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Internal Report
DESY Zeuthen–96–08
December 1996

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by

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Abstract

The contribution of the instanton induced quark-gluon interaction to the double spin asymmetry in polarized J/ψ leptoproduction is estimated. Asymmetry values as large as 0.1 are obtained for Q^2 values of a few GeV^2 at incident energies of the HERMES and COMPASS experiments.

1 Introduction

In the recent years the interest in polarized lepton nucleon interactions at high energies has grown strongly, as documented by the increasing number of dedicated experiments in past, present, and future at CERN (EMC, SMC, COMPASS [1]), SLAC(E-142/143 and E-154/155), and DESY (HERMES [2]) (see [3]). Also, a number of anomalous polarization phenomena in both exclusive and inclusive hadronic reactions at high energy are known for some time. As it is well known, perturbative QCD predicts a decreasing strength of helicity breaking effects with growing energy and transverse momentum, i.e. pQCD to a large extent fails to describe polarized data [4].

Recently, a new approach to the theory of polarized effects based upon non-perturbative QCD was proposed [5][1]. In this approach the origin of the large polarized effects is the interaction of quarks with strong vacuum fluctuations of the gluon fields, so-called instantons [7]. In the instanton liquid model of the QCD vacuum [8] the instanton size is rather small. Therefore, the instanton induced quark-quark interaction [9] is point-like. Similar to the case of the point-like four-fermion Fermi interaction, it should lead to an anomalous growth of the cross sections induced by instantons. Also, one of the features of this new interaction is the spin-flip of quarks in the instanton field. Due to these reasons a large instanton contribution to the spin dependent cross sections at high energy in QCD can be anticipated [10].

A first estimation of the instanton contribution to the sea quark polarization $\Delta\bar{q}$ was obtained in [11]. It was shown that the contribution is *negative* and allows to explain the observed decrease of the polarized structure functions $g_1^{p,n}(x)$ in the region $x > 0.1$ compared to the naive quark-parton model expectation which takes into account only the valence quark contribution to the nucleon spin.

An alternative way to explain the decrease of $g_1^{p,n}(x)$ at $x > 0.1$ is the introduction of a large *positive* gluon polarization ΔG inside the nucleon [12].

A *positive* gluon polarization in the proton is expected in the framework of perturbative QCD due to conservation of helicity at the perturbative quark-gluon vertex [13]. However, the possibility of having a *negative* gluon polarization within the bag model and a non-relativistic quark model was shown by Jaffe [14]. Recently, it was also suggested that instantons can lead to a *negative* gluon polarization and, consequently, to a *positive* contribution to $g_1(x)^{p,n}$ at $x < 0.1$ [15]. This provides an elegant explanation of the increase of $g_1^p(x)$ in the low x region as found by SMC [16].

Since a long time, open charm and J/ψ production in hadron-hadron, hadron-nucleus and lepton-hadron interactions have been suggested as a very useful tool to extract information on the unpolarized gluon distribution [17]. Recently a physics program was proposed by the COMPASS Collaboration at CERN [1] to investigate open charm production in polarized DIS to eventually measure $\Delta G(x)/G(x)$ at $x \approx 0.1$. From estimates of the projected statistical error of the double spin asymmetry in J/ψ production, based essentially on the colour singlet model, it was shown that also the HERMES experiment might eventually have sufficient sensitivity to access the polarized gluon distribution by measuring J/ψ production in doubly polarized electron-proton scattering at HERA [18].

In this paper a first estimate will be given on the contribution of the instanton induced gluon polarization in the proton to the spin-dependent J/ψ cross section in DIS. First, the calculation of the polarized gluon distribution will be illustrated. Second, this distribution will be utilized to calculate the J/ψ cross section asymmetry in the context of the color singlet model.

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[1] The same mechanism was discussed by other authors [6] as well.

2 Polarized Gluon Distribution

Up to now there exist no reliable measurements, neither direct nor indirect ones, of the polarized gluon distribution; both shape and integrated value are fairly undetermined at present. Recently, an NLO analysis of the polarized DIS world data on $g_1(x, Q^2)$ was performed to extract the polarized parton densities in the nucleon [19]. The result suggests a *positive* integral of the gluon polarization. Still, this result is sensitive to the input shapes of the polarized valence and sea quark densities as well as to the marginal statistical strength inherent in the Q^2 dependence of existing polarized DIS data. Hence it remains to be proven that a similarly good description of the data can not be accomplished by introducing a large *negative* strange quark polarization in conjunction with a *negative* gluon polarization.

The polarized gluon distribution is a non-perturbative object as any other parton distribution function and hence can not be calculated in the framework of perturbative Quantum Chromodynamics. In this situation a most viable approach is to utilize existing models based upon non-perturbative QCD to derive predictions for the polarized gluon distribution function.

One of the models for the description of non-perturbative effects in QCD is the instanton liquid model [8]. In this model many properties of the hadrons as masses, decays widths etc., have been described rather well.

The existence of instantons leads to a specific spin- dependent quark-quark interaction through the QCD vacuum which determines the spin-spin mass splitting in hadron multiplets [20] and gives rise to a negative sea quark polarization in the nucleon [5].

Recently, it was shown that instantons induce the *chromomagnetic quark-gluon* interaction [21]. This new type of quark-gluon interaction should also give a contribution to the spin-dependent cross-section due to its spin-flip property.

In [15] it was shown that the spin-flip chromomagnetic quark-gluon interaction gives rise to a non-zero gluon polarization in the nucleon. The effective chromomagnetic quark-gluon interaction has the following form:

$$\Delta L_A = -i\mu_a \sum_q \frac{g}{2m_q^*} \bar{q}\sigma_{\mu\nu} t^a q G^a_{\mu\nu}. \tag{1}$$

The value of the quark anomalous chromomagnetic moment can be estimated in the liquid instanton model for the QCD vacuum [8] as

$$\mu_a = -\frac{f\pi}{2\alpha_s(\rho_c)}, \tag{2}$$

where $f = n_c \pi^2 \rho_c^4$ is the so-called packing fraction of instantons in the vacuum, and $m_q^* = m_q - 2\pi^2\rho_c^2 < 0 \mid \bar{q}q \mid 0 > /3$ is the effective quark mass. The value of n_c is connected with the value of the gluon condensate by the formula:
$n_c =< 0 \mid \alpha_s G^a_{\mu\nu} G^a_{\mu\nu} \mid 0 > /16\pi \approx 7.5\ 10^{-4}\ GeV^{\ 4}$, and ρ_c is the average instanton size in the QCD vacuum. We note that the value of the average instanton size is not well constrained in the model [8] yet, $\rho_c = 1.6 \div 2\ GeV^{\ -1}$.

An estimate of the gluon polarization in the proton as induced by the non-perturbative chromomagnetic quark-gluon interaction (1) can be obtained by applying the Altarelli–Parisi method [22]. The result of the calculation of the quark splitting function averaged over transverse momentum is [15]

$$P_{G_\lambda, q_+}(z) = \frac{C(1-\lambda)}{z} \int_0^\infty d\beta F^2(\beta, z), \tag{3}$$

where $\beta = p_\perp^2 \rho_c^2$, λ is the final gluon polarization, $F(\beta, z)$ is the instanton form factor and

$$C = \frac{\alpha_s {\mu^2}_a}{3\pi {m^*}_q^2 \rho_c^2} = \frac{|\mu_a|}{8}, \tag{4}$$

where relation $2n_c = < 0 \mid \bar{q}q \mid 0 > m_q^*$ [8] for the light quarks $(m_q = 0)$ have been used.
It should be mentioned that due to the spin-flip of the quark at the instanton vertex the quark splitting function (3) has a very specific dependence on the gluon helicity. It is non-zero only if the emitted gluon has the opposite helicity compared to the initial quark helicity.
This is in contrast to the the case of the perturbative quark-gluon vertex, where due to helicity conservation the probability is larger to emit the gluon with the same helicity as the initial quark. As result we anticipate a *positive* gluon polarization induced by the perturbative quark-gluon vertex and a *negative* gluon polarization induced by the non-perturbative instanton-quark vertex.
Since the instanton is the classical solution of the QCD equation of motion, the dependence of its formfactor on momentum transfer can be only connected with initial-final and final-final interactions of particles created at the instanton vertex. The contribution of these interactions to the probability of the transition between two states with a different number of gluons was estimated in [25]. It was shown that to take this effect into account one should introduce a form factor:

$$F(p_i) = exp\left\{ - \frac{\alpha_s}{16\pi} \sum_{i,j} p_i p_j \rho^2 log(p_i p_j \rho^2) \right\}, \tag{5}$$

where p_i are momenta of gluons. We will assume that our form factor F has a similar form as (5). This assumption is based on the fact that the Lagrangian (1) was obtained from considering zero modes of the quarks in the instanton field. In this case all momentum of the initial (final) quarks should be transferred to the instanton through some intermediate gluon states. The final result for the form factor is [15]:

$$F(\beta, z) = exp\left\{ - \frac{\alpha_s \beta}{16\pi} \left(\frac{2}{z(1-z)} log\frac{\beta}{2} - \frac{1+z}{z(1-z)} log(z(1-z)) \right) \right\}.$$

To estimate the gluon polarization induced by instantons, the convolution formula

$$\Delta G(x) = \int_x^1 \frac{dy}{y} \Delta P_{G,q}(y) \Delta q\left(\frac{x}{y}\right), \tag{6}$$

will be used, where

$$\Delta P_{G,q} = P_{G_+, q_+} - P_{G_-, q_+} \tag{7}$$

and $\Delta q(z)$ describes the valence quark polarization. For the polarized valence quark distributions a very simple shape was utilized:

$$\begin{aligned} \Delta u_V(x) &= 3.7 \cdot (1-x)^3 \\ \Delta d_V(x) &= -1.3 \cdot (1-x)^3 \end{aligned} \tag{8}$$

These distributions have been normalized to experimental data on the weak decay coupling constants of hyperons [2]:

$$g_A^3 = \Delta u_V - \Delta d_V = 1.25; \; g_A^8 = \Delta u_V + \Delta d_V = 0.6, \tag{9}$$

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[2] We assume that the isosinglet contribution of the sea quarks is absent in (9).

where

$$\Delta q_i = \int_0^1 \Delta q_i(x)dx. \tag{10}$$

For the numerical calculation, we use the NLO approximation for the strong coupling constant

$$\alpha_s(\rho) = -\frac{2\pi}{\beta_1 t}(1 + \frac{2\beta_2 logt}{\beta_1^2 t}), \tag{11}$$

where

$$\beta_1 = -\frac{33 - 2N_f}{6}, \ \beta_2 = -\frac{153 - 19N_f}{12} \tag{12}$$

and

$$t = log(\frac{1}{\rho^2\Lambda^2} + \delta). \tag{13}$$

In Equation (13), the parameter $\delta \approx 1/\rho_c^2\Lambda^2$ provides a smooth interpolation of the value of $\alpha_s(\rho)$ from the perturbative ($\rho \to 0$) to the nonperturbative region
($\rho \to \infty$) [23].
For $N_f = 3$, $\Lambda = 230\mathrm{MeV}$, by using the standard value for the gluon condensate

$$< 0 \mid \frac{\alpha_s}{\pi} G^a_{\mu\nu} G^a_{\mu\nu} \mid 0 >= 0.012\mathrm{GeV}^4, \tag{14}$$

we have the estimate the value of the anomalous quark chromomagnetic moment [21]

$$\mu_a = -0.2 \ for \ \rho_c = 1.6\mathrm{GeV}^{-1}. \tag{15}$$

and

$$\mu_a = -0.4 \ for \ \rho_c = 2GeV^{-1}. \tag{16}$$

The results of the calculations of the polarized gluon distribution for two different values of the average instanton size, $\rho_c = 1.6 \ GeV^{-1}$ and $\rho_c = 2 \ GeV^{-1}$, are presented in Fig. 1. The most remarkable features are that the sign of the polarization is negative all over the kinematical range and its size is steadily increasing for decreasing x values. The total instanton contribution to the gluon polarization in the nucleon appears to be very sensitive to the average size of the instanton,

$$\Delta G = -0.35 \ \text{ for } \rho_c = 1.6 \ GeV^{-1} \ , \ \Delta G = -0.66 \ \text{ for } \rho_c = 2 \ GeV^{-1}.$$

Clearly, the instanton induced quark-gluon interaction leads to a rather large *negative* integral of the gluon polarization.

3 J/ψ Cross Section Asymmetry

The next step is to calculate the double spin asymmetry for J/ψ production in polarized deep inelastic scattering utilizing the just obtained polarized gluon distribution.
The double spin asymmetry is given by the formula

$$A_{LL} = \frac{d\sigma^{\uparrow\downarrow} - d\sigma^{\uparrow\uparrow}}{d\sigma^{\uparrow\downarrow} + d\sigma^{\uparrow\uparrow}}, \tag{17}$$

where the arrows denote relative orientations of the longitudinally aligned lepton and proton spins.

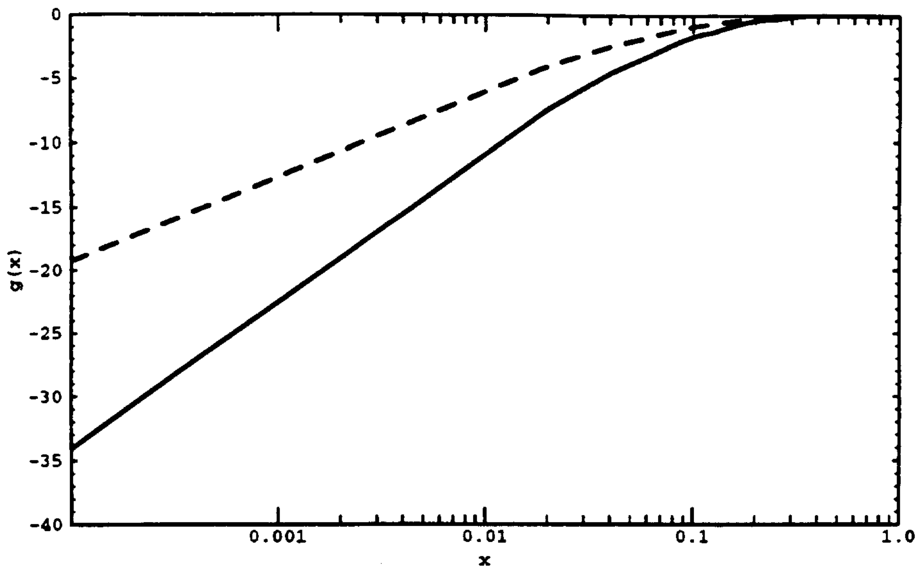

Figure 1: *x dependence of the gluon polarization induced by instantons. The solid line is obtained for an average instanton size of $\rho_c = 1.6\ GeV^{-1}$, the dashed one for $\rho_c = 2\ GeV^{-1}$.*

A comfortable way to do so is to calculate this asymmetry in the framework of the colour singlet model (CSM) [24]. This model is known to describe existing data fairly well [26].
In the CSM the asymmetry is directly related to the polarized gluon distribution, more exactly to the ratio $\Delta G/G$ properly integrated over the available phase space,

$$A_{LL}(z) = \frac{\int_{x_{Hmin}}^{x_{max}} dx_H \int_{x_H}^{x_{max}} \frac{dx}{x} \Delta G(\frac{x_H}{x})(1-(1-y)^2)C(x,z,M^2,Q^2)}{\int_{x_{Hmin}}^{x_{Hmax}} dx_H \int_{x_H}^{x_{max}} \frac{dx}{x} G(\frac{x_H}{x})[(1+(1-y)^2)A(x,z,M^2,Q^2)+2(1-y)Q^2B(x,z,M^2,Q^2)]} . \quad (18)$$

Here $z = k.p/k.q$, k is the momentum of the incoming gluon, p and q are the momenta of J/ψ and virtual photon respectively, $Q^2 = -q^2$, M is the J/ψ mass, $x_{Hmin} = Q^2/2(P.q)$, P is the proton momentum,

$$x_{max} = \frac{z(1-z)}{{p_\perp}^2 + (1-z)(M^2 + zQ^2)}, \quad (19)$$

$p_\perp$ is the J/ψ transverse momentum, and

$$\begin{aligned} A(x,z,M^2,Q^2) &= \frac{M^2}{2}[(M^2+Q^2-\frac{Q^2z}{x})^2z^2 \\ &+ (1-z)^2(Q^2\frac{(1-z)}{x}+M^2+Q^2)^2+(Q^2\frac{(1-x)}{x}-M^2)^2] \\ &+ (1-z)Q^2[Q^2\frac{(1-x)}{x}z-M^2][2M^2(1+(1-z)^2)+M^2+Q^2], \\ B(x,z,M^2,Q^2) &= (1-z)[-(M^2+Q^2)^2(1-z)(4z-3) \end{aligned}$$

$$
\begin{aligned}
& + \; 2(M^2+Q^2)\frac{Q^2}{x}(x(1-z)(-2z^2+6z-2)+xz-2z(1-z)^2) \\
& + \; \frac{Q^4}{x^2}(4z^2-8z+2)(x^2(1-z)+xz)] - (M^2+Q^2-\frac{Q^2 z}{x})^2, \\
C(x,z,M^2,Q^2) \; = & \; (1-z)\{(M^2 - z\frac{Q^2}{x}[M^2 z(M^2 - \frac{zQ^2}{x}) \\
& + \; (z-2)M^2\frac{Q^2}{x} + 2z^2 M^2 Q^2] - M^4 Q^2 \\
& - \; M^2\frac{Q^4}{x^2}(x^2(-2z^2+2z+1) - 2x(1-z)^2) + \frac{Q^6}{x}z(1-x)\}.
\end{aligned}
$$

For the asymmetry calculation the unpolarized gluon distribution is required in addition. Its shape is rather well constrained by unpolarized DIS data. We used three different sets of parametrizations from [27] (GRV), [28] (GS), and from the recent paper [29] (CCFR).
To present specific applications, we calculated the asymmetry at initial lepton energies of HERMES ($E_e = 27.5$ GeV) and COMPASS ($E_\mu = 100$ GeV). The value $p_\perp = 0$ have been chosen in (19) which represents a good approximation at least in the kinematical situation of HERMES. In Fig. 2 the results on $A_{LL}(z)$ are shown as calculated at both initial leptons energies for the GRV parametrization. In Fig. 3 the z-dependence of the asymmetry for two different values of the momentum transfer by the virtual photon, $Q^2 = 1\ GeV^2$ and $Q^2 = 3\ GeV^2$, is shown for HERMES.

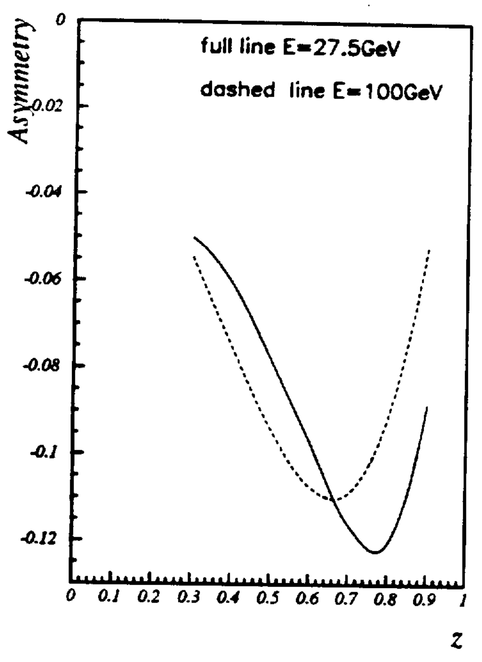

Figure 2: *z-dependence of the instanton contribution to the double spin asymmetry in J/ψ production at* 27.5 *GeV (HERMES) and* 100 *GeV (COMPASS), $Q^2 = 3\ GeV^2$, GRV parametrization, $\rho_c = 2\ GeV^{-1}$* .

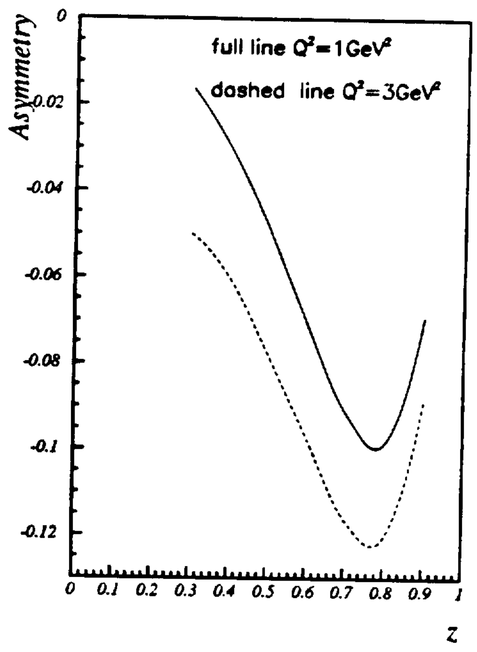

Figure 3: *z- dependence of the instanton contribution to the double spin asymmetry in J/ψ production for different values of Q^2; $E_0 = 27.5\ GeV$, GRV parametrization, $\rho_c = 2\ GeV^{-1}$.*

We note that in the present calculation a higher Q^2 value at fixed initial lepton energy leads effectively only to a larger average $y = x_H/x$ value in the ratio $\Delta G(y)/G(y)$ that determines the double-spin asymmetry (18) [3].

In Fig. 4 the calculated z-dependence of the asymmetry is presented for the discussed two different values of the average instanton size, in Fig. 5 we show the z-dependence of the asymmetry for different shapes of the unpolarized gluon distribution.

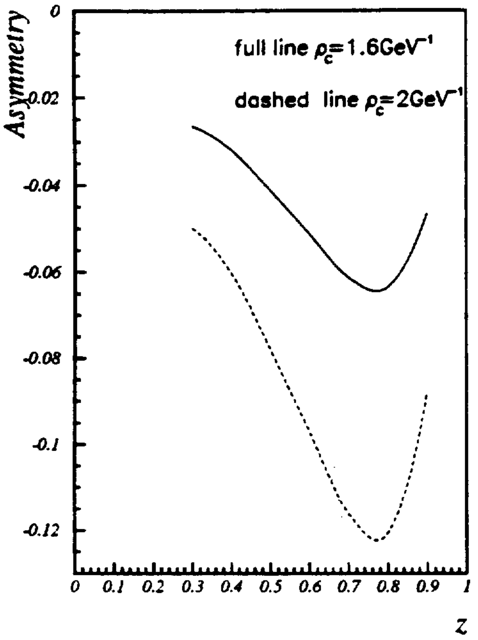

Figure 4: *z-dependence of the instanton contribution to the double spin asymmetry in J/ψ production for two different values of ρ_c; $E_0 = 27.5$ GeV and $Q^2 = 3$ GeV^2, GRV parametrization.*

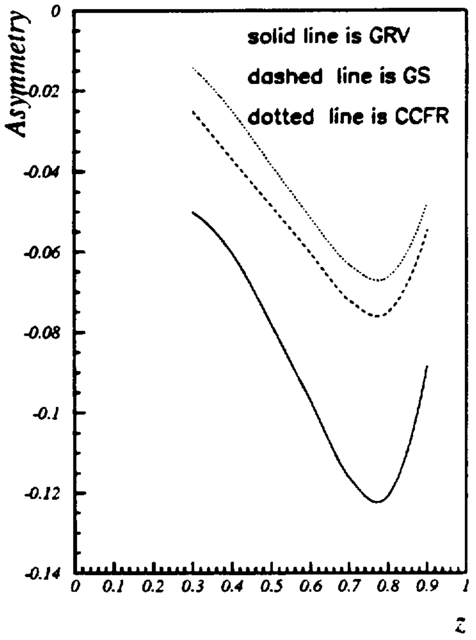

Figure 5: *z-dependence of the instanton contribution to the double spin asymmetry for different parametrization of the unpolarized gluon distribution; $E_0 = 27.5$ GeV and $Q^2 = 3$ GeV^2, $\rho_c = 2$ GeV^{-1}.*

In any case the maximum contribution of the instanton induced quark-gluon interaction to the double spin asymmetry is expected at rather large z, $z \approx 0.75 \div 0.8$. The absolute value is about -0.1 at $E_0 = 27.5$ GeV for the GRV parametrization when assuming an average instanton size of 2 GeV^{-1}.

As can seen, the contribution of the instantons is predicted to be *negative* at small but non-zero photon virtuality. It rather strongly depends on the value of the average instanton size; this opens the principal possibility to derive certain restrictions on the average instanton size from data on the double spin asymmetry in J/ψ production. However, the predicted decrease of the asymmetry with decreasing photon virtuality requires to calculate the asymmetry close to the real photon point, as well.

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[3] We did consider neither a Q^2 dependence arising from the evolution of the polarized gluon distribution nor a possible additional Q^2 dependence due to the finite instanton size. The estimation of these effects is beyond the scope of this paper and will be subject of a forthcoming paper.

4 Summary

In summary, we have shown that instanton induced quark-gluon interactions lead to a large negative contribution to the double spin asymmetry in polarized J/ψ leptoproduction. The size of the double spin asymmetry depends rather strongly on the value of the average size of instantons in the QCD vacuum.

Acknowledgements

We are indebted to Prof. Paul Söding for his permanent support of the present project. One of us (N.K.) would like to thank DESY-Zeuthen for the hospitality extended to him. Many thanks to V. Korotkov for help in preparing the manuscript. This work was supported in part by Heisenberg-Landau program.

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