remaining final state particles. In Fig. 1 the Born-level distribution in the transverse momentum of the outgoing muon and the relative contribution of the inverse bremsstrahlung are shown. One can see that the contribution has to be taken into account in order to reach the one percent precision level.

In order to study the interplay of EW and QCD corrections we implemented also the NLO QCD effects [12] into the SANC Monte Carlo for the processes under consideration.

So, in this way the SANC group made a concrete contribution into the preparation of the LHC physical program. Besides the Drell-Yan processes we consider several other ones, which will be studied at LHC as well.

[1]On behalf of the SANC team: `http://sanc.jinr.ru`

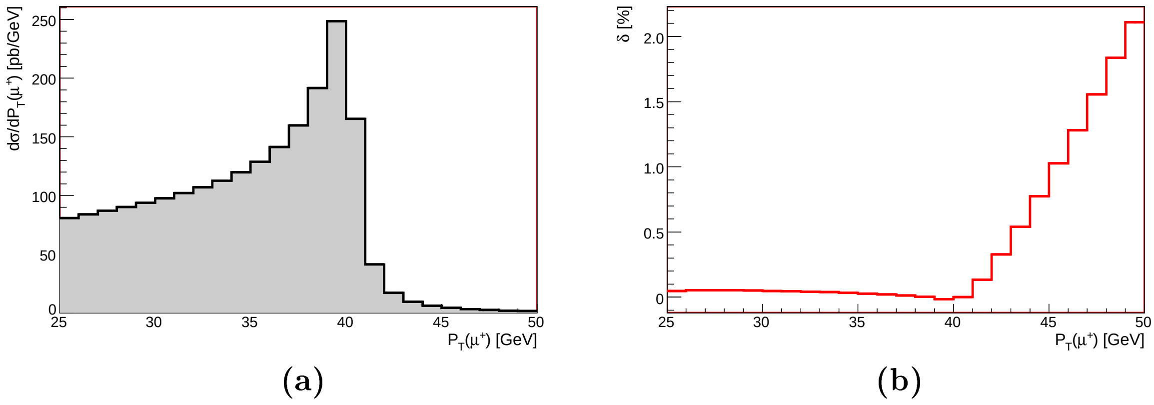

Рис. 1: The Born-level CC Drell–Yan cross section and the relative contribution of the inverse bremsstrahlung versus the μ^+ transverse momentum.

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DISTRIBUTION AMPLITUDES OF LIGHT MESONS AND PHOTON IN THE INSTANTON MODEL.

A. E. Dorokhov

Investigations of hard exclusive processes are essential for our understanding of the internal quark-gluon dynamics of hadrons. Theoretically, such studies are based on the assumption of factorization of dynamics at long and short distances. The short-distance physics is well elaborated by perturbative methods of QCD and depends on particular hard subprocesses. The long-distance dynamics is essentially nonperturbative and within the factorization formalism becomes parametrized in terms of hadronic *distribution amplitudes*. These nonperturbative quantities are universal and are defined as vacuum-to-hadron matrix elements of particular nonlocal light-cone quark or quark-gluon operators. In the present study we find the leading- and higher-twist distribution amplitudes of pion, ρ-meson and real and virtual photons are analyzed in the instanton liquid model [1, 2]. The first experiments measuring the photon DA in the photon dissociation to two pions via two-gluon (Pomeron) exchange have been carried out at HERA.

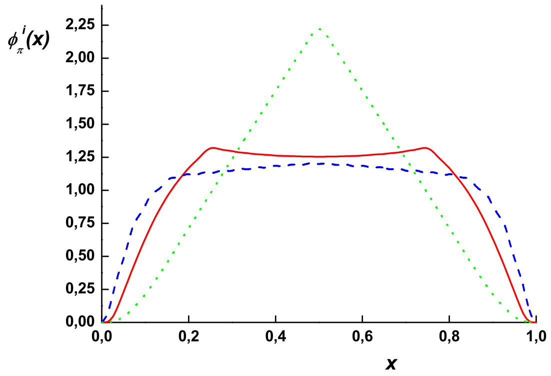

Рис. 1: ρ-meson twist-2 distribution amplitudes: transverse (solid line) and longitudinal (dashed) projections. The third line is distribution amplitude at asymptotic scale.

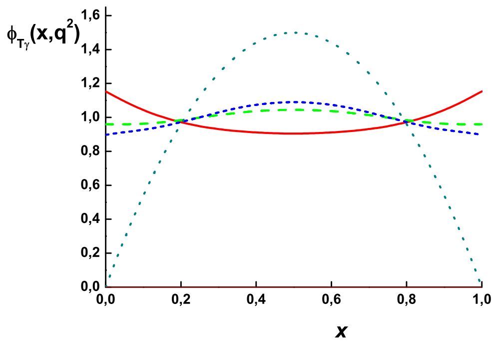

Рис. 3: Dependence of the twist-2 tensor component of the photon DA on transverse momentum squared ($q^2 = 0.25$ GeV^2 solid line, $q^2 = 0$ GeV^2 dashed line, $q^2 = -0.09$ GeV^2 short-dashed line, asymptotic DA - dotted line) given at the quark model scale.

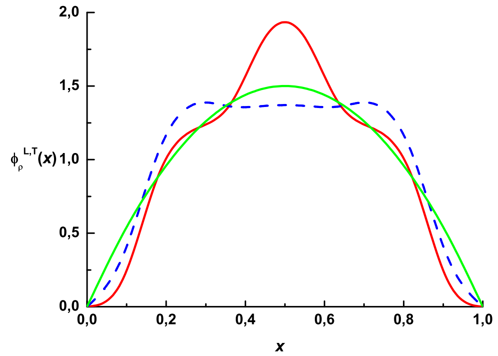

Рис. 2: ρ-meson twist-2 distribution amplitudes: transverse (solid line) and longitudinal (dashed) projections. The third line is distribution amplitude at asymptotic scale.

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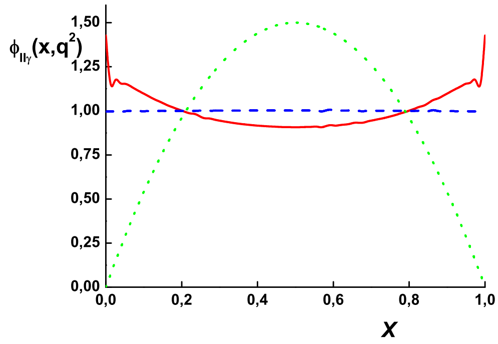

Рис. 4: Same as in Fig. 3 for the twist-2 vector component of the photon DA.

LOW-ENERGY PHOTON-PHOTON COLLISIONS IN CHPT TO TWO LOOPS.

J. Gasser (Bern), M. A. Ivanov, M. E. Sainio (Helsinki)

The amplitude for $\gamma\gamma \to \pi\pi$ was recalculated [1, 2] in the framework of chiral perturbation theory (ChPT) [3, 4] at two-loop order, and compared the result with the only previous calculation performed at this accuracy [5, 6]. Because the effective Lagrangian at order p^6 was not available at that time, the ultraviolet divergences were evaluated in the $\overline{\text{MS}}$ scheme, then dropped and replaced with a corresponding polynomial in the external momenta. The three new counterterms which enter at this order in the low-energy expansion were estimated with resonance saturation. Whereas such a procedure is legitimate from a technical point of view, it does not make use of the full information provided by chiral symmetry.

Over the last ten years, considerable progress has been made in this field, both in theory and experiment. As for theory, the Lagrangian at order p^6 has been constructed [7], and its divergence structure has been determined [8]. This provides an important check on the above calculations: adding the counterterm contributions from the p^6 Lagrangian to the $\overline{\text{MS}}$ amplitude evaluated in [5] and in [6] must provide a scale independent result. Also in the theory, improved techniques to evaluate the two-loop diagrams that occur in these amplitudes have been developed [9]. The improvement arises mainly in the evaluation of diagrams with four external legs, where the techniques of Ref. [9] allow one to extract the ultraviolet divergences by use of simple recursion relations. We are now able to present the final result for the two-loop amplitudes in a rather compact form (in Refs. [5, 6], the result was presented partly in numerical form only, because the algebraic expressions were too long to be published).

Our result in the case of neutral pions agrees with the earlier calculation [5] up to the coefficient in one of the chiral logarithms in the amplitude A, and up to minute differences in the numerical values of the remainder $\Delta_{A,B}$. The induced changes in the numerics of the cross section and of the dipole polarizabilities are far below the uncertainties generated by the (not precisely known) values of the low energy constants.

Our result in the case of charged pions agrees with the earlier calculation [6] up to the remainder $\Delta_{A,B}$. The induced changes in the cross section and in the dipole polarizabilities are far below the uncertainties generated by the (not precisely known) values of the low-energy constants. For the cross section below 500 MeV, the change is less than 1 percent.

We have investigated the uncertainties in the polarizabilities due to higher order corrections, and due to the uncertainties in the LECs at order p^6. According to our analysis, the two-loop result for the dipole polarizability

$$(\alpha_1 - \beta_1)_{\pi^\pm} = (5.7 \pm 1.0) \times 10^{-4}\,\text{fm}^3$$

is particularly reliable. It is in conflict with the recent experimental result obtained at MAMI [10], or with the dispersive analysis performed in [11].

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EXCLUSIVE SEMILEPTONIC AND NONLEPTONIC DECAYS OF THE B_C MESON.

M. A. Ivanov , J. G. Körner (Mainz U), and P. Santorelli (Naples U)

Recently, CDF reported first Run II evidence for the B_c-meson in the fully reconstructed decay channel $B_c \to J/\psi + \pi$ with $J/\psi \to \mu^+\mu^-$ [1]. The mass value quoted for this decay channel is $6.2857 \pm 0.0053(\text{stat.}) \pm 0.0012(\text{syst.})$ GeV with errors significantly smaller than in the first measurement.

The B_c-meson is the lowest bound state of two heavy quarks (charm and bottom) with open flavor. The B_c-meson therefore decays weakly. It can decay via (i) b-quark decay, (ii) c-quark decay, and (iii) the annihilation channel.

We have completed [2] the analysis of almost all accessible low-lying exclusive nonleptonic two-body and semileptonic three-body modes of the B_c-decays within our relativistic constituent quark model [3, 4, 5, 6]. We have updated the model parameters by using the latest experimental data on the B_c-mass [1] and the weak decay constant f_D [7]. We have given a set of numerical values for the leptonic, semileptonic and nonleptonic partial decay widths of the B_c-meson and compare them with the results of other approaches. We have provided explicit formulas for the angular decay distributions of the cascade decays $B_c^- \to J/\psi(\to l^+l^-) + \rho^-(\to \pi^-\pi^0)$ and $B_c^- \to J/\psi(\to l^+l^-) + W^-_{\text{off-shell}}(\to l^- + \bar{\nu}_l)$ by using the methods described in [8].

For the nonleptonic decay $B_c^- \to J/\psi + \rho^-$ we have also included lepton mass and $T-$odd effects in our analysis. These angular decay distributions may be of help in analyzing the cascade decay data. Also, by analyzing the cascade angular decay distributions, one can learn more details about the spin dynamics of the decay process than from the rate analysis alone.

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DASHEN'S PHENOMENON AND THE STRONG CP-PROBLEM

A. C. Kalloniatis (Adelaide Uni.), and S. N. Nedelko

Dashen's phenomenon in the dependence of CP-violating θ parameter has been studied in the domain model of QCD vacuum [1, 2, 3]. The model assumes a cluster-like vacuum structure whose units are characterised in particular by a fraction of topological charge "q"which is not necessarily an integer number. It is shown that vacuum doubling accompanied by spontaneous CP-violation (Dashen's phenomenon) occurs at $\theta = \pi$ for any $N_f > 1$ and any value of topological charge q. These features are in agreement with expectations based on anomalous Ward identities and large N_c effective theories. It has been found also that there are additional values of θ depending on q for which vacuum doubling occurs. These additional critical values provide for a mechanism for simultaneous resolution of the strong CP and $U_{\rm A}(1)$ problems, identified in general earlier by Peter Minkowski in a model independent consideration [4]: the order of thermodynamic limit and the limit $\theta \to 0$ are in general not interchangeable and thus independence with respect to θ of the infinite volume QCD partition function of QCD does not automatically lead to vanishing topological succeptibility

$$\chi = \lim_{\theta\to 0}\lim_{V\to\infty} V^{-1} d^2 Z_V(\theta)/d\theta^2.$$

Within the domain model the mechanism for resolving the strong CP-problem is realised in the following way. In the presence of nonzero gluon condensates irrational values of q are permitted and lead to a realisation of CP in which the set of critical values of the θ parameter for which the CP-breaking is spontaneous is dense in the interval $[-\pi, \pi]$. As a consequence, the infinite volume partition function with infinitesimally small quark masses

$$Z = \lim_{V\to\infty} Z_V(\theta) = \lim_{V\to\infty} Z_V(0)$$

is independent of θ, and

$$\lim_{V\to\infty} \langle \mathbb{E} \rangle_V^{\theta} \equiv \lim_{V\to\infty} \langle \mathbb{E} \rangle_V^{\theta=0}, \qquad \lim_{V\to\infty} \langle \mathbb{O} \rangle_{V,\theta} \equiv 0,$$

for any CP-even and CP-odd operators $\mathbb{E}$ and $\mathbb{O}$, respectively, which resolves the problem of CP-violation. Simultaneously, one finds that topological succeptibility in QCD with massive quarks

$$\chi^{\rm QCD} = -\lim_{V\to\infty} \frac{1}{V}\frac{\partial^2}{\partial\theta^2} Z_V(\theta) \neq 0,$$

is nonzero, independent of θ, and satisfies the anomalous Ward identity, which indicates a correct implementation of the $U_A(1)$ symmetry. In particular, in the chiral limit the mass of the η' is expressed via the topological succeptibility $\chi^{\rm YM}$ of pure gluodynamics in agreement with the Witten-Veneziano formula. If q takes a rational value, then only a finite number of such critical points exist in the interval $\theta \in [-\pi, \pi]$, which results in the standard strong CP problem.

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NEW FORMULATION OF THE HADRONIC CONTRIBUTION TO THE MUON ANOMALOUS MAGNETIC MOMENT AND RELATED TOPICS.

Yu. M. Bystritsky, V. V. Bytev, and E. A. Kuraev

The anomalous magnetic moment of muon a_μ is a very sensitive laboratory for search of new physics beyond the Standard Model. However, before driving any premature conclusions about new physics serious efforts should be made to evaluate the level of precision of known contributions. The main source of uncertainties in a_μ for now is the hadronic contribution a_μ^{hadr}, which cannot be evaluated straightforwardly at the moment. Usually this contribution is expressed in terms of the experimentally measured ratio of cross sections $R(s) = \left(\sigma_0^{e^+e^-\to hadr}(s)\right) / \left(\sigma^{e^+e^-\to\mu^+\mu^-}(s)\right)$ in the following form [1]:

$$a_\mu^{hadr} = \frac{1}{3}\left(\frac{\alpha}{\pi}\right)^2 \int\limits_{4m_\pi^2}^{\infty} \frac{ds}{s} R(s) \left[K^{(1)}(s) + \frac{\alpha}{\pi}K^{(2)}(s)\right], \tag{1}$$

where $K^{(1,2)}(s)$ are some kernel-functions which describe the correction to the electromagnetic muon vertex with additional photon exchange, where photon propagators contain hadronic excitation. We note that here the a_μ^{hadr} value is expressed in terms of $\sigma_0^{e^+e^-\to hadr}$ cross section which is obtained from the experimental one $\sigma_{exp.}^{e^+e^-\to hadr}$ by getting rid of the vacuum polarization in the intermediate virtual photon propagator in $e^+e^- \to \gamma^* \to hadr$.

In [2], we propose to reformulate the expression for a_μ^{hadr} in terms of $\sigma_{exp.}^{e^+e^-\to hadr}$. That step will reduce uncertainties which appear in vacuum polarization ridding procedure. The resulting formula will have the view of (1) but with the replacements $\sigma_0^{e^+e^-\to hadr} \to \sigma_{exp.}^{e^+e^-\to hadr}$ and $K^{(2)} \to \bar{K}^{(2)}$, where $\bar{K}^{(2)}$ is the modified kernel function of second order which we obtained in [2]. The function of first order $K^{(1)}$ remains the same.

A lot of attention was paid to radiative correction calculations of different channels of e^+e^--annihilation to hadrons, such as $e^+e^- \to \mu^+\mu^-(\gamma), \pi^+\pi^-(\gamma), \pi^+\pi^-\pi^0(\gamma)$ [3, 4]. The invariant mass distributions for the muon and pion pairs are obtained for both the initial and final state radiation. The pions were assumed to be point-like objects and scalar QED was applied for calculation. The QED radiative corrections related to the final state radiation, additional to the well-known Coulomb factor, are treated near the threshold region exactly. The final state emission of virtual and real photon is considered explicitly. Thus we write out a lot of formulae which can be used for the aims of experimental setup calibrations and evaluation of accelerator luminosity.

In [5], we showed that in the process of elastic electron-muon scattering the target-spin and charge asymmetries can be observed which mostly appear from the two-photon exchange contribution. These two kinds of asymmetries arise from the interference of the Born amplitude and the box-type amplitude corresponding to two virtual photons exchange. In the case of unpolarized particles, the charge-odd correlation was calculated. It can be measured in a combination of electron-muon and positron-muon scattering experiments. The forward-backward asymmetry is the corresponding quantity which can be measured for the crossed processes. In the case of polarized muon, the one-spin asymmetry for annihilation and scattering channels has been calculated.

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SPECTRA OF MESONS, EXCITATIONS, AND THE GLUEBALL.

G. Ganbold

Conventionally, the observed hadrons are considered as colorless bound states of quarks and gluons under the *color confinement* of the QCD. However this is achieved by taking into account the nonlinear gluon interaction and the correct summation of the higher-order contributions meets a problem because the coupling becomes stronger at the hadron scale. A number of phenomenological approaches is devoted to avoid the problem, but some of them are adapted to the specific narrow sector of heavy hadrons and introduce too many parameters, other models use a nonrelativistic method. However, the problem requires a relativistic consideration because the binding energy is not negligible for mesons and baryons. We have considered a relativistic quantum field model of interacting quarks and gluons under the analytic confinement [1] and investigated the formation and spectra of the hadrons by using the Bethe-Salpeter equation (BSE) to obtain reasonable results for the meson ground states, orbital and radial excitations, the glueball lowest state as well as for the light meson decay constants [2, 3] in agreement with latest data [4].

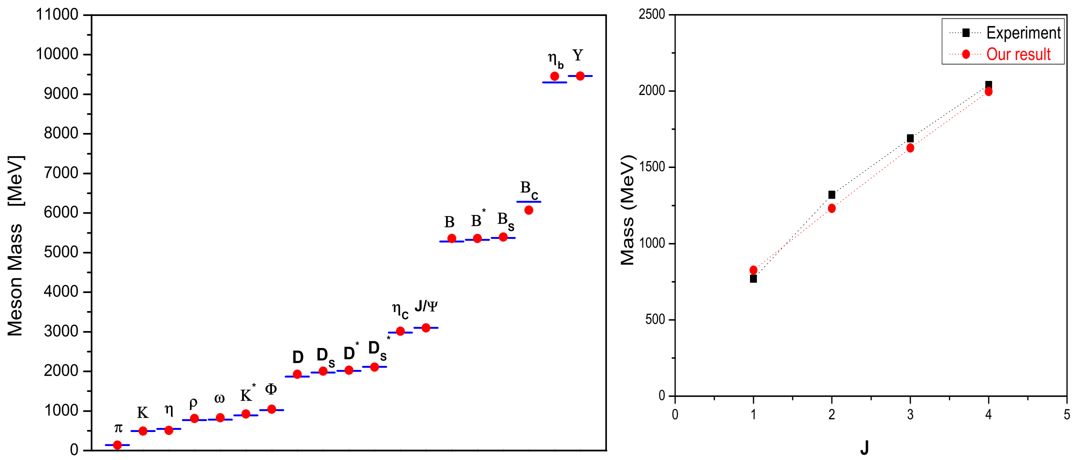

Рис. 1: Our estimates (dots) for the meson ground-state masses and the K^*-meson excitations compared with experimental data (bars and squares).

By using a minimal set of parameters, namely, the QCD coupling constant α_s, the confinement scale Λ and the quark masses $\{m_{ud}, m_s, m_c, m_b\}$ and reasonable forms of the quark and gluon propagators we describe correctly:
- the pseudoscalar and vector meson masses in the ground state (Fig.1),
- nontrivial dependencies of the meson masses $M(m_1+m_2)$ on the combined quark masses,
- the SU(3)-symmetry breaking: $M_K \neq M_\pi$,
- the so-called "$U(1)$-splitting": $M_\pi \ll M_\eta$ while $M_\rho \approx M_\omega$,
- the radial and orbital Regge trajectories for the pseudoscalar and vector mesons (Fig.1),
- the light meson decay constants $f_\pi = 118\text{MeV}, \;\; f_K = 176\text{MeV}$,
- the lowest state glueball mass $M_G = \Lambda\sqrt{2\ln\left(2\pi(2+\sqrt{3})^2/27\alpha_s\right)} = 1745$ MeV.

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PRECISION SPECTROSCOPY OF LIGHT MOLECULAR ATOMS AND IONS

V.I. Korobov

In recent years, high-precision vibrational spectroscopy of the light molecular atoms and ions has been recognized as a promising method for the metrology of the electron-to-nucleus mass ratios (m_e/m_p, m_e/m_d, $m_e/m_{\bar{p}}$, etc). The fundamental vibration frequency approximately scales as $h\nu_{\rm vibr} \propto \sqrt{m_e/m_p}R_\infty$, where R_∞ is the Rydberg constant. A comparison between experimental and theoretical data at the 10 kHz level in H_2^+ would allow a determination of m_e/m_p with about $5 \cdot 10^{-11}$ relative accuracy, a significant improvement with respect to the present accuracy of $4.6 \cdot 10^{-10}$.

In the framework of this program the leading relativistic and radiative corrections [1, 2] as well as the yet remaining unevaluated corrections of order $m\alpha^6$ [3] have been obtained for the ro-vibrational states of H_2^+, HD^+ ions and the antiprotonic helium atom with a *numerical uncertainty* below 1 kHz. The results for the hydrogen molecular ions are presented in the Table.

Table. Summary of contributions to the $(v = 0, L = 0) \to (v' = 1, L' = 0)$ transition frequency (in MHz).

	H_2^+	HD^+
ΔE_{nr}	65 687 511.0686	57 349 439.9717
ΔE_{α^2}	1091.041(03)	958.152(03)
ΔE_{α^3}	−276.544(02)	−242.118(02)
ΔE_{α^4}	−1.997	−1.748
ΔE_{α^5}	0.120(23)	0.106(19)
ΔE_{tot}	65 688 323.688(25)	57 350 154.368(21)

The major uncertainty stems from the yet unevaluated QED corrections of order $m\alpha^7$, which contribute to the transition energy at the level of about 25 kHz or $\sim 4 \cdot 10^{-10}$ of the relative accuracy.

Accurate knowledge of the hyperfine structure of the transition lines is required in order to permit precise comparison with experimental transition frequencies. The hyperfine splitting of the states of H_2^+, HD^+, and $^3He^+\bar{p}$ with accuracy of order $m\alpha^6(m_e/M_N)$ has been calculated [4, 5, 6]. These are the first complete *ab initio* calculations to this order.

The results of the current research would be included into a new volume of *Lecture Notes in Physics*, Springer, 2007: "Precision Physics of Simple Atomic Systems".

The newly obtained data on the antiprotonic helium atom spectroscopy and improved determination of the $m_{\bar{p}}/m_e$ ratio from these data will contribute to the 2006 year adjustment of CODATA recommended values for fundamental constants.

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